Department of the Army
U.S. Army Corps of Engineers
Washington, DC

Engineer Manual* 1110-2-2610

18 March 2025

CECW-EC

Engineering and Design
Mechanical and Electrical Design for Civil Works Structures

FOR THE COMMANDER:

Digitally signed by DELAROSA.DAMON.ANDREW.1134345566
Date: 2025.03.05 18:14:16 -05'00'

DAMON A. DELAROSA
COL, EN
Chief of Staff

Purpose. This engineer manual provides guidance and criteria for the mechanical and electrical design of navigation lock and dam and flood risk management operating equipment and control systems. This includes new construction and rehabilitation of existing projects. The manual can also be used as supplemental design guidance for other U.S. Army Corps of Engineers Civil Works projects, such as hydropower.

Applicability. This manual applies to all Headquarters, U.S. Army Corps of Engineers elements, major subordinate commands, districts, laboratories, and field operating activities having responsibilities for the design and construction of Civil Works projects.

Distribution statement. Approved for public release; distribution is unlimited.

Proponent and exception authority. The proponent of this manual is the Headquarters, U.S. Army Corps of Engineers, Engineering and Construction Division. The proponent has the authority to approve exceptions or waivers to this manual that are consistent with controlling law and regulations. Only the proponent of a publication or form may modify it by officially revising or rescinding it.

*This manual supersedes EM 1110-2-2610, dated 30 June 2013.

Summary of Change

EM 1110-2-2610
Mechanical and Electrical Design for Civil Works Structures

This revision, dated 18 March 2025:

- Updates the references.
- Updates the calculations.
- Updates the drawings.
- Adds separate chapters for the following topic areas:
    - Hydraulic cylinder coating and position measuring systems.
    - Inflatable gates.
    - Ship arrestors.
    - Fire protection.
    - Hands free mooring.
    - Wicket gates.
    - Commissioning.
    - Operation and maintenance.
    - Remote operation.
- Updates the design criteria for two-sided hoist lifting applications.
- Updates the lock controls chapter.

Contents

Appendixes

Table List

Figure List

Chapter 1
Introduction

1–1. Purpose

This engineer manual provides guidance and criteria for the mechanical and electrical design of navigation lock and dam and flood risk management operating equipment and control systems. This includes new construction and the rehabilitation of existing projects. The manual can also be used as supplemental design guidance for other U.S. Army Corps of Engineers Civil Works projects, such as hydropower.

1–2. Distribution statement

Approved for public release; distribution is unlimited.

1–3. References

See Appendix A.

1–4. Records management (recordkeeping) requirements

The records management requirement for all record numbers, associated forms, and reports required by this publication are addressed in the Army Records Retention Schedule. Detailed information for all related record numbers is located on the U.S. Army Corps of Engineers (USACE) Records Management Site https://usace.dps.mil/sites/INTRA-CIOG6/SitePages/Records-Management.aspx. If any record numbers, forms, and reports are not current, addressed, and/or published correctly, see DA Pam 25-403 for guidance.

1–5. Associated publications

This manual should be used in conjunction with EM 1110-2-2107, EM 1110-2-1424, and all other referenced engineer manuals (EMs) for the design of gates, operating machinery, and control systems. Other manuals applicable to the design of navigation locks and dams are listed in Appendix A.

1–6. Overview

a. This document is not intended to be an all-encompassing guide for all design situations. The designer is encouraged to apply methodologies in this document and incorporate new technologies that will economically improve operability and functionality of operating equipment.

b. In some cases, information is provided for equipment and materials that are seldom used for new installations. One example is lifting chain for dam gates; wire rope is typically used today. Such information is given not to advocate the replacement of serviceable equipment, but to provide information to help facilitate rehabilitation. This information can also lend historical perspective.

c. Some chapters provide information on mechanical components, hydraulic drives, miter gate operating machinery, sector gate operating machinery, filling and emptying valves and machinery, vertical lift gate operating machinery, and dam gate operating machinery. Other chapters provide electrical guidance on power distribution, motors, cybersecurity, controls, and electrical support systems. Separate chapters provide information on fire protection, operation and maintenance (O&M), and commissioning.

d. For the purposes of this manual, the “Tainter” name is lowercase rather than uppercase.

1–7. Drawing plates

Drawings presenting general information and typical details are presented in Appendix B.

1–8. Calculations

Sample calculations for hoist loading, sector gate machinery loads, miter gate machinery loads, vertical lift gate loads, and tow haulage unit loading are provided separately from this manual and noted as Appendix C. This information should be referenced anytime these calculations are done for either new machinery or rehabilitated machinery. These are posted on the Inland Navigation Design Center (INDC) home page at: https://usace.dps.mil/sites/KMP-IND?e=1%3Ab713b20d00f44cfdbf47aa97095687c4

1–9. General

The lock and dam gate operating equipment information presented in this document is a revision and update of the information presented in the 30 June 2013 version of EM 1110-2-2610. The information presented herein is based on years of actual experience of similar equipment and systems currently in use. The designer should also utilize EM 1110-2-2607 and EM 1110-2-2602.

a. This manual describes several different types of mechanical and electrical equipment and operating machinery. The machinery to drive lock gates and valves can be of a variety of designs, depending on existing site infrastructure and designer or operator preferences. The common attributes that should be considered in all cases and that are emphasized in this manual are reliability, longevity, life cycle cost, and ease of maintenance.

b. Flood risk management (FRM) projects often include gates, valves, machinery, and controls like navigation lock and dam gates and machinery. As such, the mechanical and electrical design guidance in this manual is directly applicable to these projects and must be used.

c. FRM projects often include pumping stations, and this manual can be used as supplemental guidance in those cases. For FRM pumping station projects, EM 1110-2-3105 governs.

d. For hydropower projects, EM 1110-2-3006 governs over this manual, as applicable.

e. Lock gates and valves serve several different functions, depending on location and conditions. Locks are often near a dam, but not always. While the major use of lock gates is to form the damming surface across the lock chamber, they may also serve as guard gates. Other uses include filling and emptying the lock chamber, passing ice and debris, and to dewater the lock chamber. Lock gates can also provide access from one lock wall to the other using walkways or a bridge installed on top of the gates.

f. A navigation lock requires closure gates at both ends of the lock so the water level in the lock chamber can be varied to coincide with the upper and lower approach channels. The sequence of "locking" a vessel upstream is to first lower the water level in the lock to the downstream water level. Then, open the lower gate and move the vessel into the lock chamber. Next, close the lower gate and fill the lock chamber to the level of the upper pool. Finally, open the upstream gate and move the vessel out of the lock. Lockage of a vessel downstream involves a similar sequence in reverse order.

g. A navigable flood gate or storm surge gate is the same as a lock gate, except there is only a set of gates and machinery and no lock chamber. These are typically sector gates but could also be other gate types like vertical lift gates. As an example, there are several of these gate types used in the New Orleans area for hurricane protection. These gates are normally open and are closed only during a hurricane event.

h. Navigation dam gates are the movable portion of a navigation dam that is used to regulate the upstream pool to maintain a minimum navigation depth. Reliability, longevity, life cycle cost, and ease of maintenance are also emphasized for dam gate machinery. Navigation dam gates are generally non-navigable. Exceptions are for some types of gates such as wicket gates. As an example, the Illinois Waterway (IWW) Peoria Lock and Dam and IWW La Grange Lock and Dam both have wicket gates. When run-of-the-river water elevation is reached, the wicket gates are lowered. The navigation channel is open pass over the wicket gate section of each dam.

1–10. Commonality and standardization

Machinery should be standardized on a waterway to the extent possible. This includes on a system level, project level, region/waterway level and enterprise level. Standardization simplifies maintenance and provides common spare parts on a waterway. All new machinery replacement should address standardization.

a. *Center of expertise*. ER 1110-1-8168 states that the INDC is the mandatory center of expertise (MCX) for navigation project design and is the proponent for USACE navigation commonality and standardization (C&S). During predesign planning, navigation project designers must review each proposed design scope with an appropriate INDC representative to assess the opportunity to apply standardization to the project. During design, with customer concurrence, the INDC will guide designers to incorporate existing or develop new standard designs with the project. Per ER 1165-2-217, designers should also use the INDC to help plan and execute required independent quality reviews for navigation projects, including C&S components.

b. Standardization. The goal of design standardization is to create a circumstance where machinery, equipment, and components (including structural design members) with similar application are interoperable; present common hazards to personnel safety; require consistent maintenance, sustainment action, and resources; and present common competency requirements of maintenance staff.

c. Common components. Common components are the desired end state where USACE maintenance staff has reduced complexity of parts, uses common parts to improve maintainability, and can staff and resource facilities consistently due to like-functioning machines and repairs with consistent adjustment or calibration requirements.

d. Design goal. Common components on a waterway should be a design goal, and the impacts of potentially updating components for standardization should be assessed during design and repair. Design and maintenance elements should prioritize using repetitious elements in the planning, design, construction, and maintenance (rehabilitation and component renewal) of facilities.

e. Interoperability. Electrical, mechanical, and hydraulic equipment, including position indicators, supervisory control and data acquisition (SCADA), programmable logic controls, hoisting equipment, and powertrain equipment, should be interoperable to the maximum practicable extent between similar facilities.

f. Common components as standard practice. Where practical, facility rehabilitation and component replacement should incorporate common components. This reduces time for programming, design, and construction of standardized parts.

g. Integrated sustainment. Design and construction practices must account for spare parts inventories procured regionally and/or nationally for equipment and components that can then be available between multiple facilities.

h. Reliability-centered maintenance. Maintenance plans should leverage commonality to support data analytics used to optimize maintenance intervals for components.

1–11. Design life

This manual emphasizes the importance of design for reliability, longevity, and ease of maintenance, regardless of the gate or machinery design. For purposes of this manual, the design life of a component is defined as the expected life that a component should have under normal environmental conditions.

a. There are locks and dams in USACE that are over 100 years old, and equipment selection and design must consider this. For lock and dam machinery, the design must be as robust as possible for permanent installation, with a minimum 50-year life span.

b. In general, the equipment designed and selected should be built for the longest life span available. In some cases, an economic analysis is necessary to determine the type of equipment to use. As noted, a minimum service life of 50 years with proper maintenance must be the goal for any equipment.

c. For life cycle purposes, note that equipment such as cylinders, pumps, and motors may require overhaul after 20 to 25 years. Many electronic control components and systems may require upgrade or replacement at even shorter intervals. This should be a guide for preparing the design and the specifications for equipment. Life cycle costs and project and product service life must be evaluated according to ER 1110-2-8159.

1–12. Floodproofing and resilience

Machinery and controls must be elevated to the extent possible at navigation sites. Floodproofing must be considered in all new designs. The designer must establish the flood elevations at the lock or dam and establish the machinery and control design accordingly. Electrical cable splices that will be submerged often or for long periods should be avoided.

a. The designer should provide 18 in.(457 mm) of freeboard to avoid damage from wave action. If machinery will be flooded, the designer must consider either removal ahead of the flood or designing machinery for submersible conditions. If machinery and controls are flooded, the designer must incorporate recovery and clean-up into the design and detail these requirements in the project O&M manual.

b. A system can be considered resilient if it continues to perform its mission in the face of adversity. In the case of lock machinery, this could be floods, extreme weather conditions, etc. Machinery design must be resilient to withstand flooding conditions and for exposure to extreme weather conditions. Drive machinery at a lock and dam site will be subjected to a range of temperatures and this must be accounted for.

1–13. Drive systems

Selecting operating machinery depends on several factors. The reliability of the operating machinery is one critical consideration since the failure of the operating machinery can take the gate or valve out of service. Some of the design considerations for selecting gate drive machinery include the type of gate or valve, loading conditions, site conditions, operation requirements, maintenance requirements, and operator preference. The design of the operating machinery system must consider the weight of the gate or valve, the friction forces, and the hydrodynamic forces. This manual does not dictate a specific drive system for any gate type.

a. The designer must always provide a methodology for machinery selection that includes both risk assessment and life cycle cost. This manual does not dictate the methodology to be used. One such methodology is operational risk assessment (ORA), described further in ER 1105-2-101 for FRM projects, and ECB 2019-3. The designer could also use ECB 2022-7 although that document is much more in depth than required.

b. The type of drive selected is often based on the skills and knowledge of the operating staff or is a drive type already used on the same waterway. Often, the operating machinery must match the machinery already installed in a waterway system. This is done to minimize spare parts, reduce repair time, and reduce the amount of operator and maintenance training.

c. Two typical drive systems (and the most common) are hydraulic drive systems and electrically operated gear-driven machinery, referred to as electromechanical drive machinery. Regardless of the drive machinery selected, the components of the drive system must be capable of moving the gate or valve through the full range of motion, with varying loading conditions, and in a range of weather conditions.

d. Electromechanical drive systems have a longer tradition of use. However, hydraulic drive systems are becoming more common for both new construction and for rehabilitation of existing drive systems. Hydraulic drive systems generally have lower initial cost but may have a shorter life span than electromechanical drives. As an example, the original Panama Canal lock miter gates installed in 1914 were originally all electromechanical drive and have recently been converted to direct-connected hydraulic cylinders.

e. Some drive systems and operating machinery use both electromechanical and hydraulic equipment. An example is the miter gate drives on the Ohio River in the United States that use a hydraulic cylinder to drive a rack and pinion (see Figure 1–3). Another example is rolling gate operating machinery in Europe that uses a hydraulic motor to drive a wire rope winch.

f. Forces from drive system machinery, especially at startup, can be large and can impart stresses to gates and valves that are not designed for such forces. It is important to design operating machinery that allows a slower startup and shutdown speed at the extreme ends of gate or valve travel.

g. The designer needs to be aware of forces not only at start up but under overload conditions and how that affects structural components. As such, the design of operating machinery must be done in collaboration with structural engineers. EM 1110-2-2107 must be used for any structural design. It is imperative that controls, limit devices, and interlocks not only protect machinery but also mitigate unintentional forces to structural components.

1–14. Electromechanical drives

Electromechanical drives have been used for over 100 years on gates and valves, including the original Panama Canal miter gates and many of the early rolling gates in navigation locks of the United States and Europe. For an electromechanical drive, there is always a linkage or some mechanical connection between the drive system and the gate or valve. See Figure 1–1.

Figure 1–1. Electromechanical drive system at Lock 2 on Mississippi River

a. Electromechanical drives use an electric motor and a combination of shafting, couplings, bearings, struts, open gears, and/or enclosed gearboxes to move a gate or valve. Most of the lock sites built in the 1930s on the United States Mississippi River, Ohio River, and Illinois Waterway used electromechanical drives and mechanical linkages.

b. Many of the United States inland navigation locks still use electromechanical drives for operating lock gates and valves. Electromechanical drives can offer accurate speed control with variable-frequency drive (VFD) systems. VFDs may also be referred to as adjustable speed drives (ASD) or alternating current (AC) drives and the terms are used interchangeably. Dual winding motors can offer different speeds and power ratings. This is the design of the drive system shown in Figure 1–1. Main advantages of electromechanical drives include:

(1) Proven design;

(2) Greater life span than a hydraulic drive;

(3) Ease of operating personnel to understand and troubleshoot.

c. Disadvantages of electromechanical drives, as compared to hydraulic drives, include a more complex operating machinery linkage, and, for miter gates in particular, the adjustment available in the strut connection to the gate is usually minimal. There are more pivot points for wear and additional greasing requirements. Other disadvantages include:

(1) More components requiring grease or lubrication;

(2) Components can be difficult to replace and remove;

(3) Operating components are generally custom-built with long replacement lead time (gearboxes and open gears are examples);

(4) Initial install and alignment can be critical and, if not done properly, the life of the machinery is shortened.

1–15. Hydraulic drives

Hydraulic drive systems offer inherent speed control, typically through a proportional valve. Hydraulic drives controlled electronically are preferred for remote and automated locks. Direct-connected hydraulic cylinders are used often today on miter gates (Figure 1–2). Hydraulic drive systems are further discussed in Chapters 4 and 5 of this manual.

a. Advantages of hydraulic drives include:

(1) Hydraulic power units (HPUs)can be remote, placed a considerable distance from cylinders and actuators, and can serve many cylinders and actuators at once;

(2) Operating speed can be widely varied and adjusted typically through a proportional valve or other throttling valve;

(3) Fewer moving parts to be maintained compared to an electromechanical drive;

(4) Inherent shock absorbing characteristics.

b. There are some disadvantages of hydraulic drive systems. On a direct-connected miter gate drive, for example, the piston rod is used as a strut, resulting in a larger piston rod diameter. On a miter gate drive, the piston rod is often installed closer to the pivot point of the gate, which reduces the stroke and increases the necessary force to move the gate. This can also increase forces on the miter gate anchorage.

c. Hydraulic drives generally have more environmental issues to consider, simply because the cylinder operates directly over the waterway. Hydraulic drives can leak fluid through seals, and loss of fluid leads to less efficiency. Hydraulic drives also have the potential to leak large quantities of fluid into the waterway. Drainage sumps may require an oil-water separator. Hydraulic drives require many companion parts, including a fluid tank, motors, pumps, and valves. Other disadvantages of hydraulic drives include:

(1) Requires a more complex pumping and control system to control gate acceleration and de-acceleration and compensate for opening/closing time differential;

(2) System operates at high pressure – safety concern for operating staff;

(3) Gate or valve can drift if pressure is taken off the system;

(4) Requires effective filtration system for hydraulic oil.

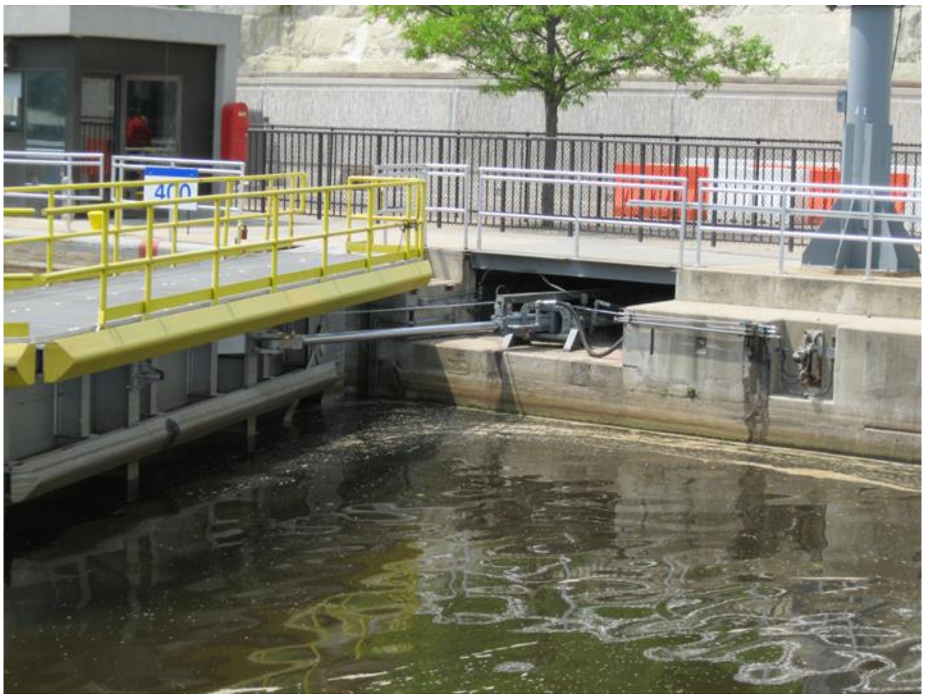


Figure 1–2. Direct-connected hydraulic cylinder on a miter gate

1–16. Miter gates and machinery

Most of the locks in the United States are equipped with double-leaf miter gates, which are used for low, moderate, and high-lift locks. The construction and operation of these gates are simple. They can be opened or closed more rapidly than most other gate types. Maintenance costs generally are low. A disadvantage of this gate is that it cannot be used in an emergency to close off flow with an appreciable unbalanced head. Further miter gate description and structural design information are in EM 1110-2-2107.

a. When miter gates are open, they fit into recesses in the wall. The bottom of the recess should extend below the gate bottom to preclude operating difficulties from silt and debris collection. Enlarged recesses are sometimes used to facilitate the removal of accumulated ice. Air bubbler systems are recommended to help clear ice and debris from gate recesses.

b. Miter gate machinery arrangement typically falls into two broad categories: electromechanical drives and hydraulic drives. See Figure 1–1 and Figure 1–2. The drive system can also be a combination of these two systems. An example is a hydraulic cylinder driving a rack typical on many Ohio River Lock miter gates. See Figure 1–3. It is common now to drive miter gates directly with hydraulic cylinders. However, many lock miter gates are still driven with an electromechanical linkage system, and this is the oldest drive system. This includes a sector gear and strut described further in Chapter 6.

Figure 1–3. Hydraulic cylinder driving a rack and sector gear on Ohio River Locks

1–17. Sector gates and machinery

A sector gate is similar in shape to a tainter gate except that it is oriented to rotate on a vertical axis and is supported at the top and bottom like a miter gate. Like miter gates, sector gates are primarily used in pairs, meeting at the center of the lock when closed and swinging into recesses in the lock walls when open. The trunnions are in the lock walls, and the skin plates face in the direction of the normally higher pool level. Further sector gate description and structural design information are presented in EM 1110-2-2107.

a. Sector gates are used for both lock gates and flood gates. The Chicago Lock at Lake Michigan uses sector gates. On the IWW, the T.J. O’Brien (LD01) navigation lock has upstream and downstream sector gates. Several locks in New Orleans use sector gates. A flood gate application is shown in Figure 1–4 at the West Closure Complex in New Orleans. This photo was taken during construction of the complex. This sector gate provides a 225-ft navigable closure.

b. Sector gates are typically used in tidal reaches of rivers or canals where the lifts are low and where the gates might be subjected to reversal of heads. Since these gates can be opened and closed under head, they can be used to close off flow in an emergency. The gates swing apart, and water flows into or out of the lock through the center opening between the gates. In some cases, flow is admitted through culverts to improve filling characteristics or where ice or drift might not permit adequate flow between the gates.

Figure 1–4. West Closure Complex, New Orleans, under construction

c. Since the turbulence area at the upper end of a lock filled by a sector gate (created by flow into the lock through the gate opening) impacts the lockage of vessels, the length of the lock chambers must be increased proportionately. This turbulence can shift the vessel and possibly break mooring lines. Model tests indicate about 100 ft (30.48 m) of additional length is required. Like other end-filling systems, sector gates cannot be used for filling and emptying high-lift locks unless the filling and emptying rates are greatly reduced. The practical lift limitation is usually about 10 ft (3 m), although gates with higher lifts have been built.

d. The disadvantages of the sector gates are high construction cost, long opening and closing times, and larger wall recesses.

e. Sector gates typically are driven by rotary actuators, electric or hydraulic motors, driving gear reducers that drive a pinion mated with a rack bolted to the radius of the gate. Alternate arrangements pull the gate in and out of recess with wire ropes wrapped on a drum or use a hydraulic cylinder directly connected to the top frame of the gate near the hinge.

1–18. Vertical lift gates and machinery

Vertical lift gates can be used in several different applications. These include lock gates, flood gates, dam gates, and as culvert valves in a lock. Vertical lift gates may be used at both ends of a lock or at only one end combined with a miter gate at the other. They can be raised or lowered under low to moderate heads. The operation time of older gates is typically slower, and maintenance costs are higher than those of miter gates, but they can be used in emergency closure. Newer gates, however, often can be designed to achieve operating speeds equal to, or even faster than, miter gates. As with other gate types, the structural criteria for vertical lift gates is provided in EM 1110-2-2107.

a. A vertical lift gate installation at the upstream end of a lock normally consists of a single- or double-leaf submergible gate, which rises vertically to close off the lock chamber from the upper pool. As shown in Figure 1–5, the Mel Price Lock on the Mississippi River uses a triple-leaf gate arrangement. When the lock is filled, the gate is opened by sliding the leaf vertically downward until the top of the leaf is at or below the top of the upper sill.

Figure 1–5. Mel Price Lock vertical lift gate

b. In some cases, a double-leaf vertical lift gate can be used. The upper leaf can have a curved crest, which permits overflow to supplement flow from the primary filling system when the lock chamber is nearly full. This type of gate also can be used for skimming ice and debris.

c. When a vertical lift gate is used at the downstream end of a lock, it is raised vertically to a height above the lower pool level so that vessels can pass underneath. The gate leaf is suspended from towers on the lock walls and is usually equipped with counterweights to reduce the required hoisting power. Lock gates of this type are practical only for very high locks and where required vertical clearance can be provided under the gate in its raised position.

d. Vertical lift gates can be driven by either electromechanical drive or hydraulic drive.

e. Friction loads can be significant for vertical lift gates. Vertical lift gates are mostly driven by an electric motor-driven, wire-rope hoist that lifts both sides of the gate using a single hoist drum connected by reeving and a tunnel under the lock. Another drive type uses hydraulic cylinders on both sides of the gate. A variation of this type is hydraulic cylinders on each side of the gate, connected through wire ropes and reeving.

f. Another hoist arrangement uses a bull wheel or friction wheel driving a wire rope connected to the gate and a counterweight to reduce the hoisting loads. With these types or any other type that uses an independent or semi-independent hoist on each side of the gate, synchronization of the two hoists must be accounted for in the design.

g. With hydraulic drives, this is done with wound-rotor motors that form a virtual shaft for regulating skew. With VFDs, the drives compare position measurements using a master-follower scheme with proportional loop to eliminate skew.

h. Each side of the downstream gates at Ice Harbor, Lower Monumental, and John Day have a large sheave, counterweight, and driving machinery.

1–19. Tainter gates

Tainter gates are also sometimes referred to as a radial gate especially in Europe. These gates were first developed by Jeremiah Tainter in the 1800s, hence the name. The convex side of the gate faces upstream. The hydraulic forces act through the radius of the gate and are concentrated on the pivot point or trunnion. Further tainter gate description and design information is in EM 1110-2-2107. The lower case tainter gate is used throughout this manual.

a. Tainter gates as navigation dam gates. Tainter gates are widely used on navigation dams to control the upstream pool. Figure 1–6 shows a chain lifting system that is not common for new construction. However, chains are extensively used on older gates. Nearly all the tainter gates on the Mississippi River built in the 1930s use chains. Tainter gates require a lower hoist capacity and have a relatively faster operating speed than other types of dam gates. Also, because side seals are used, gate slots are not required. This reduces problems associated with cavitation, debris collection, and ice buildup.

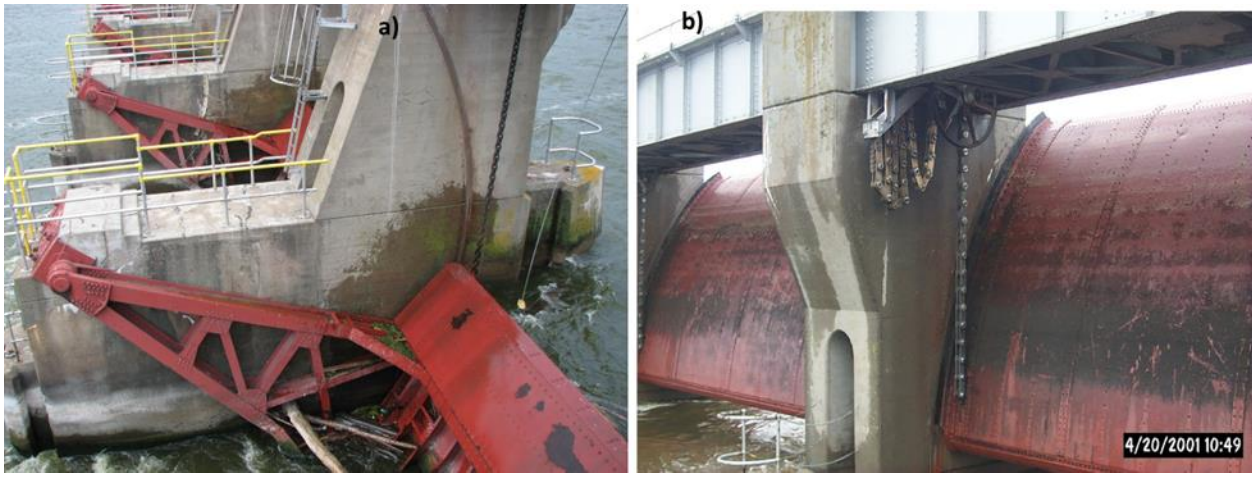


Figure 1–6. Tainter gate and associated machinery and lifting chain

b. Submergible tainter gates as lock gates. The locks of The Dalles Dam, some Lower Snake River projects, and the Upper St. Anthony Falls (USAF) Locks have submergible tainter gates. The USAF Lock gate is shown in Figure 1–7. Ice Harbor, Little Goose, and Lower Granite also have this gate type. This type of gate is raised to close the lock chamber and lowered into the lock chamber to open it. The gates are also used to pass water through the lock during flood conditions and to pass ice through the lock. The end frames are recessed into the lock wall, so no part of the end frame projects into the passageway.

Figure 1–7. Upper St. Anthony Falls Lock gate

(1) This type of gate was chosen for these projects because it is structurally efficient and is estimated to be lighter in weight and less costly than a double-leaf miter gate. The tainter gate also permits the length of the approach channel to be reduced by the leaf width of the miter gate. There are two potential problems in the operation of this type of gate: skewing of the gate during opening and closing, and vulnerability to damage if hit by lock traffic. These gates can also be prone to vibration issues.

(2) The designer must consider the risk of damage from lock traffic for submergible gates. The repair cost can be very high, and the lock may be taken out of service for an extended period.

c. Tainter gate machinery. Tainter gates traditionally have been operated by hoists located in machinery houses above the gates and connected to the gates with wire rope or chain. See Chapter 11 of this manual. More recently, hydraulic cylinder hoists have been used at some installations, including Olmsted Dam. Some challenges have included the vulnerability of the cylinder rods to impact damage and to corrosion caused mainly by a combination of improperly selected rod materials and the infrequency of use of some gates. Skew of the gate for all types of tainter gates must be considered by the designer. This is further discussed in Chapter 11.

1–20. Rolling gates

PIANC Working Group (WG) 173 Report provides an in-depth analysis of rolling gate design and should be referenced for specific design requirements. Rolling gates and sliding gates for navigation locks are stored in the lock wall perpendicular to the axis of the lock and move across the lock to create a damming surface. Rolling gates use a carriage and wheel assembly to support the gate.

a. This type of gate becomes an option when the width of the lock exceeds that practical for miter gates or when the area available for gate monoliths is limited. Rolling gates were commonly used in the United States in the late 1800s and early 20th century. Since that time, miter gates are the gates of choice for locks in the United States. Rolling gates now are primarily used in Europe on sea locks and for the new locks that are part of the Panama Canal Third Lane expansion. The Panama Canal rolling gates are shown in Figure 1–8 and Figure 1–9. Rolling gates are some of the most massive hydraulic steel structures (HSS) in the world. See further discussion in Chapter 10.

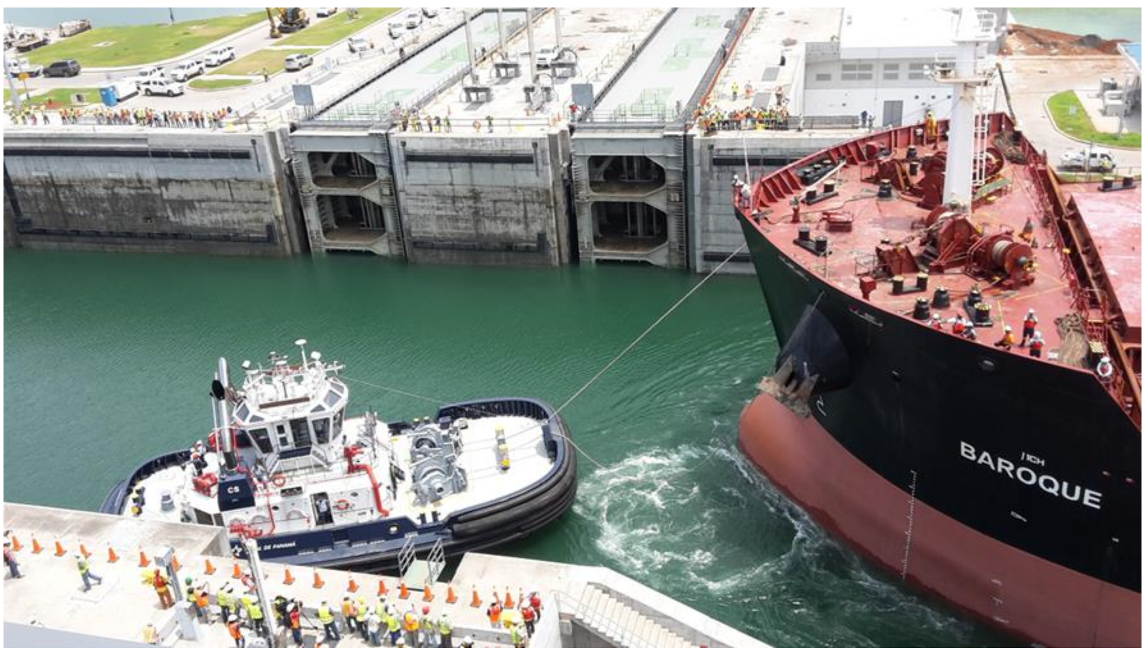


Figure 1–8. Panama Canal Third Lane opening (roller gates in background) (courtesy of Autoridad del Canal de Panamá)

b. Rolling gate machinery is typically a winch system that drives the gate in and out of recess. See Chapter 10. Rolling gates typically use multiple-wheel trucks rolling on tracks on the bottom of the gate or, in the case of a wheelbarrow gate, on the bottom of one end and at the top of the gate at the other end.

c. Buoyancy tanks often are built into the gate to decrease the wheel loads and required hoist capacity. Sliding gates do not use wheels but instead slide on hydrodynamic bearings. This type has been successful in Europe. The gate machinery typically consists of electric motor-driven hoists that drive double-wire rope drums, pulling the gate open or closed.

Figure 1–9. Rolling gates of Panama Canal Third Lane

1–21. Culvert valves and machinery

Culvert valves are used to control the flow of water through the lock's filling and emptying system to raise or lower the lock water elevation. A variety of valves have been used for this purpose.

a. For large locks, the most efficient has been the reverse tainter valve, which is like the tainter gate but with the convex side of the valve facing downstream. Other culvert valves used have included regular orientation tainter gates, butterfly valves, vertical slide gates, caterpillar gates, and Stoney gate valves. The choice depends on site constraints, culvert size, and pool elevations. Further information on the hydraulic design of lock culvert valves is available in EM 1110-2-1610.

b. Machinery for opening and closing the culvert valves can be electromechanical or hydraulic. If the culvert valve cannot be closed by gravity, the culvert valve machinery must be designed to ensure that adequate hoist machinery power is available under all conditions to both open and close the valve.

1–22. Control systems

This manual provides the means to develop control systems for new projects and for the replacement or upgrade of existing systems. It is written for navigation lock and dam application, but much of the same technology and design information can be adapted to FRM and other USACE Civil Works (CW) projects.

1–23. Hydropower projects

For hydropower projects, the designer should reference and use EM 1110-2-3006. The guidance in EM 1110-2-3006 governs this manual.

1–24. Regulating outlets

USACE operates Reservoir Regulating Outlets (ROs) that are critical for water management and flood damage reduction. ROs are used throughout USACE districts and are an integral part of dam safety. Due to their age, condition, and criticality, many ROs are currently scheduled for rehabilitation. Appendix E provides a link to the full RO report that should be followed for standardizing RO design across all USACE districts.

1–25. Flood risk management projects

For FRM projects, the criteria in this manual governs machinery design. For pump station design, the designer should use EM 1110-2-3105. The guidance in EM 1110-2-3105 governs this manual.

1–26. Department of Defense Building Codes

Comply with Unified Facilities Criteria (UFC) 1-200-01 and UFC 1-200-02, which adopt various codes and standards and include requirements for application of other UFC.

1–27. Fire protection

For any fire protection requirements, the designer must follow the requirements in UFC 3-600-01 and reference Chapter 21 of this manual. Follow the requirements of ECB 2024-7.

1–28. Elevators

Elevator design and construction must follow the requirements of UFC 3-490-06 and ASME A17.1.

1–29. Heating, ventilating, and air conditioning for buildings

Comply with UFC 3-401-01, which requires use of other UFCs such as UFC 3-410-01 and UFC 3-410-04.

1–30. Plumbing

Plumbing design must follow the requirements in UFC 3-420-01.

1–31. Electrical design

Electrical design requires use of UFCs as noted in ECB 2024-6.

1–32. Building electrical requirements

Comply with UFC 3-501-01, which requires use of other UFCs such as UFC 3-520-01, UFC 3-530-01, or UFC 3-550-01. Comply with NFPA 101 as applicable.

1–33. Anti-Terrorism and force protection for buildings

Comply with UFC 4-010-01.

1–34. Mandatory requirements and deviation from design criteria

a. This manual provides guidance for the protection of USACE structures. In certain cases, guidance requirements, because of their criticality to project safety and performance, are mandatory as discussed in ER 1110-2-1150. Those cases will be identified as “mandatory,” or the word “must” will be used in place of “should.”

b. When the project delivery team (PDT) determines that designing to less than the mandatory requirements stated in this manual is appropriate and reasonable, a cover letter, along with the supporting cost and risk analysis documentation, must be submitted to USACE-HQ requesting exemption. See ECB 2021-5 for waiver requirements.

c. See the paragraph below for requirements for dam safety studies, major rehabilitation studies, and reliability (issue evaluation) studies.

1–35. Review requirements

All projects and designs must follow the requirements in ER 1165-2-217. All projects must also document risks according to ER 1165-2-217 and ECB 2022-7.

1–36. Safety requirements

Certain occupational health and safety provisions are required by EM 385-1-1 guide specifications, trade standards, codes, and other manuals referenced herein. The designer should also use the requirements in American National Standards Institute (ANSI) B11.0, as applicable, during design development. ANSI B11.0 provides a formal means of risk assessment regarding safety.

a. Additionally, the requirements of the Occupational Safety and Health Administration (OSHA) (generally referred to as OSHA standards) are to be considered minimum requirements in USACE design.

b. Areas of particular concern to mechanical and electrical design are safety, noise levels, personnel access provisions, open shaft protection, pinch points, working temperature conditions, air contamination, load handling provisions, and sanitary facilities. OSHA standards are continuously being modified and expanded. Conformance to the latest published requirements is essential.

c. Any requirements for a Safety Assurance Review must follow the requirements in ER 1165-2-217, as applicable.

1–37. Design guidance

This manual is not intended as a comprehensive step-by-step solution to lock and dam design. The designer is responsible for exercising sound engineering judgment while using this manual. Other useful material information, which is readily available in standard publications, is referenced herein and listed in Appendix A.

a. All design computations must be provided and included in the project Design Documentation Report as described in ER 1110-2-1150 and ER 1165-2-217. Design computations should be clear, concise, and complete. The design computations should document assumptions made, design data, and sources of the data. All references (manuals, handbooks, catalog cuts), alternate designs investigated, and planned operating procedures should also be provided.

b. The design should include the quality of the materials to be used and the workmanship involved. Designs should be as simple as practicable. Increased complexity tends to increase initial and future O&M costs. Designs, equipment, and material selection that require less frequent maintenance are recommended. The design goal should be to ensure minimal maintenance and ensure any required maintenance is simple, accessible, uses readily available parts and supplies, and reduces operator, mechanic, and electrician burden.

c. During construction, the designer should be involved in reviewing shop drawings and as-built drawings, preparing the O&M manual, and field and shop inspections. The designer of record must also be consulted when a field change is recommended or required.

1–38. Dam studies, major rehabilitation studies, and issue evaluation

Studies require an evaluation and risk assessment of the entire lock and dam structure, or portions thereof. The mechanical and electrical components may be excluded, screened out, or sometimes the results of these studies may require an analysis of lock and dam machinery. The designer should follow the guidance in ECB 2022-7.

a. If an analysis is required, it should include a review of the design criteria used to build the machinery. If it is found that the design criteria for the machinery have changed since it was originally constructed or last upgraded and is not consistent with current criteria, further investigation may be warranted. This further investigation, if required, should include an assessment of the performance of the machinery over the life of the project under all conditions.

b. Furthermore, an assessment of the risk accepted by not upgrading the machinery to meet new criteria should be evaluated within the context of the study being conducted. This performance and risk assessment should be documented. The old and current design criteria should also be documented, and deviations from current criteria should be noted where warranted.

c. A decision to upgrade the machinery solely to meet current criteria should be based on this assessment. A budgetary cost analysis should be provided as part of the study to bring machinery and components up to current standards. If upgrades to mandatory requirements are not recommended based on performance and risk assessment, then concurrence must be obtained from USACE HQ. Deviations from mandatory safety-related criteria (such as interlocks) should be documented separately.

d. The designer should use EC 1110-2-6062 for guidance on reliability engineering for major rehabilitation studies related to existing USACE CW infrastructure. This includes developing fault trees and hazard functions. A new engineer manual is under development to replace and update EC 1110-2-6062. A new ECB is also under development that will provide further guidance for reliability analysis.

e. EC 1110-2-6062 has historical background that may aid new engineers in determining the best methods to perform reliability analysis as part of a risk assessment. The designer should consult with the USACE INDC prior to starting any reliability analysis. This is to ensure the designer has the most current tools and guidance available, and that additional or updated reliability documents have not been published.

f. For navigation lock and dam projects and FRM projects, deviations should follow the risk-informed guidance in ECB 2022-7. When a deviation to mandatory requirements is necessary, the designer should also follow the guidance in ER 1110-2-1150, as applicable.

g. For all risk drivers associated with the project, the designer must understand how to efficiently reduce incremental risk to life safety (structural and non-structural) within the limits of the authorized project. ECB 2022-7 helps ensure the analysis falls within USACE Tolerable Risk Guidelines (TRGs). The primary principles of risk-informed design are as follows:

(1) *Hold life safety paramount*. USACE will consider risk to life safety as a priority while seeking to manage risk to people, property, and the environment. TRGs will be used as the risk-informed decision goal for life safety.

(2) *Risk-informed decision-making*. Decisions for risk management actions will be commensurate with the level of risk that exists when a dam is present to ensure wise federal investment.

(3) *Ensure open and transparent engagement*. USACE will engage project sponsors in all design activities related to their dams.

(4) *Learn and adapt*. Risk assessments will be used to evaluate if designs must be up-scaled (use more stringent design criteria) or downscaled (use less stringent design criteria) using a risk-informed approach as compared to solely considering traditional standards.

(5) *Do no harm*. Risk-informed designs should not increase the risk to the population and property above the risk the population currently experiences.

h. There are other design objectives the designer must consider, as noted in ECB 2019-15, ECB 2019-3, and Planning Bulletin 2019-04. The designer must determine the applicability of all these documents for any new design or rehabilitation.

1–39. Operation and maintenance work

Often, portions of mechanical and electrical machinery are replaced, such as wire rope, chain, motors or a gear or a gearbox. The existing project design criteria may be followed in this case. New design criteria in this manual should be followed to the extent possible but is not mandated. If O&M funding is used to replace the entire set of lock machinery or dam machinery, then new design criteria in this manual must be followed.

1–40. Structural revisions

If hydraulic structures such as miter gates are replaced, it is important to verify the existing machinery still has adequate capacity to move the gate. In the case of miter gates, new gates can often be significantly heavier and put more loads on the pintles and anchorages. Structural revisions to tainter gates can add more weight and require more lifting capacity. In the case of tainter gates, the existing machinery can be reused, and wire rope can have a reduced factor of safety from 5.0. However, in these cases, a risk analysis must be done as described above in paragraph 1-37 to determine if machinery must be replaced. It is up to the District and PDT to determine the level of effort needed for the risk analysis.

1–41. Machinery lubrication

For design information on machinery lubrication, see EM 1110-2-1424 and INDC TR 2018-01. INDC TR 2018-01 is further described in ECB 2018-16.

1–42. Remote operation

Designers of all new lock construction and major rehabilitation projects, defined as Category 1 work by ER 1110-1-8168, will need to consider the feasibility of remote operation as part of the design. The feasibility evaluation of remote operation and the determination for applicability should be documented within the project Design Documentation Report. For all Category 1 work, the INDC MCX will assist in the remote operation feasibility assessment. Chapter 18 of this manual further defines requirements for remote operation and remote control.

1–43. Environmentally acceptable lubricants

Use EM 1110-2-1424 and INDC TR 2018-01 for further information on environmentally acceptable lubricants (EALs).

1–44. Painting and cathodic protection

Lock gates usually are in river water or brackish water, which are submerged corrosive environments. Corrosion causes different degrees of structural and metallic deterioration of the gates that, in turn, affects O&M of the gates. Drawing plates 74, 75, 76 and 77 in Appendix B provide some typical details.

a. Corrosion protection is a combination of the proper materials selection and proper coating system selection for the application. In some instances, it also might include using cathodic protection systems as described in EM 1110-2-2704. It is not the intent of this EM to provide specific design guidance for coatings and cathodic protection. The designer should become familiar with the engineer manuals referenced below and guidance provided in the Construction Engineering Research Laboratory (CERL) Technical Report (TR)-02-7 for the proper selection of materials.

b. EM 1110-2-3400 provides guidance on paints and coatings, along with UFC 3-190-06. The designer must also utilize UFC 3-570-01 and UFC 3-570-06 for cathodic protection system design and cathodic protection O&M. This includes for both gates and machinery. Unified Facilities Guide Specifications (UFGS) 09 90 00 must be used for the proper selection of coating systems. EM 1110-2-2704 also provides design guidance for the different types of cathodic protection. The Mobile District Technical Center of Expertise (TCX) on Cathodic Protection Systems can be consulted for design guidance on cathodic protection systems.

c. The National Association of Corrosion Engineers (NACE) also provides design guidance. NACE SP0169 is one applicable reference. NACE has now merged with the Association for Materials Protection and Performance (AMPP). The NACE standards have been carried over to AMPP.

d. The primary corrosion control system for lock gates and machinery is painting. Vinyl paint systems traditionally have been used in freshwater applications for gates. Vinyl paint systems are durable and have a proven track record. They should not be used in brackish water or saltwater applications. Coal tar epoxy systems and high-solid epoxy systems have been used successfully in salt water. Consult Engineer Research and Development Center's (ERDC) CERL for specific design guidance and paint applications.

e. The designer should be aware of galvanic corrosion issues caused by dissimilar metals. Galvanic reaction charts are readily available. These charts are designed to assist in broadly assessing the risk of galvanic corrosion associated with a given metal contacting another metal. EM 1110-2-2704 also provides guidance on this subject. Consult the Mobile District TCX for design assistance.

1–45. Environmental considerations

The planning, design, construction, and operation of navigation locks and dams must occur within the respective statutory authority of such projects and comply with all applicable federal environmental laws. Applicable federal legal requirements are project-specific and action-specific and can be professionally identified by USACE Counsel. Studies of project features are pursuant to the National Environmental Policy Act (NEPA) and identify potential impacts and define environmental objectives and constraints.

a. The designer should provide designs that keep oils and greases out of the waterway. The designer must consider adverse impacts to the environment that can include waste fuel oil and lubricating oil and greases.

b. Through proper planning, design, construction, and operation, many of the adverse impacts noted can be avoided or minimized. Remaining impacts should be mitigated, and environmental enhancement addressed. The following steps should be taken to better ensure satisfactory compliance with the environmental objectives of navigation projects:

(1) Consult with USACE Counsel to identify applicable legal requirements and legally sufficient courses of action within the respective statutory authority of the project.

(2) Identify all potential environmental effects, both adverse and beneficial.

(3) Incorporate design, construction, or operation features that avoid or minimize adverse effects.

(4) Identify unavoidable adverse effects and incorporate appropriate mitigation features.

1–46. Sole source and other contracting considerations

The designer must be aware of current contracting guidance regarding sole sourcing of equipment and current Buy American Act requirements. This applies to unique and one-of-a-kind machinery. Reference ECB 2022-1 for additional requirements and information.

a. Effective 31 May 2019, a justification and approval (J&A) is required to use brand name or equal purchase descriptions or proprietary specifications and standards. Brand name or equal designations will now require a J&A based on section 888 of the 2017 John McCain National Defense Authorization Act (NDAA). While this is not standard practice in the UFGS, it is common for designers in the field to use brand name or equal designations in specifications edited for specific projects.

b. DoD issued this final rule amending the Defense Federal Acquisition Regulation Supplement (DFARS) to implement section 888 of the NDAA for FY 2017. This requires that competition on DoD contracts not be limited by specifying brand names or brand name or equivalent descriptions, or proprietary specifications or standards in solicitations, unless a justification for such specification is provided and approved according to 10 U.S.C. 2304(f).

Chapter 2
Mechanical Components

2–1. General description and application

The components and design criteria described herein are applicable to components the designer might deem appropriate for use in both electromechanical and combination hydraulic-mechanical systems. For a more thorough discussion of components applicable strictly to hydraulic drive systems, see Chapter 4 and Chapter 5. Chapter 5 provides criteria and discussion of hydraulic cylinder coating and measuring systems. The list of components provided in this chapter is not all inclusive for the designer, rather it presents a list of commonly used components that have design parameters established to meet a broad range of CW projects.

a. Additional guidance. Structural guidance, including material selection, is provided in EM 1110-2-2107. Additional specific guidance for the material selection of various mechanical system components is in ERDC/CERL TR-02-7. The Machinery's Handbook (Oberg et al. 2012) is another reference source for the design of many mechanical components, including gears, bearings, bolts, keys, and shafting. The designer should also reference the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Movable Highway Bridge Design Specifications. Much of the mechanical and electrical design criteria in the AASHTO document can be applied to lock and dam machinery including bearings, gears, keys, shafting and motors. The AASHTO document is much more prescriptive than this engineer manual and can be utilized for design of specific components like bearings.

b. Machinery component criteria. All components of lock and dam operating equipment should be designed for the maximum normal full load, 100% rated, torque of the electric motor, or the maximum effective hydraulic actuator pressure, with a minimum factor of safety of five (5.0), based on the ultimate tensile strength of the material. Where original equipment manufacturer (OEM) products are specified and published rating data is available, the designer must use caution in blindly applying factors of safety to OEM components that already have inherent service factors in their design. This is to avoid having the designer grossly oversize a component by applying safety factors to already established manufacturer safety factors.

(1) All components should also be designed for a unit stress not to exceed 75% of the yield strength of the material, using the locked rotor torque rating of the electric motor, or the maximum hydraulic actuator pressure available through the control system. A fracture mechanics/fatigue analysis should also be performed to help identify localized stress concentrations that will govern the percentage of yield strength established for the lower limit strength.

(2) These criteria determine the maximum allowable tensile stresses for all components. Allowable shear stresses should not exceed published relative shear to tensile ratios such as those listed in the Machinery's Handbook or Machinery Design

texts like Shigley's Mechanical Engineering Design. Components used as fuses, such as some shear bolts, shear keys, torque-limiting couplings, etc., will not be designed to these criteria.

c. Buckling criteria. The designer should reference Chapter 4 for buckling criteria related to hydraulic cylinders. Buckling criteria also needs to be considered for components such as gate stems and miter gate struts. Components that might fail in buckling compression should be designed for a minimum factor of safety of 3, using the Euler or J.B. Johnson formulas, as appropriate.

(1) The factor of safety must be applied to the maximum working load on the member and the critical buckling load.

(2) A factor of safety less than 3 may be justified in some cases. In most cases, however, the end fixity coefficient for pin-ended columns should be used (C = 1). Using an end fixity coefficient greater than C = 2 is not recommended. When end fixity other than pin-ended columns is used, the designer should carefully document the rationale supporting the decision in the design documentation report. While C = 1 is often used, the engineer needs to carefully evaluate the end fixity to ensure a sound design while avoiding unnecessary oversizing of components. For example, sometimes an end fixity of C = 1.2 or 1.5 may be justified.

(3) For other cases, like overload conditions, a factor of safety less than 3 for buckling may be used. It is up to the designer to evaluate these overload conditions and select an appropriate factor of safety. The designer also needs to ensure that any catastrophic failure related to buckling does not lead to life loss or significant property damage.

(4) For slide gates, except for the above-mentioned factors of safety and end fixity coefficients, the designer should use American Water Works Association (AWWA) C560 and AWWA C561 and other industry standards, where appropriate. The designer should note the AWWA standards uses C = 2. This could be viewed as a compromise between Pinned-Pinned (C = 1) and Fixed-Fixed (C = 4) connections. The designer should also reference the further discussion in Chapter 9 on slide gates.

d. Two-sided gate lifting criteria. Most larger gate types are lifted from both sides of the gate. This includes tainter gates, vertical lift gates, and tainter valves. The criterion for two-sided lifting is provided in Chapter 11. The criteria in Chapter 11 includes equal loading on both sides of the gate and offset loading to one side of the gate. Offset loading may occur when one side of the gate becomes jammed. The designer should use the criteria detailed in Chapter 11 for all two-sided lifting applications. If the designer elects to use other criteria, that must be fully documented in the project design documentation. The designer must also fully document the reasons for deviating from these criteria. Vertical lift gates are discussed in Chapter 9. Lock valve machinery is discussed in Chapter 8.

e. Standard manufactured products. All standard manufactured products should be selected based on the manufacturer's published catalog ratings, or actual data procured by correspondence with all known major manufacturers of that type of component. The intent is to provide open competition for standard manufactured items, while permitting the designer to use available data to provide a fully functional design. Plans and specifications should be presented in a manner that defines a range of performance obtainable by most of the manufacturers.

f. Delivery details. The designer should be aware of product delivery times through correspondence with known major manufacturers to allow a realistic delivery schedule. Delivery information will aid in estimating the construction schedules for the prescribed contract period and development of any required interim completion dates.

g. Design basis. Where applicable, the designer should consider identifying the design basis for any specialty equipment incorporated in the design. The design basis should be used with the salient characteristics included in the drawings and specifications for the benefit of the contractor.

h. Component efficiencies. The following operating efficiencies should be used as a design guide for motor sizing only where relatively conservative values are used to ensure sufficient motor horsepower in power calculations. Several factors could reduce the efficiencies noted. The designer should work with the manufacturers to verify actual efficiencies.

(1) Silent chain (including oil-retaining case) 90% to 97%.

(2) V-belts (including drive/driven sheaves) 80% to 90%.

(3) Spur gearbox:

(a) 1:1 to 16:1 80% to 88%.

(b) 16:1 to 40:1 75% to 84%.

(c) 40:1 to 150:1 70% to 78%.

(4) Helical, herringbone, or planetary gearbox:

(a) Single reduction 90% to 97%.

(b) Double reduction 90% to 95%.

(c) Triple reduction 80% to 90%.

(d) Quadruple reduction 80% to 88%.

(5) Worm gear gearbox: Worm gear efficiencies must be provided by the manufacturer. The manufacturers must furnish the certified starting and running

efficiency of the unit, particularly if the unit is operated at other than standard speeds. Factory testing of worm gear boxes is recommended to verify efficiency.

(6) Spur gear set 95% to 97%.

(7) Bevel gear set 90% to 95%.

(8) Bearings:

(a) Ball and roller 98%.

(b) Bronze plain bearings (> 5 revolutions per minute [rpm]) 90% to 95%.

(c) Bronze plain bearings (< 5 rpm) 90% to 93%.

i. Efficiencies and operating conditions. Certified starting and operating efficiencies should be obtained from manufacturer's data for the normal operating speeds. Special operating conditions, such as high or low ambient temperatures or lubricant heaters, should be coordinated with the manufacturer's engineering departments. The lowest efficiency obtained from a minimum of three standard manufacturers should be used. Designers should also consider how age, wear, debris intrusion, and insufficient maintenance may affect efficiencies and reduce manufacturer provided efficiencies (where appropriate) to ensure sufficient system power as the machinery ages.

j. Efficiencies in the stall load condition. For the locked rotor or stall torque overload scenario described in Section 2-1 (b) (1), adding efficiencies would reduce the stall torque load so using a higher efficiency is conservative. In relative efficient machinery systems, using 100% efficiency for all components can be appropriate. However, in systems where inefficient components such as high ratio worm gear reducers are used, 100% efficiency may significantly overestimate the system efficiency. In these systems, some efficiency should be applied to the system to keep the stall torque to a reasonable value.

k. Manufacturer efficiencies. Manufacturers can typically provide maximum operating efficiencies that can help the designer estimate the best-case efficiency, which will result in a reasonably accurate stall load for components in the machinery system.

l. Worm gear boxes. For worm gear reducers in particular, the efficiency typically decreases with the rotational speed of the worm. This means the maximum normal operating efficiency at rated speed for a worm gear reducer is likely conservative for determining a reasonable stall load.

m. Mechanical and structural coordination and equipment forces. Forces from equipment startup can be large and can impart stresses to structures that are not designed for such forces. The designer needs to be aware of the forces not only at startup but under overload conditions and how that affects structural components. Controls, limit devices, and interlocks not only protect machinery but also ideally could eliminate many unintentional consequences to structural components. This includes damage to expensive structural gates and machinery foundations. Assets are better managed and protected with properly designed controls and safety interlocks.

n. Fits and Finishes. Provide fits and finishes per AASHTO LRFD Movable Bridge Design Specifications Table 6.7.8.-1.

2–2. Machinery components bearings

Ball, roller, tapered roller, and spherical roller bearings should be selected according to the manufacturer's published catalog ratings of the group, type, and size required. AASHTO LRFD requirements can be utilized for sizing.

a. The manufacturer's ratings for loads and speeds should be used in determining the bearing capacity. Service and installation factors must be in line with the bearing manufacturer's recommendations. The L-10 bearing life should be a minimum of 75,000 hours, based on the largest full-load motor horsepower (hp) provided by the specified motor. Bearings, which remain static for extended periods, should be designed with greater safety factors, using the basic static load rating (Cor). The B-10 life and load ratings calculation methods are defined in International Organization for Standardization (ISO) Industry Specifications ISO 281 or Japanese Standards Association (JIS) B1519.

b. All bearings should be equipped with labyrinth seals to exclude foreign matter and retain lubrication without leakage under both static and dynamic operating conditions. Only one fixed-mount bearing should be used on shafts with multi-bearing installations to permit thermal expansion in the axial direction. Manufacturers should be consulted for typical axial capacities of the bearings.

c. Plain bearings, also called sleeve bearings or bushings, should be designed for a maximum normal bearing pressure of 6.9 mega Pascals (MPa) (1,000 psi), except for bearings operating below 5 rpm. Under this special, slow speed, uniform load condition, the bearing pressure may be designed for up to 27.6 MPa (4000 psi).

d. Common bearing materials to be specified for their strength, high load-carrying capacities, good wear, and corrosion resistance include the tin bronze alloys. Alloy C90500 is suitable for most slow-to-moderate speed applications, according to American Society for Testing and Materials (ASTM) B271, ASTM B505, or ASTM B584. The tin bronzes should be used with reliable grease lubrication systems.

e. Examples of plain bearings for miter gate and trunnion pin connections are shown in Figure 2–1 and Figure 2–2. Mating shaft material should be specified with a hardness of 300–400 Brinnell Hardness Number (BHN). Special materials, or pressure designs, should be coordinated with several manufacturers to ensure adequate competition is available.

f. Where an easily machined bronze or the environment and lubrication might be questionable, the designer may elect to use high-leaded tin bronzes. Alloy C93200 is an exceptional bronze for medium loads and speeds. The alloys C93800 and C94300 are

15% and 25% lead. Their high lead percentages allow them to easily conform to misaligned shafts and embedded contaminants. They provide a high level of lubricity under poor lubrication conditions and can be used with unhardened shafts. A high-lead, poured, and scraped babbitt bearing for a low-rpm pump is shown in Figure 2–3.

g. Spherical roller bearings and tapered roller bearings should not be utilized for submerged applications.

Figure 2–1. Plain bearing for a miter gate connection

Figure 2–2. Plain bearing for a tainter gate connection

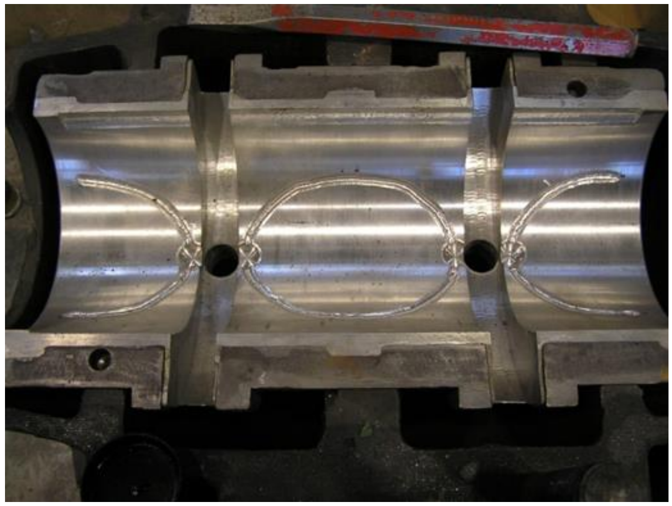


Figure 2–3. Babbitt plain bearing

h. The length-to-diameter ratio (L/D) should be designed close to unity (1.0), considering the bearing pressure required, to minimize wear and misalignment. Some consideration should be given to spherical plain bearings for such things as tainter gate trunnions, bellcranks, struts, and other partial-rotation, slow-motion joints that require an extra degree of freedom. Spherical bearings minimize wear between pins and bushings by accommodating modest misalignment.

i. Grease grooves should be designed and incorporated into the bearings to provide redundant grease pathways. The pathways should be capable of delivering the grease around the entire circumference of the bearing and mating surface without relying on rotation of the components. Delivery of the grease through the pin to the bearing grease grooves in lieu of delivery through the bearing housing should be the preferred method where feasible. Pathways through the bearing housing can become cut off or comprised, should the bearing ever rotate within the housing during the life of the bearing.

j. Extended grease lines for pintles, bushings, and bearings need to be oversized to compensate for grease hardening over the life of the project and to ensure adequate grease delivery. The grease lines should be rigid in areas prone to damage from debris and ice. Schedule 80 stainless steel rigid piping has proven adequate in many installations. The piping should be routed to provide the maximum protection to the line while also maintaining accessibility for replacement by divers, should damage occur. Using flexible lines should be minimized and must be armored and rated for the maximum anticipated pressure of the greasing system.

k. Self-lubricated bearings are manufactured of materials that transfer small amounts of lubricants to the mating surface without the need for external lubrication. See Chapter 3 for additional discussion of self-lubricated material case studies, recommendations, and detailed discussion of self-lubricated bearings. The designer should also reference INDC TR 2018-01 and EM 1110-2-1424. Both documents provide extensive discussion and design limitations of self-lubricated materials.

l. Pillow blocks should be cast iron, cast steel, or fabricated from forged steel. Pillow blocks should be designed to provide full radial and axial capacity in all directions. Mounting bolts, nuts, etc., should be rated for the bearing's full basic dynamic load rating capacity in all directions, including upward through the cap. This rating is obtained from the bearing manufacturer's published data for commercially available bearings or from formula calculations available in specifications ISO 281 or JIS B1519 for custom bearings.

m. Ball-bearing pillow blocks and flange blocks should have a two-bolt base. Roller-bearing pillow blocks must have a four-bolt base. Spherical roller bearings should be either fixed or expansion type, as required. End caps must be provided on open-ended shafts. Roller-bearing housing caps must be recessed into or dowelled onto the bases and secured with no fewer than four bolts, Society of Automotive Engineers (SAE) Grade 8. Slotted mounting holes may be used for the base, as required, but dowel pins or keeper bars should be permanently installed after final alignment and testing.

n. Only one fixed-mount pillow block should be used on shafts with multiple pillow block installations to permit thermal expansion in the axial direction. Some examples of pillow-block installations are in Figure 2–4 and Figure 2–5.

Figure 2–4. Pillow block bearing machinery drive

Figure 2–5. Pillow block bearings for culvert valve machinery

o. Pintle bushings for lock gates traditionally have been grease-lubricated aluminum bronze. The aluminum bronze alloy used is typically C95400, meeting the requirements of ASTM B148 or ASTM B271. Plate 18 provides recommended grease groove and seal details. The aluminum bronze bushing is press fitted into the pintle socket and secured by bolting to the socket. The amount of press fit of the bushing in the socket should be kept minimal (0.001 to 0.003 in.) to prevent any alteration of the machined fit between the bushing and pintle ball after assembly. The pintle assembly at Lower Granite Lock is shown in Figure 2–6. Chapter 6 of this manual provides further discussion of miter gate pintles.

(1) The bearing surface should be finished truly hemispherical and the pintle ball fitted to the bushing by scraping or lapped until uniform contact is attained over the entire bearing surface. This can be determined by testing with carbon paper or similar media transfer technique. The pintle and bushing need to be match marked. Surface finishes should be shown on the drawings according to the American Society of Mechanical Engineers (ASME) B46.1. Determining compliance with surface requirements typically is done by sense of feel and visual inspection of the work and comparing it to the roughness comparison specimens of ASME B46.1. Plates 20 and 21 provide additional pintle information.

(2) Grease-lubricated bronze continues to work well, but environmental issues created by pumping grease to the pintle bushing is causing a shift in recent designs toward the self-lubricated pintle bushings.

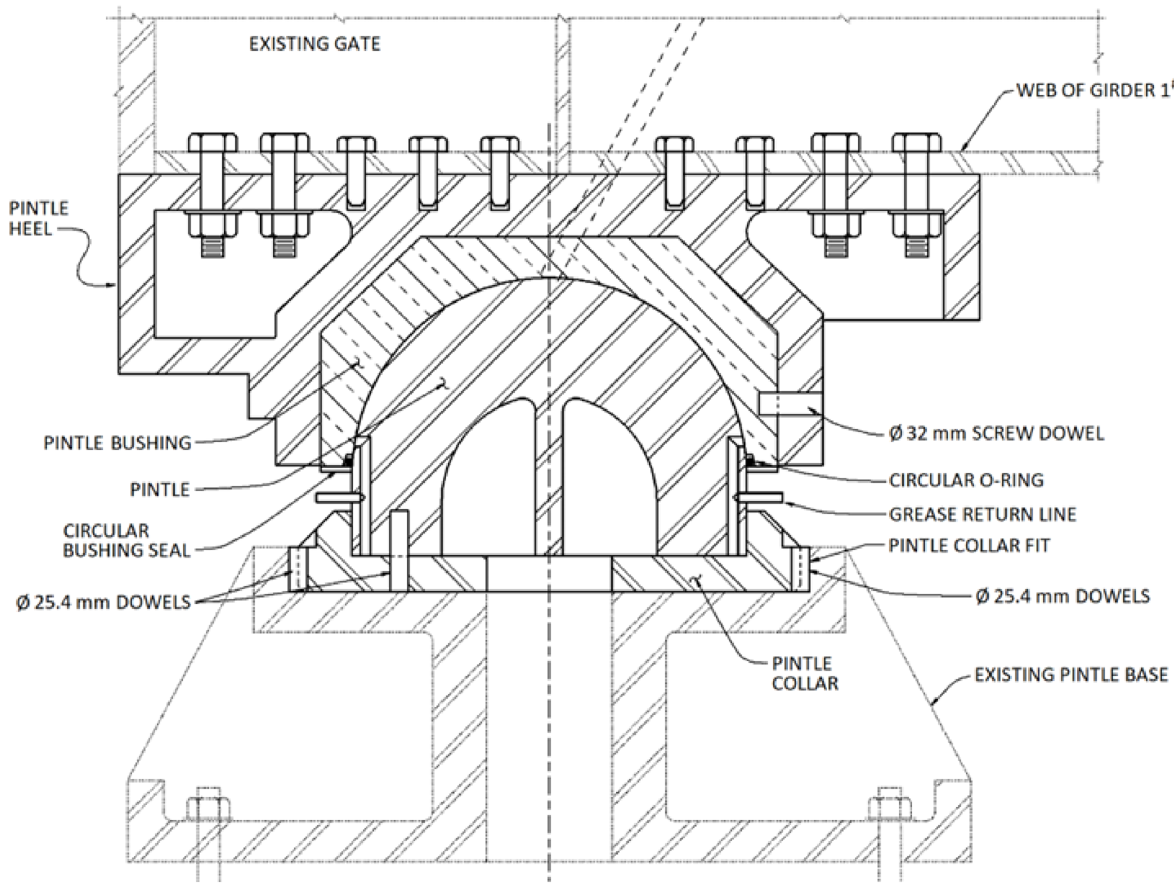


Figure 2–6. Lower Granite Lock pintle assembly

2–3. Machinery component brakes

Brakes should be spring set and have a minimum continuous-duty torque rating of 150% of the maximum full load torque rating of the electric motor or hydraulic actuator, as applied to the brake wheel. Special consideration in brake selection must be provided by the designer to prevent runaway speeds from developing in gates with the potential for free fall. The brake set reaction time must be minimized to prevent the downward momentum of the gate from exceeding the holding torque of the brake or causing excessive glazing or wear of the brake shoes. All electromechanical drives must have brakes. All brakes should fail to the set position if power is lost such that they will catch and hold a lifted load.

a. Shoe-type brakes should be direct current (DC), magnet-operated, alternating current (AC)-rectified solenoid, or AC hydraulic thruster release. The DC type actuates by electromagnets (Figure 2–7), and the AC-rectified type typically uses a solenoid and plunger as shown in Figure 2–8. The AC thruster type, shown in Figure 2–9, uses a small hydraulic pump and hydraulic-actuated cylinder. UFGS 35 20 20, Electrical Equipment for Gate Hoist, provides design parameters for specifying brakes.

b. Disc-type brakes should be solenoid released and can either be foot mounted or motor shaft mounted. The latter allows the brake to be directly mounted to the motor. These brakes can also be specified with enclosures that withstand a degree of water submergence. A motor-mounted brake of this type is shown in Figure 2–10.

c. Fuses should not be used in the brake control circuit. Brakes should be mounted in watertight and dust-tight enclosures, with heaters for moisture protection, manual release devices, limit switches as applicable, and indicators and electrical connections, as required by the operating environment.

d. Brakes must be self-compensating to adjust for shoe or pad wear. The designer should ensure enclosures are designed with removable enclosure panels for access to perform inspection and maintenance of the brake components.

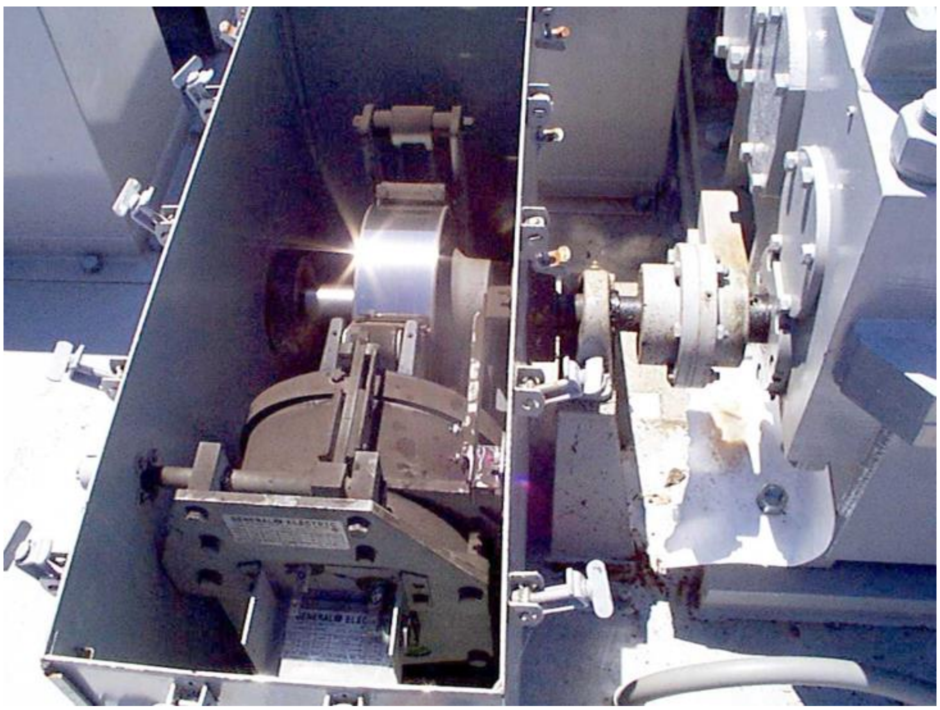


Figure 2–7. Direct current brake

Figure 2–8. Alternating current-rectified brake

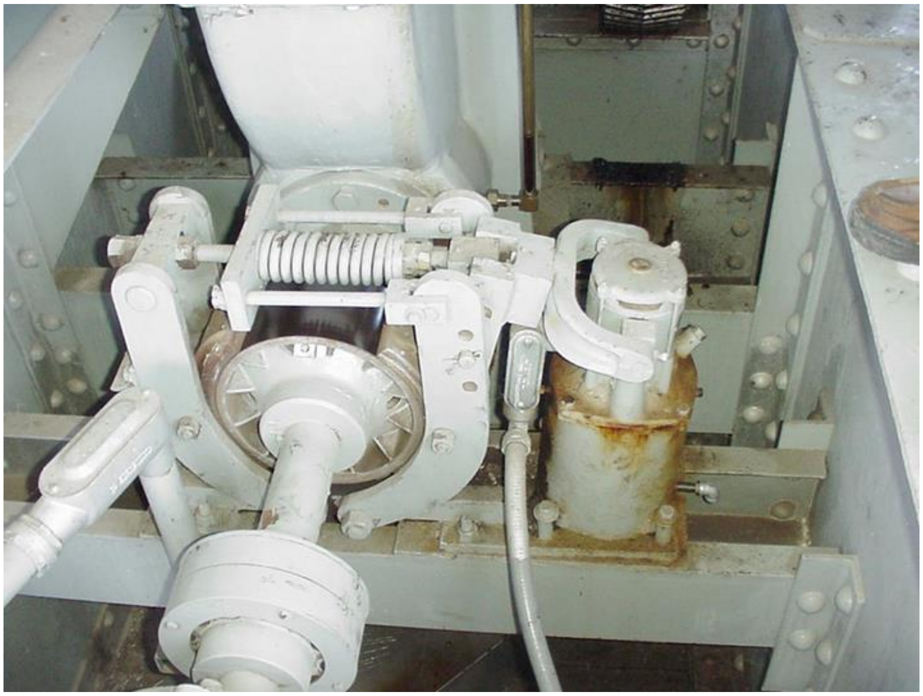


Figure 2–9. Alternating current thruster brake

Figure 2–10. Motor-mounted disc brake

2–4. Machinery components couplings

There are many different types of shaft couplings. The torque ratings, angular misalignment capabilities, axial float capabilities, and shock-absorption characteristics are the main factors that differentiate them. Some of the more common types used on inland navigation projects are mentioned here. These include flexible-disk couplings, elastomeric couplings, chain couplings, gear couplings, grid couplings, and jaw-type and rigid couplings. A manufacturer catalog should be used to make appropriate size selection of couplings. Nominal size can then be called out in the specification and the manufacturer can provide additional details as part of the shop drawing review.

a. Coupling device. A coupling is a device for joining two rotating shafts. The most basic form is rigid and can accommodate no angular misalignment or shaft float. Other coupling designs are available to accommodate some amount of angular misalignment or axial shaft movement. Couplings can be selected to absorb shock loading between shafts and to protect against a momentary over-torque condition.

b. Design options. It is the engineer's responsibility to select the correct coupling design for each application, anticipating the conditions in which the coupling must continue to perform reliably. Couplings should be selected using the manufacturer's published catalog ratings. The designer should work with the coupling manufacturer to the extent possible during design. Exceeding the limitations of any coupling has led to the premature failure of the coupling or damage to machinery. Couplings requiring grease that are oriented vertically should be specified with an appropriate seal that can retain grease in this orientation.

c. Flexible disk. Flexible-disk couplings are suitable only for specific applications such as precise control equipment (turbines, etc.). Flexible-disk couplings require no lubrication, and their components are external to allow visual inspection. They are suitable for only slight misalignment, and the replacement of the disk pack is not as easy as the elastomeric coupling inserts.

(1) They are suitable for heavy-duty, slow- to medium-speed applications. Flexible disk couplings can be used where high starting torques, shock loads, torque reversals, or continuous alternating torque is encountered. Flexible-disk couplings transmit torque and provide for angular and axial misalignment between shafts with a coupling comprised of shaft-mounted hubs connected through flexible-disk packs with spacer or sleeve assemblies.

(2) Since these couplings do not require lubrication, maintenance costs can be considered comparably low. They are easy to inspect for proper operation. Disadvantages include a relatively high initial cost. They also require more precision on alignment and assembly.

d. Elastomeric. Elastomeric couplings incorporate a flexible synthetic insert between coupling halves, providing either a flexible cushion between jaws or a direct torsion connection. These are available in a variety of designs and capabilities.

(1) The elastomeric coupling in Figure 2–11 is secured at each bolt. Each elastomer sleeve consists of a hollow cylinder through which the bolts join each half of the coupling. The elastomer serves to accommodate severe angular misalignment and to cushion shock overloading. Advantages include low maintenance costs, because lubrication is not required, and ease of inspection when the coupling is accessible. The couplings also can be easily fitted to existing coupling applications.

(2) There are power limitations due to the varying elasticity modulus of the flexible elements. Environmental conditions such as temperature and humidity, chemical attack, and ultraviolet (UV) exposure can have an adverse impact on the life and performance of the insert material for this type of coupling. Designers must consider these factors during selection.

e. Chain. Chain couplings provide inexpensive coupling alternatives in the medium torque range. They can be exposed or enclosed within hub/sleeve assemblies to retain lubrication. The chain couplings transmit torque through sprocket hubs mounted on the shaft ends that are coupled by double-width roller chain. A chain-coupling drawing is shown in Figure 2–12. Chain couplings do not tolerate large misalignment.


Figure 2–11. Elastomeric coupling

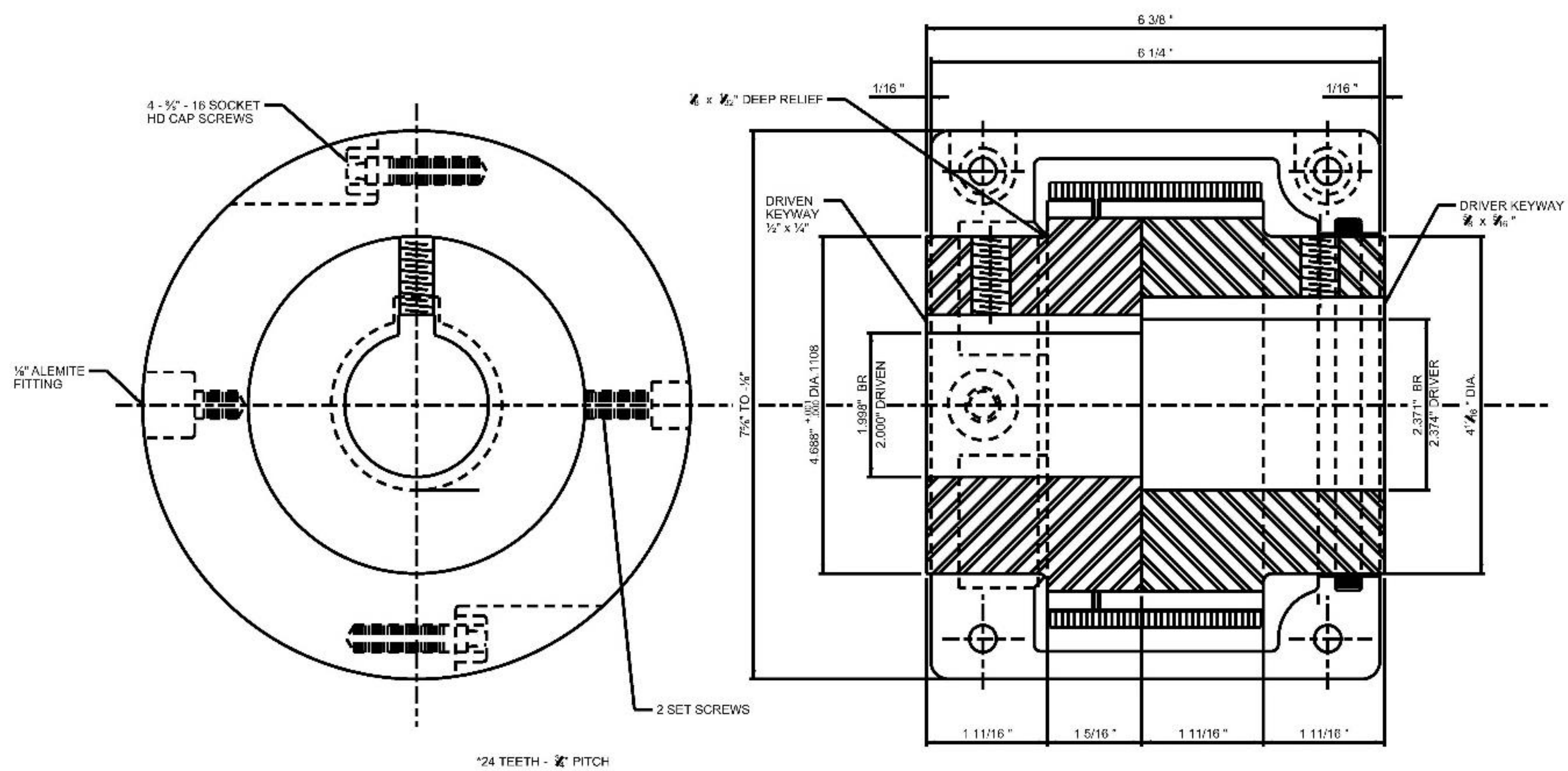


Figure 2–12. Chain coupling

f. Gear. Gear-type couplings provide the highest torque-carrying capabilities with small, compact designs and can accommodate small amounts of angular and slight parallel misalignment. A gear coupling is shown in Figure 2–13. Gear couplings can be more tolerant of axial growth and shaft shrinkage, which can be advantageous for the wide temperature variations common on inland navigation projects.

(1) Gear couplings tolerate the misalignment through the clearance between the outside teeth of the hubs and the inside teeth of the sleeves. The tooth-to-tooth sliding motion caused by misalignment can be detrimental if it is a permanent condition and can lead to premature failure. Misalignment for gear couplings must be minimized by not exceeding the manufacturer's recommendations for installation limits pertaining to gap-hub separation, angular alignment, and parallel offset alignment measurements.

(2) Gear-type couplings must maintain their internal lubrication for successful operation. External grease fittings are often replaced with a plug for safety reasons and must be installed temporarily during periodic maintenance lubrication.

(3) Gears must be machined according to applicable ANSI/American Gear Manufacturers Association (AGMA) standards. Couplings must be of sufficient capacity to develop the full strength of the shafting that they connect and must be pressed and keyed thereon. The key fits should be accordance with ASME B17.1 and AASHTO LRFD. The designer can provide a tighter fit for fabricated components where it’s reasonable but that shouldn’t apply to manufactured components where the manufacturer should provide the design requirements. Gear couplings should have steel housings and hubs, with integral lips to contain the seals and retain the sleeves, with lubrication. Sleeves should be fastened such that they cannot slip or loosen. The mating sleeve flanges join both halves of the coupling to transmit the torque between the shafts.

(4) The proper bolt type and torque must be installed in the flanges to avoid premature bolt bending fatigue and shear failures. Gear couplings that use snap rings to hold the sleeves should not be permitted. Internal shaft hubs must be bored to match their mating shaft diameters and matched keyways provided. This interface most often requires interference fits specified to develop full load-carrying capacity. Reversing loads often require special considerations in the design. The designer must carefully identify and match bore diameters to shaft sizes with special contract language to ensure the contractor and equipment manufacturer are aware of this requirement.

(5) Bolts must be SAE Grade 8. Spare couplings purchased should not have their final bores specified and should be rough bored with final boring completed after the shaft sizes can be measured.

Figure 2–13. Gear-type coupling, Lock 2, Mississippi River

g. Grid. Grid couplings are like gear-type couplings using an interlocking steel grid between two slotted shaft hubs to transmit the torque. A disassembled grid coupling is shown in Figure 2–14. The grid is contained within a sealed housing to retain the lubrication for the coupling. The grid flexes in a sliding action within the hubs to transmit torque and compensate for misalignment. Grid couplings are also capable of reducing vibration by absorbing impact energy and are easy to install and maintain. Grid couplings are commonly used to couple prime movers to the machinery system to reduce the transfer of vibrations to the rest of the machinery.

h. Jaw. Jaw-type couplings have two metallic hubs interconnected by a center insert referred to as a spider. The hub jaws engage the lobes on the spider to form the torque transmitting connection. The spiders are fabricated from a variety of different materials and hardness to fit the application. As the damping ability of the coupling increases, the load-carrying capacity is decreased. Two jaw-type couplings are shown in Figure 2–15 and Figure 2–16. The jaw-type couplings are common for small shaft sizes and lighter loads. Misalignment with this type of coupling must be minimized because rapid deterioration of the spider could occur. One advantage of jaw couplings is they are fail-safe. The hub jaws will continue to engage and transmit torque even if the spider assembly fails.

i. Rigid. Rigid couplings are the simplest form used to transmit torque in a power transmission arrangement. They have either bolted flanges, a keyed shaft with sleeved hub, or a clamp design to connect shaft ends. Rigid couplings cannot compensate for misalignment or axial expansion. Designers should use caution and consider the application carefully before installing rigid-type couplings. Perfect alignment must be provided and maintained to use this type of coupling. If misalignment is present, the load will be transferred to the shafts and bearings, likely resulting in premature failure.

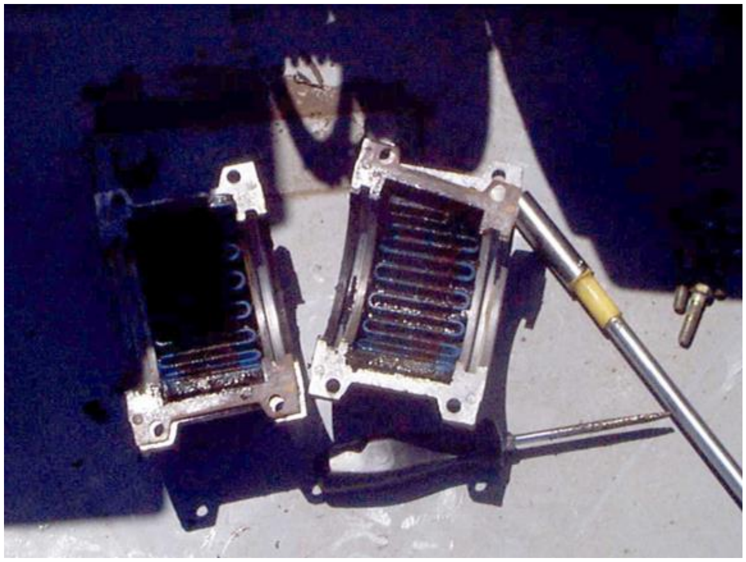


Figure 2–14. Grid coupling

Figure 2–15. Jaw-type coupling detail

Figure 2–16. Jaw-type coupling

2–5. Machinery components load-sensing devices

Load-sensing devices can be used to control overloads in single- or multi-part, wire rope hoists. The device can be installed between the wire rope and the dead-end anchorage connection or in other locations with pinned connections. The designer should be cognizant of the requirement for periodic recalibration of these devices and select devices with minimal recalibration requirements and ensure that labor required for recalibration is minimized.

a. Force-control limit switches. Force-control switches consist of a force beam that deflects under tension or compression, actuating microswitches at preset loads. The designer should provide switches for high load conditions such as locked rotor torque or gate-seizing or obstruction.

(1) High and low force-control limits can be set with backup trip switches for each limit. One switch is set slightly above the normal operating load, and a second is set higher as an emergency backup device. A low load switch can be set for the load encountered in raising due to a seized sheave. Low load, at the end anchorage, could indicate an overload in the portion of the wire rope from the sheave nest to the drum.

(2) The low load switches also should be capable of recognizing a slack cable condition. This condition likely would occur while lowering the gate and the gate encounters an obstruction or becomes wedged in the operating slot. The low load switches would prevent the possibility of the wire rope coming off the sheave or dropping the gate and shock-loading the machinery.

(3) The main limit switches interrupt the control circuit, while the backup switches de-energize the hoist. The forces are determined by calculating the wire rope tension

that would be produced by the maximum load used in the design of machinery components. Backup switches typically are set at approximately 900 kg (2,000 lbs) differential from the primary switch.

b. Load cells and pins. Another alternative is using electronic load cells that can be furnished as pins, links, or various other configurations. Pins are the most useful for crane and hoist applications (Figure 2–17). A load cell is a transducer that converts force into a measurable electrical output. Strain gauge load cells are the most common type. They can provide continuous system monitoring and can easily be incorporated into overall or stand-alone programmable logic controller (PLC) systems to provide similar set point control, as discussed above, for force-control limit switches.

Figure 2–17. Load pin on the anchored end of wire rope

c. Pressure-limit switches. Pressure-limit switches in the hydraulic circuits, shown in Figure 2–18, of wire rope hoisting arrangements with sheaves mounted to the hydraulic actuator rams have been used successfully for operational control. These are set below the hydraulic pressure reliefs valves for high overload conditions and can monitor for slack cable conditions under low pressure when not affected by hydraulic system counterbalance valves.

Figure 2–18. Hydraulic pressure limit switch

2–6. Machinery components torque-limiting devices

Torque-limiting devices are another device useful in limiting excessive machinery hoist loads. Motor torque can approach 2 to 3 times or more of the 100% rated torque if the machinery encounters an unusual loading condition. This depends on the specific motor design.

a. If the designer elects to use a torque-limiting device, machinery components should not fail if the torque-limiting device fails. The designer needs to evaluate the torque characteristics of the motor and protect machinery components from yielding from 30% additional torque beyond the setting of the torque-limiting switch. For example, if the torque-limiting device is set at 160% of the motor full load torque, then components should not yield at 190% of the full load motor torque. These criteria should govern if the designer elects to utilize a torque limiting device. If there are multiple torque limiting devices, then the 30% criteria should be applied to whatever device has the highest torque setting.

b. Common torque-limiting devices include slip clutches, torque transducers, and torque switches. Clutches and transducers are reactionary devices, meaning that there is a delay from when an overload torque is detected until it is relayed to the motor control system and the motor is shut down. Lag time must be evaluated for acceptability on a case-by-case basis for any selected device. Other methods of limiting torque include custom-wound motors and VFDs. Couplings are also available in today’s market that can be set to limit the torque into the drive system. These couplings are designed to slip at a certain set point.

c. Torque-limiting devices are typically used to measure or react to the torque applied to the system by the motor instead of directly to the gate structure. Equipment efficiencies need to be accurately estimated to determine an accurate load applied to the gate structure.

d. Slip clutches are couplings in which the two halves move relative to each other if torque exceeds a set value.

(1) Friction-type slip clutches limit the torque through the friction coefficient of discs moving against each other. Multi-plate, slip-type clutches with fiber-type friction disks are shown in Figure 2–19 and Figure 2–20. They should be adjustable and use coil springs. The coil springs must be properly adjusted and maintained to compensate for any slippage wear in the friction plates. To protect the machinery and components, the torque coupling must be adjustable and set to slip at the designer's predetermined torque value. The torque slip should have a minimum adjustment range of plus or minus 20% of the specified load, depending on the designer's requirements.

(2) The friction coupling should continue to slip until the torque drops below the set level. The torque slip range should be controlled by a spring-type mechanism that can be adjusted by tightening or loosening the through bolts.

(3) Slip clutches should be equipped with a means of sealed lubrication. Most slip-type torque-limiting couplings require a break-in period after assembly to the motor and shafts, and the designer should specify such in the execution section of the specifications. Slip clutches normally are rated for 200% of the maximum calculated torque requirement and should be adjusted to initiate slipping at a setting slightly above the normal operating torque requirement. However, the manufacturer's recommendations should be considered for both sizing and adjustment.

(4) The torque capacity requirement is minimized if the clutch is located on the motor side of the speed reducer. Heat-rejection capacity is not an important consideration as the device would not be expected to slip, except for very short periods. The designer should provide protection from the weather and oil or grease contaminating the friction elements.

e. Ball and detent torque limiters are another type of limiting device that can accurately disengage the machinery at a preset torque value. The ball and detent type can fully disengage or reset once the overload condition is removed. To protect the machinery and components, the torque coupling must be adjustable and set to slip at the designer's predetermined torque value. The coupling will continue to slip until the torque drops below this level. They also can also be equipped with limit switches for control signaling of an overload condition.

f. Friction and ball and detent torque limiters should not be used on lifted loads as they may be unable to hold the lifted load if they degrade over time.

Figure 2–19. Slip clutch

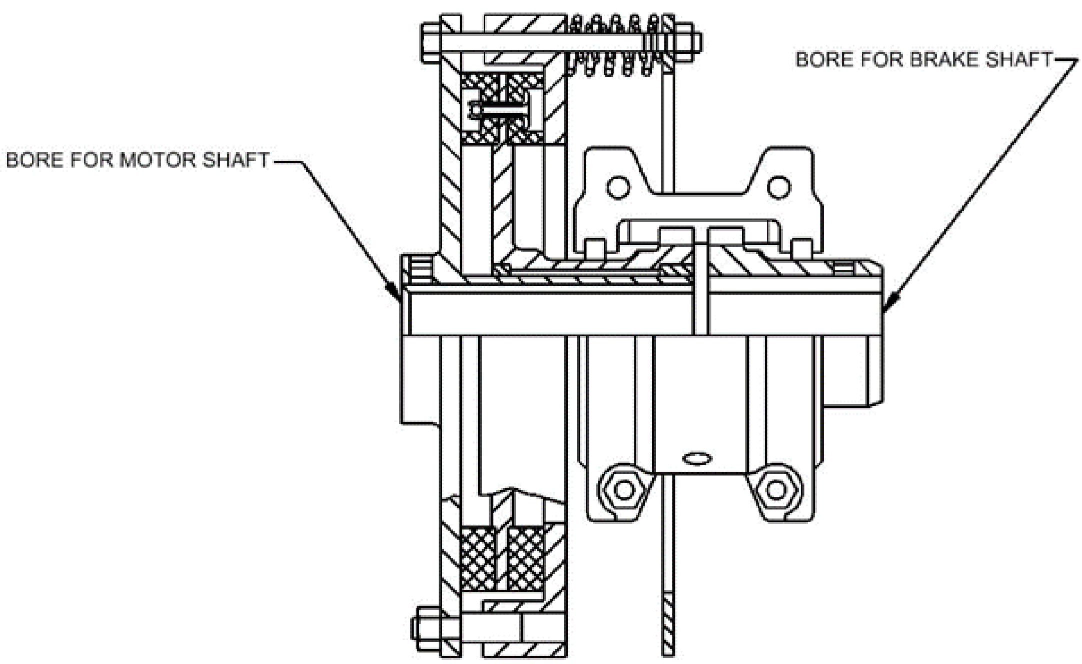


Figure 2–20. Slip clutch detail

2–7. Machinery components torque transducers

There are two types of torque transducers: C-faced and in-line. Both devices measure torque and then transmit a signal to components in the motor control system. Both can be more accurate than other types of torque limiting devices.

a. C-faced torque transducers (Figure 2–21) are mounted between the motor and the primary reducer. The torque applied by the motor creates a reaction force at the motor mounts. C-faced torque transducers serve as the motor mounts and measure the equal and opposite torque required to hold the motor in place as it delivers torque to drive the system. C-faced torque transducers have a rigid metal frame that is used to mount the motor to the primary reducer. Strain gauges are placed on the rigid metal frame to measure the torsional strain developed to hold the motor in place.

b. C-faced torque transducers should be calibrated on a regular basis. Calibration is performed by applying a known torque to the device and measuring the resulting electrical signal. This could be accomplished by applying a torque to the motor frame with a torque wrench and measuring the electrical output. This calibration should be performed while the system is not running, likely annually during system maintenance.

Figure 2–21. C-faced torque transducer

c. Torque transducers are available with various output signal options +/- 10 volts DC (VDC), which can be used to drive a control relay to drop out the motor control circuit on an over-torque condition. The additional equipment needed for the electrical control system are an external power supply (10VDC) and a control relay, both of which are very reliable for a high number of operations.

d. Torque transducers are generally not designed for use outdoors. If used outdoors, a suitable weatherproof enclosure must be included.

e. In-line torque transducers are mounted in the drive train of the operating machinery, typically between the motor and the primary reducer. In-line torque transducers have a shaft that rotates with and carries the torque of the drive train. Standard styles of flex couplings are used on the input and output sides of the rotating shaft to transfer torque between adjacent components. Torsional strain is measured with strain gauges mounted to the rotating shaft. The device is then calibrated to output the corresponding torque. The transducer housing is stationary and is typically rigidly foot mounted. These devices are available with various output signal options +/- 10VDC, which can be used to drive a control relay to drop out the motor control circuit on an over-torque condition.

2–8. Variable-frequency drives

VFDs, described further in Chapters 16 and 17, are an electronic device that can operate a motor at variable speeds by controlling the frequency of the power applied to the motor. VFDs may also be referred to as ASD or AC drives and the terms are used interchangeably.

a. Current sensing devices can enable the VFD to directly monitor current and resulting torque, or current and torque can be inferred from an algorithm that uses applied voltage, frequency, and motor parametric data. It is this torque control capability that enables the VFD to act as a load-limiting device. Models are available with programmable torque and current limits. Many other operating features are available, such as controlling the system brake to ensure that the motor is producing sufficient torque before it is released.

b. VFDs provide accurate control of torque and are considered reliable, but they have not been fully tested in an environment where they are idle for long periods over many years. One major manufacturer suggests a service life of 20 years. VFDs can be complex, with many customizable features. Operations staff must be able to operate and maintain these over the life of the VFD.

2–9. Custom-wound motors

Custom-wound motors are fabricated by the motor manufacturer with a custom winding design that can change the torque versus speed characteristics of the motor. Manufacturers can often custom design the motor windings to limit the overload characteristics of the motor. Other than a winding design that does not match the standard National Electrical Manufacturers Association (NEMA) design type, custom-wound motors are essentially standard motors. Since the overload properties are limited by the winding design, no additional electrical devices (relays, PLCs, etc.) are needed to operate the load-limiting function.

a. Custom-wound motors should be shop tested by the manufacturer to verify the desired overload properties are provided. No additional calibration should be required, as the windings providing the overload limit are not modified because of operation.

b. Custom-wound motors are designed by the manufacturer on a case-by-case basis to meet the needed overload limits. Designers need to coordinate with the manufacturer during the design to verify that their specific overload limit requirements can be met.

c. Sizes of motor housing and frames sometimes need to increase to accommodate heat dissipation requirements to provide continuous operation.

d. Replacing motors in the future requires matching the custom winding requirements.

e. Appropriate sizing of custom-wound motors requires either measuring the system loads or accurate calculation of the needed motor operating loads. As with any load-limiting device, this includes estimates of overload conditions. Appropriate uncertainty factors should also be used to account for unexpected loading. Not estimating the correct operating loads can result in a motor that stalls out too early.

2–10. Machinery components open spur gears

For USACE machinery applications, gear sets are nearly always used to reduce speed and increase torque. Open gears should have spur teeth of the involute form, in compliance with applicable AGMA standards. A greased open spur gear set is shown in Figure 2–22. The designer should provide lubrication requirements for all open gear sets both in the plans and specifications and in the O&M manual. Basic strength should be based on the static load from the Lewis equation, as modified by the Barth equation (design stress = Lewis stress x 600/(600 + pitch-line velocity-fpm)).

a. Spur gears should be designed with forged steel rims according to ASTM A290, while the hubs and arms can be cast (ASTM A148) or fabricated from rolled steel plate. Gearing must be cut from solid steel and may be integrally cast with the hub, drum, or shaft. Large spur gears can be split radially, along two of the support arms, to permit more convenient handling and removal. The split line can be fastened by high-strength bolting materials, designed for the maximum loads on the gear.

Figure 2–22. Open spur gear sets

b. Pinions should be fabricated from ASTM A291 forged steel. Pinion gear teeth should have a hardness of approximately 50 BHN greater than the driven gear teeth to equalize wear. A pinion gear is shown in Plate 6. Gears should not be overhung on shafts, including speed-reducer shafts.

c. The designer should specify the minimum contact area between pinion and spur gears. The specifications should establish what misalignment is acceptable, define tolerances on the gear sets, and define what minimum contact area should be achieved.

d. The material hardness and corresponding strength of the gear and pinion has a direct impact on the amount of torque the gear set can transmit. Gears should not be overhung on shafts, including speed-reducer shafts. The AGMA provides multiple design standards that gear manufacturing in the United States follow.

e. Gear geometry is a critical consideration. The gear geometry data allows estimating tooth contact stress, bending stress, lubricant film thickness, and gear tooth contact temperature based on transmitted loads. These values can be calculated using ANSI/ AGMA 2001. Gear strength and the flexural strength of gear teeth typically follow the Lewis equation as described in Dudley – Handbook of Practical Gear Design. The AASHTO LRFD Movable Highway Bridge Design Specifications states three criteria for open spur gear design: failure of the teeth at the fatigue limit state, surface durability through pitting and wear resistance, and resistance for overload conditions. The AASHTO criteria is an interpretation of AGMA 2001-D04.

f. To ensure efficient power transmission, gears in a gear train must have the same circular pitch and pressure angle to effectively work together. A diagram of a spur gear set from Fundamentals of Machine Elements (Schmid et al. 2013) illustrates gear geometry (Figure 2–23). Circular pitch is the value of distance between the centers of one gear tooth to the next tooth. To determine the circular pitch, first the diametral pitch needs to be calculated. Diametral pitch is the ratio of the number of teeth to the pitch diameter of the gear. Pitch diameter is the distance between opposing tooth centers on a gear. The gear reduction between gear sets is simply the ratio of the pitch diameters of the two gears. See equations 2–1 and 2–2.

$$DP = N/PD \tag{2–1}$$

$$CP = \pi/DP \tag{2–2}$$

where:

DP = diametral pitch
PD = pitch diameter
N = number of gear teeth
CP = circular pitch

g. Pressure angle is the angle between the tooth face and the gear wheel tangent. More precisely, it is the angle at a pitch point between the line of pressure (which is normal to the tooth surface) and the plane tangent to the pitch surface. The pressure angle gives the direction normal to the tooth profile. The pressure angle is equal to the profile angle at the standard pitch circle and can be termed the “standard” pressure angle at that point.

h. Standard values of pressure angles in the United States for spur gears are 14.5°, 20°, and 25°. To run gears together properly, their pressure angles must be matched. The larger pressure angles have better load-carrying capacity. Gear manufacturers typically provide design and sizing tables showing circular pitch, diametral pitch, addendum, working depth of tooth, etc. for a variety of gear sizes.

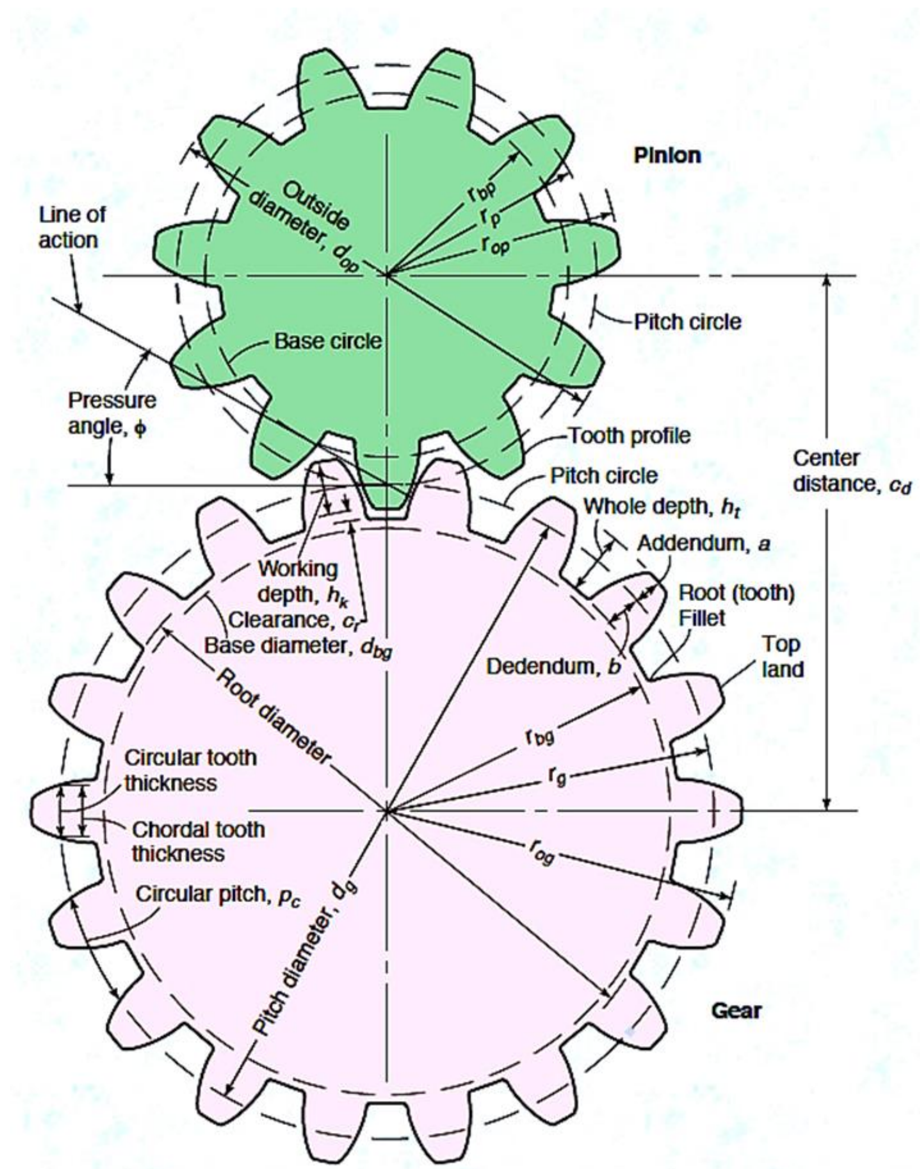


Figure 2–23. Spur gear geometry (from Schmid et al. 2013)

2–11. Machinery components round link chain

Round link chain hoists use both pocket wheel and grooved drum lifting mechanisms. A close-up top view of a dual pocket wheel and chain is shown in Figure 2–24. These types of hoists have been used primarily to replace existing roller chain hoists. Selecting a chain-handling device depends entirely on the type of chain to be used. There are many types of chains available for various applications of lifting service.

a. Link design. The links of the round link chain are not actually round but have round ends and approximately parallel sides. The calibrated links are designed specifically to be used with a pocket wheel that drives the chain properly, loads each link in tension and bearing, and eliminates the bending stresses in the links that occur when a grooved drum is used. This type of chain is applied widely to both low-speed and high-speed lifting and is both abrasion and corrosion resistant.

Figure 2–24. Dual pocket wheel and chain

b. Pocket wheel. The pocket wheel, shown in Plates 67 and 68 and Figure 2–24, is a universally applied lifting mechanism to handle and hold a round link chain to the limit of the chain's breaking strength. A pocket wheel is designed to properly load the chain in tension and bearing without inducing the bending loads predominant in a grooved drum. The wheel may be either a ring forging of alloy steel or a weldment. Two spare dual chain pocket wheels with accompanying spur gear and shaft are shown in Figure 2–25.

Figure 2–25. Dual chain pocket wheels with spur gear

c. Design standard.

(1) Round link chain used in chain hoists, shown in Plate 69, is made from an alloy steel. Although the materials and heat treatment might vary among manufacturers, American Iron and Steel Institute (AISI) 8620 is common for this chain. This material is heat treated to the required tensile strength. Proof testing and visual inspection of each link of chain should be specified. The hardness of this chain from different manufacturers also might vary, but a figure of 300 BHN is considered average, with higher values desired as specified below. The higher hardness of this material provides improved wear qualities over low-alloy chain. Low-alloy chain of equal breaking strength has a greater energy-absorbing capacity for greater shock load capacity over that of high-alloy chain. A standard specification for a ring forging:

(a) Material ASTM A290, Class K, or AISI 8620 cast steel.

(b) Tensile strength, minimum 1,170 MPa (170,000 psi).

(c) Yield strength, minimum 1,000 MPa (145,000 psi).

(d) BHN range of 340 to 400.

(2) The standards for the design of a pocket wheel are derived indirectly from the dimensions included in Deutsches (German) Institut Fur Normung (DIN) 22252, Part 1 (High-Tensile Round-Link Steel Chains for Mining: Testing). This standard covers the dimensions and tolerances for chain that is compatible with pocket wheels. Preliminary design calculations for pocket wheels using a specific chain size are necessary to determine that the unit size is compatible with any physical space limitations imposed by the gate machinery location. DIN standards for round link chain include DIN 5684.

d. Chain locker.

(1) An additional auxiliary item required for a pocket wheel mechanism is a chain locker. The general arrangement of a tainter gate pocket wheel chain hoist with divided chain storage locker as viewed from beneath is shown in Figure 2–26 and Plate 67. The size of a chain locker should be such that it adequately contains the slack length of chain when the gate is in the fully raised position. Chain locker volume should be a minimum of the product of the diameter of the chain in inches squared, multiplied by the length of the chain in fathoms (6 ft), multiplied by 0.85.

(2) In pocket wheel designs with dual hoisting chains on a single pocket wheel, the chain locker should be equipped with a center divider to keep each chain separate and prevent the chains from piling up on one another.

e. Availability. While no manufacturer will have a standard off-the-shelf product that will fit a given application exactly, the technology to build a pocket wheel to a given design criteria is available. The pocket wheel has been successfully installed at locks and dams on the Upper Mississippi and Illinois rivers. The designer should be aware of long lead times in the fabrication of large pocket wheels when assembling the contract documents and establishing construction schedules.

f. Assembly test. After the first set of machinery is fabricated and completed, a factory assembly lift test should be required as part of the contractor's responsibility for the gate-lifting machinery. These tests should include not only a design load test, but an overload test that proves that the maximum specified motor torque will not deform the chain nor allow the chain to slip on the pocket wheel. The field hoisting assembly and pocket wheel elevation views are shown in Figure 2–27 and Figure 2–28, and Plate 67.

Figure 2–26. Pocket wheel chain hoist with chain locker

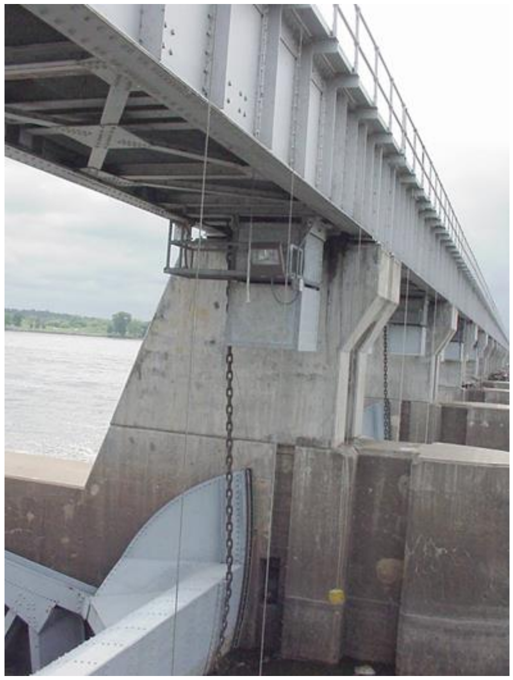


Figure 2–27. Pocket wheel hoisting assembly

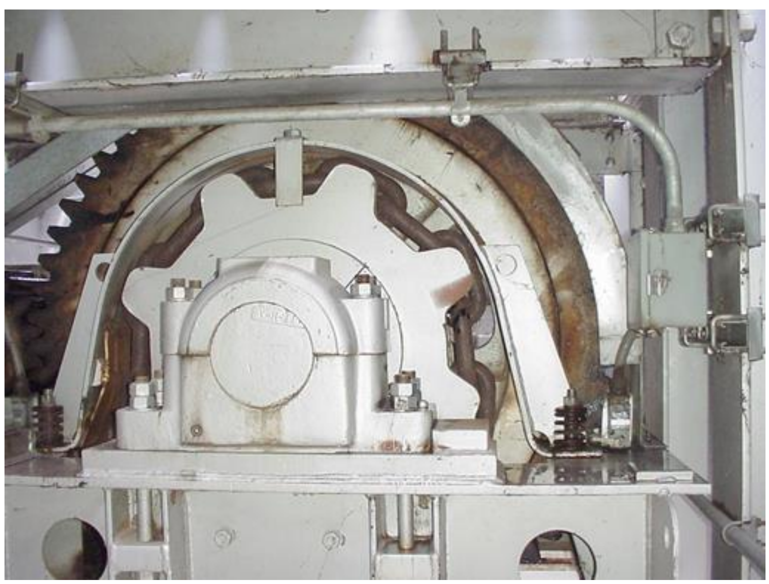


Figure 2–28. Pocket wheel elevation

g. Grooved drum. Another type of round link, chain-lifting mechanism is a cylindrical grooved drum. An example of a grooved drum arrangement is shown in Figure 2–29. This design includes a cast or fabricated cylinder with a helical groove that is either cast or machined into the surface. The groove is designed to accept every other chain link and must be sized large enough to wind the entire length of chain around the drum in a single row. One advantage of a grooved drum is that it requires no chain locker since it stores the chain on the drum like a wire rope drum. The diameter of the grooved drum should not be less than 25 or 30 times the diameter of the bar used for the chain links. For applications where there is no additional room for chain storage, using a grooved drum might be indicated.

(1) An added advantage of the grooved drum is that it can accept a deformed link without becoming jammed. The main disadvantage is the way it loads the chain links. Each link is loaded in both tension and bending.

(2) This loading situation puts undue stresses on the links, especially since chain links are not meant to be loaded in bending. Even under a normal tensile load, the chain is often loaded at or near its yield point. Chain is typically known by its breaking strength, and a proof load is normally specified. Actual stress levels in a chain under loading are determined by an involved analysis dependent on criteria such as chain geometry, hardness, material properties, etc.

Figure 2–29. Grooved round link chain drum

h. Compatibility with existing material. The type of chain that can be used for gate hoisting should be compatible with the existing gate and hoist component materials to prevent undue wear and abrasion. Chain guides must be fabricated and installed on curved face gates that have the gate connection at the bottom of the gate to allow the chain to lay flat over the curvature face of the gate. Hoisting chains mainly bear against the chain guides or plates at every other chain link parallel to the face of the gate. The chain guides or bearing plates should be sized specifically for the chains that will be installed. The chain guides and bearing plates should be compatible in size and hardness with the lifting chain selected. Galvanic corrosion due to dissimilar metals also should be considered during the design process.

i. Tolerances. Manufacturing standards for calibrated round link chain require that each length of chain meets certain tolerances in link size and breaking strength. High-alloy hoist chain is manufactured to length and width, plus or minus 0.51 to 0.76 mm (.02 to .03 in.). These tolerances are an international standard so that all chain, regardless of manufacturer, will be suitable for the intended use. The DIN standards for strength testing of this chain are rigorous and include tensile, bending, and shock tests.

j. Abrasion. For chain to be suitable for dam gate-lifting service, it must be resistant to abrasion caused by silt trapped in the submerged links. Chain used for dam gate lifting probably will never be washed or cleaned because it would be difficult and impractical to do so. High-alloy conveyor chain must be specified to be abrasion resistant.

k. Shock. To resist shock loads, a material must be strong and be able to absorb the energy imparted to it by the shock load. When carbon steel is alloyed and heat treated to increase strength, its energy-absorbing capacity does not increase proportionately. Thus, for equal breaking strength, lower-alloy material normally will be more resistant to shock loading than higher-alloy material. Round link alloy chain is tested for shock loads by the manufacturer.

(1) To reduce the possibility of shock loads, the designer should incorporate a pocket wheel guard with limit switches. The guard should be mounted over the pocket wheel on spring mounts to allow the guard to detect when the chain has debris caught in it or the chain tries to ride out of the pocket wheel.

(2) The limit switch for the chain guard shown in Figure 2–30 has been tripped due to debris caught in the chain and passing through the pocket wheel. The lever arm limit switches detect the movement of the guard and can shut down the operation of the machinery before a shock-loading condition occurs.

Figure 2–30. Chain guard limit switch in tripped position

l. *Distortion*. To be compatible with a host chain pocket wheel, the round-link chain must be capable of being loaded without being significantly distorted. If the chain is distorted, the links will no longer fit the lifting device pockets.

(1) Round link chain resists distortion because the sides of the link are designed to remain parallel. If these links distort, they tend to elongate; but they can do so only after they have exceeded the elastic limit of the material.

(2) The design criteria for lifting chain requires that the minimum breaking strength of the chain be no less than five times the design load, and that the lifting machinery must never impart to the chain a load that will exceed 75% of the yield strength of the steel in the chain in both tension and bending. When a chain is selected within these design limits, link distortion will not be a factor.

m. *Corrosion*. The round link chain discussed in this chapter normally should be protected against corrosion. Hoist chain is available with a variety of special corrosion coatings such as special paints and epoxies. Rock Island projects have used Tectyl 846-10 MIL Specification MIL-PRF-16173E, Grade 4, Class I. Hot galvanizing should not be used for chain in this type of application unless the reduced strength due to reheating is considered. The galvanization might also affect the chain’s ability to ride in the pocket wheel correctly. Specifying the corrosion coating is the designer’s responsibility and depends on the specific application and environment for which the chain is intended.

n. *Prototype pocket wheel testing*. Lock and Dam 20 on the Mississippi River was first in a series of projects to receive prototype pocket wheels to simulate load conditions. The existing chains on the prototype pocket wheels at Lock and Dam 20 on the Mississippi River have worked very well for a period simulating 50 years of operation with no corrosion coating at all. After the prototype tests were completed, the pocket wheels were installed from Lock and Dam 11 to 25 on the Mississippi River. However, mid-1980s field installations on the Illinois River have revealed moderate corrosion and seized links in the lower sections of chain normally submerged. These sections of corroded chain normally are not raised out of the water or capable of being exercised through the pocket wheel.

o. Replacement. Replacement of the round link chain described in this manual should not be a problem in the future. This type of chain is widely used around the world.

p. Chain cost. For comparison purposes and cost estimates, the cost figures for chain in the round link hoist category can be obtained from various manufacturers and from previously constructed USACE projects. Chains should meet the strength and durability requirements for gate-lifting service at CW projects. Differences in cost could influence the chain selection criteria in projects with large quantities of chain required. For example, the Mississippi River Lock and Dam 20 project required almost 1 mile of chain to power all the tainter gates.

2–12. Machinery components engineered steel chain

In addition to round link chain, engineered steel chain also should be considered as a replacement for existing roller chain. Roller chains (using pins, rollers, and sidebars) have been a source of operation, maintenance, and environmental problems at gated dams and spillways owned and operated by USACE for many years. Original roller chain designs were difficult to lubricate, causing bearing surfaces to corrode and bind, preventing smooth operation of the chain over the sprocket. As a result, spillway gates could not be operated, chains failed, and gates were dropped. This created both a dam safety problem and a hazard for operating personnel.

a. The chain design described here has solved several problems associated with previous roller chain designs for both tainter and roller gates at John Martin Dam, Robert Byrd Lock and Dam, and others across USACE and the St. Paul District and Tulsa District. It has been used at these sites since 1997. Discussed next are material selection, corrosion prevention, first cost, and life cycle cost. An engineering analysis of this type of chain is presented and maintenance issues are examined.

b. It is important to show how a lifting chain for a tainter gate is different from a bicycle chain or roller chain, beyond the obvious size and strength differences. There are several standards and a chain manufacturer’s association that classifies various types. The chain industry, chain manufacturers, and American Chain Association (ACA) make a distinction between roller chain and engineered steel chain.

c. In general, roller chain is used for power transmission between sprockets at moderate to high speeds. The chain speed, sprocket design, and kinematics between the sprocket and chain are crucial. Roller chain is manufactured per ANSI/ASME B29.1M. The tension members between pins (side plates) are called link plates. This type of chain generally is produced in large quantities. The size and strength ratings are relatively low.

d. Engineered steel chain is intended for a wider variety of applications, including materials handling, conveying, and other industrial uses. The engineered steel chain is usually manufactured in smaller quantities; has greater strength, more corrosion resistance, and greater shock resistance; and is designed to be used in severe environments. The chain is manufactured per several standards, including ANSI/ASME B29.10M and B29.15M. The side plates are called sidebars. The pin-bushing area is called the chain joint. The sidebars establish the chain pitch (see Figure 2–31).

e. The ACA defines tension linkage chain as a chain application in which the main function is to move a load slowly and intermittently through a short distance, or to hold a load. These types of chains are well suited for USACE projects to hoist and support gate loads. The function of a tension linkage chain is to transmit a moving force using chain tension, hence the nomenclature. Lifting chain for roller and tainter gates, thus, falls under the category of a tension linkage, engineered steel chain. Pitch is the distance between the centers of adjacent chain joint members, or center-to-center distance between adjacent pins. Sidebars are tension members connecting the chain joints. Pins connect one link section to another. Pins are the shear members between the inner and outer sidebars.

f. ANSI and ASME both publish standards for chain, as stated above. There are manufacturers that make a true metric chain. Also, the European DIN (German) Standards and the ISO categorize metric chain.

g. Many of the original tainter gate chain designs (from the 1930s) for the Upper Mississippi River projects used offset sidebar roller chain as opposed to straight sidebar roller chain. The primary benefit of offset sidebar type of chain is the links are all identical. Offset sidebar chain can be used in odd or even number pitches.

(1) The primary advantage of using straight sidebar chain is that the chain is easier to manufacture and, for a given sidebar plate thickness, the straight sidebars have more strength. Straight sidebar chain consists of inside and outside links.

(2) Sections of this chain type must be used in an even number of pitches (lengths). This chain also can be constructed without rollers. However, in gate-lifting applications, the rollers are necessary for reducing friction as the chain is going over the sprocket.

h. Most of the ANSI/ASME standards concern chain used in power transmission rather than lifting applications. However, this difference is generally irrelevant. The loading on the chain is basically the same in both applications where the chain is going over a sprocket. The biggest difference between power transmission and lifting application is likely to be the speed. In lifting applications, the chain travel will be extremely slow.

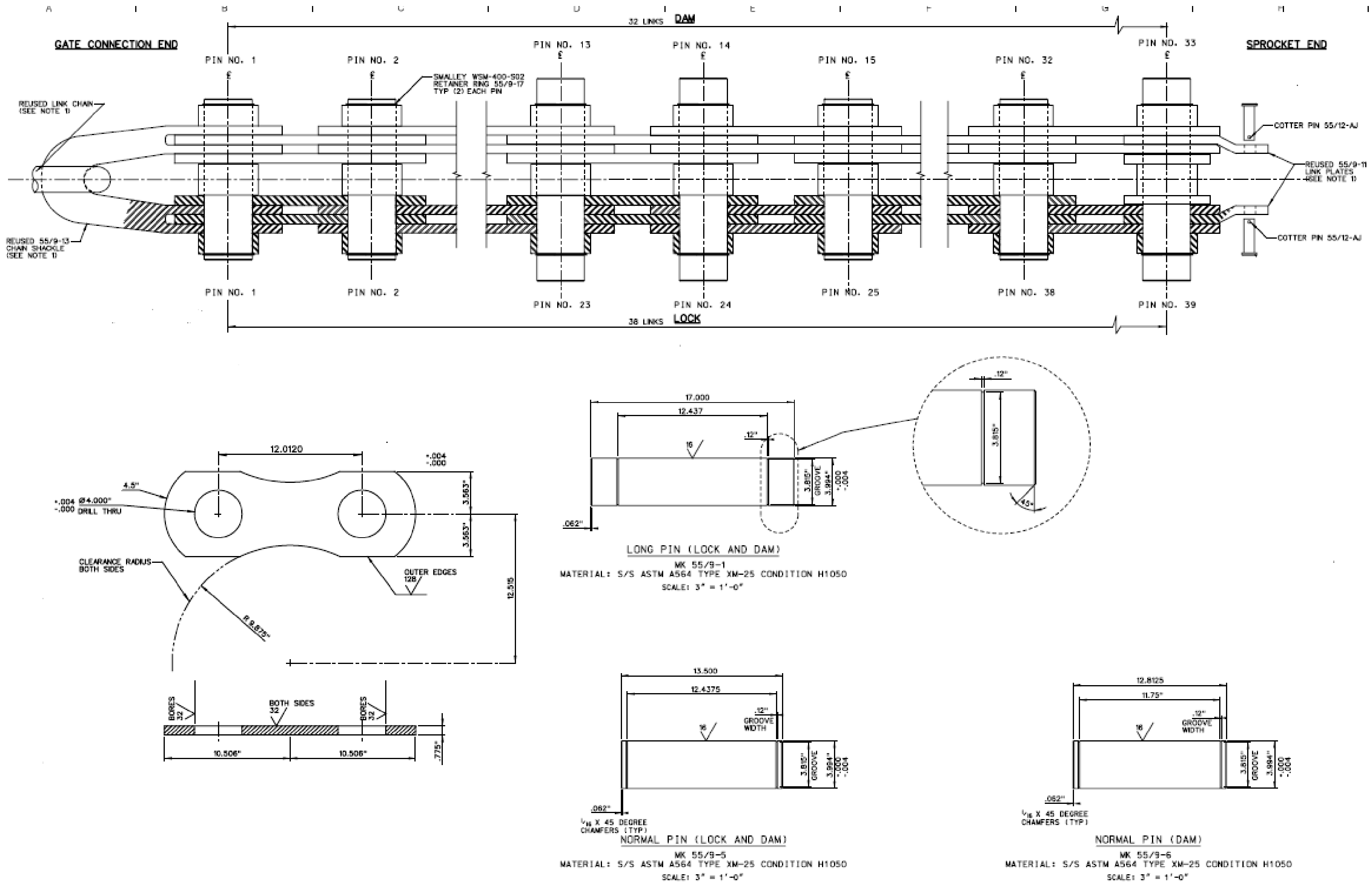


Figure 2–31. Chain assembly

i. ASME B29.1M lists a series of standard roller chains. This standard classifies only chain with pitch dimensions up to 3.0 in. ASME B29.1 assigns standard number designations to chain based on pitch, chain width, and roller diameter.

j. The chain sizes given in B29.1 are generally inadequate for the majority of tainter gate and roller gate lifting applications. The primary benefit of this standard is that any chain manufactured according to it will fit over any corresponding sprocket manufactured to the standard. The chain of one manufacturer will replace the chain of another manufacturer. ANSI B29.10M standardizes only offset sidebar chain. This standard is an engineered steel chain standard and includes chain with pitch dimensions up to 7 in. (177.8 mm) and a minimum ultimate strength of 425,000 lbs (1,890 kiloNewtons [kN]).

k. Material selection is likely the single most important feature of the lifting chain design. The type of material used impacts the strength, corrosion resistance, and overall life of the chain. Proper material selection must be made to ensure a 50-year life for the lifting chains. Lifting chains normally are subjected to all weather and river conditions. For projects that maintain upper pool, the portion of the chain that connects to the gate is submerged in the river. This subjects the chain to silt and debris. Since the dam gates rarely are moved completely out of the water, the lower section of chain is submerged for most of its service life. This lower portion of chain also is subjected to sandblasting and paint overspray when the dam gates are being painted.

l. Recent lifting chain design uses aluminum bronze sidebars and stainless steel pins (see Figure 2–32). Both materials should provide adequate corrosion protection to allow the chain to last 50 years. Aluminum bronze is manufactured per ASTM B505, and 62,000 psi (427,586 kilopascal (kPa)) minimum yield strength is specified.

m. Chain designs using aluminum bronze sidebars and stainless steel pins act like a bushing/pin interface. These two metals have good compatibility in terms of their bearing properties. These materials also have a low corrosion potential (from dissimilar metal corrosion or galvanic corrosion). The lower the potential difference, the less likely galvanic corrosion will occur.

n. One issue with aluminum bronze is that the material is brittle and heat treatment needs to be done correctly. Several sidebars in the St. Paul District have cracked over the last several years. To help address the brittleness, consider selecting alloys with higher fracture toughness and require toughness testing of the purchased materials for the side bars. Depending on the strength requirements, other aluminum bronze materials may also work in this application. It is critical that factory testing and inspection of the aluminum bronze sidebars are done at the manufacturing plant to insure proper heat treatment.

Figure 2–32. Typical engineered chain installation

o. The stainless steel pins are manufactured per ASTM A564, Type XM-25, Condition H1050. This stainless steel is equivalent to Type 304 stainless steel for corrosion resistance. The primary disadvantage of using this type of stainless steel is it was developed by one manufacturer and is not readily available from others. Other options for the stainless steel include using ASTM A564, Type 630 (17Cr-4Ni). This material is close in properties to XM-25 and is available from more manufacturers.

p. There are some disadvantages of using Type 630 stainless versus XM-25. The Type 630 stainless is more difficult to machine and must be age hardened prior to using. A comparison of the stainless steels is provided below in Table 2–1. Plates 1, 2, and 3 show engineered steel chain assemblies and components. Figure 2–33 shows a chain using aluminum bronze sidebars and stainless steel pins installed on a tainter gate. This chain had been in service more than 20 years.

Table 2–1
Engineered steel chain material comparison

	ASTM A A564, Type XM-25, H1050	**ASTM A564, Type 630, H1025**
Min Tensile	145,000 psi	155,000 psi
Min Yield	135,000 psi	145,000 psi
BHN	321	331

Note: BHN is Brinell Hardness Number.

q. The cost of the lifting chain primarily is a function of the materials used. Although carbon steel materials have the lowest initial cost, it is likely that the underwater portions of the chain will need replacement over 50 years. The stainless steel and aluminum bronze chain design, thus, has a lower life cycle cost, including maintenance costs.

Figure 2–33. Engineered chain installation on a tainter gate

r. Chain design should be based on a 50-year service life. Several design considerations should be analyzed to ensure this 50-year life. Strength and material selection are the most important. As discussed, the material selection dictates how much the chain will corrode over 50 years. This applies in particular to the lower section of the chain constantly submerged. There are other design considerations that must be analyzed. These include yield strength, shear strength, fatigue strength, bearing stress at the chain joint, bearing clearance at the chain joint, and shock loading.

s. The ANSI/ASME standards define minimum ultimate strength (MUS) as the tensile load in pounds (or kilonewtons) at which a chain, in the condition at the time it left the factory, might break in a single load application. The yield strength of the chain should be 40 to 60% of the MUS.

t. The chain should also be designed for shock loading. An example of this is when a gate falls under a slack chain condition. The ACA Design and Applications Handbook (ACA 1982) lists a service factor of 1.4 to 1.7 for heavy shock loading. Several of the lock sites have broken chain when a gate has been dropped under slack chain conditions or when slack chain was generated to provide additional momentum for breaking loose a frozen gate. Though these practices are not recommended by the designers, the lifting chain likely will be subjected to these conditions sometime over the course of its service life.

u. Since the lifting speed of dam gates is very slow, the chain/sprocket design is not paramount. The main factor for the chain is the ability to hoist and hold the load from the dam gates and perform under all service conditions. The interface between the pin and sidebar of the chain (or the chain joint) is the highest stress area of the chain. A chain failure usually results from either a sidebar or pin failure in this area. At the chain joint area, the sidebar is in tension and shear. The pin undergoes bending stress in the center between sidebars and shear stress at the chain joint. Both values need to be calculated.

v. Corrosion in the chain joint area might cause the pin to not rotate as the chain is going over the sprocket, causing damage to the gate hoist machinery. The bearing clearance necessary in the chain joint depends on the materials used for the sidebar and pin. A minimum clearance of .005 in. (0.127 mm) is used in the current chain designs. This value should be doubled or tripled if steel sidebars and pins are being used.

w. An appropriate design standard is necessary to adequately design the chain joint area and determine a bearing stress. The AASHTO LRFD Movable Highway Bridge Design Specifications and ASME BTH-1 are two standards that can be used. ASME BTH-1 provides minimum structural and mechanical design and selection criteria for ASME B30.20 below-the-hook (BTH) lifting devices.

x. ASME BTH-1 provides design equations for pinned connections that are appropriate for chain design in paragraph 3–3. These equations include bearing calculations that match the criteria from the AASHTO Highway Bridge Design Specifications indicated for design of chains in previous versions of this standard. However, the ASME standard additionally includes checks for shear and edge tear out of the eyebars, pin bending, and shear. Similar checks are provided in the American Institute of Steel Construction (AISC) Steel Construction Manual in various sections with slightly higher allowable stresses that are more appropriate for fixed connections.

y. Chain designs using stainless steel pins and side bars should include bushings to prevent galling, which can occur as low as 2 ksi between certain grades of stainless steel. See the American Society for Metals (ASM) Metals Handbook Book for specific galling values between various stainless steels. The Nitronic grades of stainless steel have high galling resistance and have been used in tractor gate chains successfully without galling as the actual load between the pin and side bar is relatively low.

z. Fatigue strength of the chain also should be considered in the chain design, though the chain speed is slow. Fatigue strength is not likely to be the limiting factor in chain design at many USACE projects. Each specific application should be verified by the specific site conditions and projected cycles of operation. As each chain link section goes over the sprocket, it is subjected to maximum tension. The link section then is slack as it goes over the sprocket and is coiled in the chain rack.

aa. A primary goal of chain designs should be either to eliminate or reduce the amount of maintenance necessary on the gate-lifting chains. For projects that normally maintain an upper pool, it is reasonable to assume that it takes a crew of four people one week to bulkhead a single gate, temporarily support the dam gate, and grease the lifting chains (two per tainter gate).

(1) Switching to a non-lubricated chain offers a significant cost savings over 50 years. When compared to replacing existing chain with wire rope, chain replacement offers several advantages. First, the existing gate-lifting machinery can be reused. Using chain instead of wire rope also requires less maintenance and replacement over 50 years. Wire rope must be lubricated regularly. Any damaged part of chain can be replaced individually, while wire rope must be completely replaced.

(2) Original (1930s design) lifting chains for the tainter gates were lubricated in several different ways. All these lubrication methods allowed oil and grease to enter the water. Some of the lock sites lubricated the chain with 30W motor oil. Other sites used diesel fuel or waste oil. None of these methods allowed any lubricant into the chain joint because the bearing clearances were too tight.

bb. Zebra mussels have become prevalent in the Upper Mississippi River system within the last several years. Zebra mussels attach themselves to submerged gates, intake valves, grating, concrete, etc. The submerged portions of the gate-lifting chain should be designed to reduce or eliminate zebra mussel attachment. Proper material selection is one method to reduce or eliminate zebra mussels from attaching themselves to the chain and its components. Testing and research by ERDC/CERL have shown that zinc and copper are toxic to zebra mussels.

(1) As stated, the latest designs for hoisting chains use aluminum bronze sidebars and rollers. The specific alloy used in their design was UNS No. C95500. This alloy is 78% copper. Recent field inspections of these components indicate little zebra mussel attachment to the lifting chains.

(2) Recent inspections have shown zebra mussels were attached to the stainless steel collars and pins, but no mussels were attached to the aluminum bronze sidebars.

2–13. Machinery components shafts

Shafting should be designed according to the machinery component criteria for the rated loads and increased by applicable shock and fatigue factors. The ASME B106.1 code and standard should be utilized for shaft design. This standard is an inactive ASME document but still valid. This code is also still used and considered applicable in many industries. The AASHTO LRFD Movable Bridge Design Specifications also have a similar shafting design code in the most recent edition.

a. A factor of safety of 5 should be applied to shafts based on the ultimate strength of the materials, provided the stresses produced by the maximum torque of the motor do not exceed 75% of the yield point of the materials involved. The design criteria for all shafts should be the ASME B106.1 Shafting Code equations with applied torsional and bending factors for heavy shock loading. The ASME Shafting Code requires additional stress reduction factors for keyways in the shaft. Stress concentration factors should be used where applicable. A combined shock and fatigue factor of 1.25 is recommended.

b. Shafts should be supported at locations required to minimize bending and axial movement yet allow thermal expansion. The distance between bearings on shafting subject to bending, except that due to its own weight, should be such that the maximum bending moment deflection is limited to 0.83 mm/m (0.01 in./ft) of length at the maximum rated load. Bearings should also be located near couplings to prevent deflection under dead weight that can complicate coupling alignment.

c. Torsional shaft deflection should not exceed 0.26 deg/m (0.08 deg/ft) of shaft length at the maximum rated load. Shafts should be fabricated from forged steel, such as ASTM A668 or ASTM A291. For longer line shafting, more generic hot rolled material such as ASTM A434 may be appropriate if stringent size and straightness tolerances are applied such as those for turned, ground, and polished (TGP) shafting material in ASTM A108. ASTM A108 does not have separate straightness tolerances for TGP shafting. The standard is 1/8” over a 10-foot length for cold finished shafting. The designer should place requirements as needed for their machinery alignment requirements. Specialty manufacturers can typically hold 0.002” per foot or better on TGP shafting.

d. Stainless shafting per ASTM A564, typically Type 630 (17-4) has become common for wheel axles, gate connection pins, and other failure critical components. The heat treat grade is critical as it defines the strength and toughness of the material. A564 Type 630 is typically supplied in the solution-annealed condition, which, unlike typical annealed materials, has a high hardness and low ductility. The supplier or contractor then tempers the material to the different grades (H1100, H1025, etc.) per the specification to meet the contract requirements. It is important to require toughness and tensile testing of the final tempered material for each heat rather than accepting a tensile test of the material in the solution annealed or other, higher strength, heat treat condition.

e. The ASTM A564 specification is not clear that the tensile tests must occur in final heat-treated condition that the contract drawings specify. Instead, it allows the supplier to provide tests in whatever heat treat they choose for each lot they supply. Similarly, it does not require any toughness testing unless the contract specifically requires it.

f. Where spur gears are mounted on separate shafts, the relative slope of the shafts, at the centerline of the gear mesh, should not exceed one-third (1/3) of the gear backlash divided by the smallest gear face width. The typical backlash for spur gears is 0.03/DP to 0.05/DP, where DP is the diametral pitch.

g. Fillets must be provided where changes in section occur. All keyways must have fillet radii and keys should have matching chamfers as recommended in ASME B17.1 and AASHTO LRFD. All shafts should have standard keyways and keys, according to ASME B17.1 and AASHTO LRFD. Perform key checks for bearing and shear for all keyed connections. Low-speed, high-torque connections may require two keys. If two keys are used, they should be oriented 270° from each other. Connections with very high torque may require splines or bolted flanges to transfer the torque.

2–14. Machinery components sheaves and drums

Sheaves should be heat-treated cast steel, ductile iron, or manganese steel. They should also be of standard dimensions with stainless steel rims or grooves clad with stainless steel. Sheaves are designed to have a single layer of wire rope or be able to layer the wire rope on itself with each revolution. The designer should take the sheave and wire rope construction into consideration for each type of spooling arrangement.

a. Grooved and plain drums also can be used to spool the wire rope onto a single layer or multiple layers. Multi-layered drums should avoid helical grooving and instead utilize a parallel grooving system that ensures the proper alignment of the additional wire rope layers. Drums either can be fabricated and machined assemblies or spun castings. Crane Manufacturers Association of America (CMAA) 70 provides drum design calculations for shell thickness and shaft sizing. Sheaves can be forged or fabricated. Each sheave should have a groove and pitch diameter that corresponds to the recommended factors for the mating wire rope.

b. The hubs should be fitted with plain bearings or roller bearings with appropriate lubrication fittings. The sheave flange, rim thickness, web thickness, angle of contact, and inside diameter of the hub dimensions should be according to the standard manufacturer's typical products for the appropriate size and construction of wire rope. Published ratings of sheaves should be used in determining the factor of safety.

c. Machinery using wire rope drum and sheaves are shown in Figure 2–34 and Figure 2–36. A general machinery arrangement of a hydraulic cylinder and wire rope for hoisting a vertical lift gate is shown in Plate 55.

d. The choice of a larger sheave or drum diameter, for a given nominal wire rope size, improves fatigue life and reduces bending stress for the wire rope. The diameter of the sheaves may be as small as 24 times the rope diameter when used with 6 x 37 strand wire rope for an emergency-type gate. When used with a lock or dam operating gate, sheave or drum diameter should be at least 30 times the rope diameter. See EM 1110-2-3200 for further recommendations on wire rope to sheave diameter ratios.

e. Supporting members used to support the hoist drums or sheaves on the structure or gate must be designed for both normal operating loads and overload conditions. The criteria in EM 1110-2-2107 must be followed.

f. The designer must provide specific instruction to ensure new and repainted sheaves are not painted within the wire rope grooves. Groove profile can be affected by paint accumulation and can result in accelerated wire rope wear or damage. Figure 2–35 demonstrates the loss of groove profile on a painted drum for proper seating of the wire rope.

Figure 2–34. Wire rope drum and sheaves

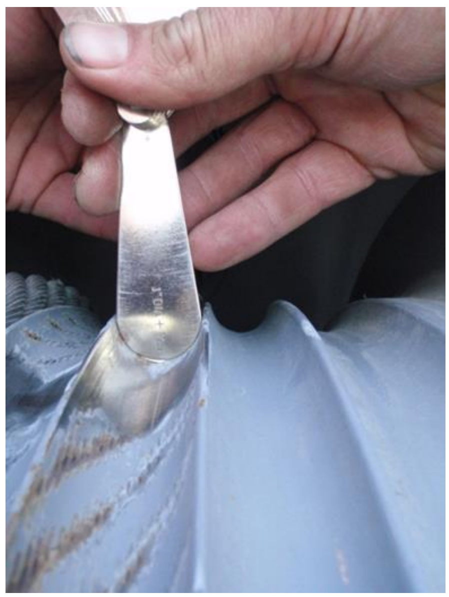


Figure 2–35. Checking wire rope drum groove profile

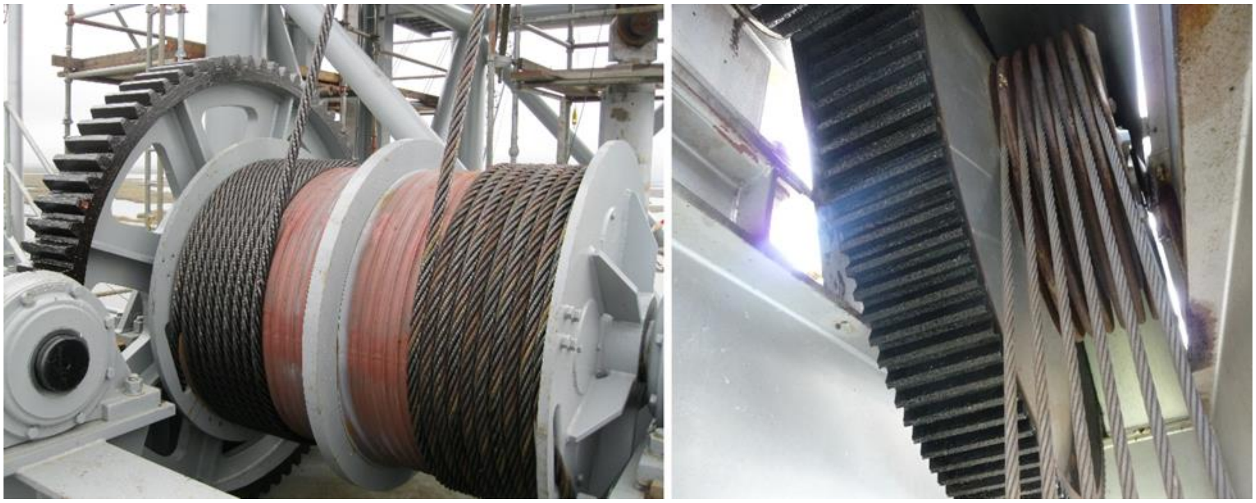


Figure 2–36. Wire rope sheaves

2–15. Machinery component speed reducers

Speed reducers should be helical, herringbone, spiral bevel, or worm type, according to the applicable AGMA standards. Applicable standards include AGMA 2001, AGMA 2003, AGMA 2015, AGMA 6013, AGMA 6113, and AGMA 9005.

a. See Figure 2–38 for a miter gate speed reducer installation. Plate 4 shows a typical worm gear-type speed reducer. Speed reducers should be selected based on the manufacturer's published ratings, including service factors, for the required operating conditions. Special shaft diameters or lengths are available from most major manufacturers.

b. Gearboxes are available in a wide range of load capacities and speed ratios. The purpose of a gearbox is to increase or reduce speed. As a result, torque output is the inverse of the speed function. If the enclosed drive is a speed reducer (speed output is less than speed input), the torque output increases. If the drive increases speed, the torque output decreases.

c. For nearly all USACE applications, the speed is being reduced and the torque is increased. Thus, gearboxes are commonly called gear reducers in gate drive applications. Gear drive selection factors include shaft orientation, speed ratio, design type, nature of load, gear rating, environment, mounting position, operating temperature range, and lubrication. Helical gearboxes and worm gearboxes are among the more common types for electromechanical drives (Figure 2–37).

d. The gearbox shown in Figure 2–37 is a quadruple reduction (4 sets of gears), right angle, and helical gear drive. The right angle means the motor transmits torque into the gearbox horizontally and the output shaft of the gearbox is vertical. This gearbox is used on multiple USACE Upper Mississippi River miter gate drive systems. The gearbox has a total reduction of 406:1.

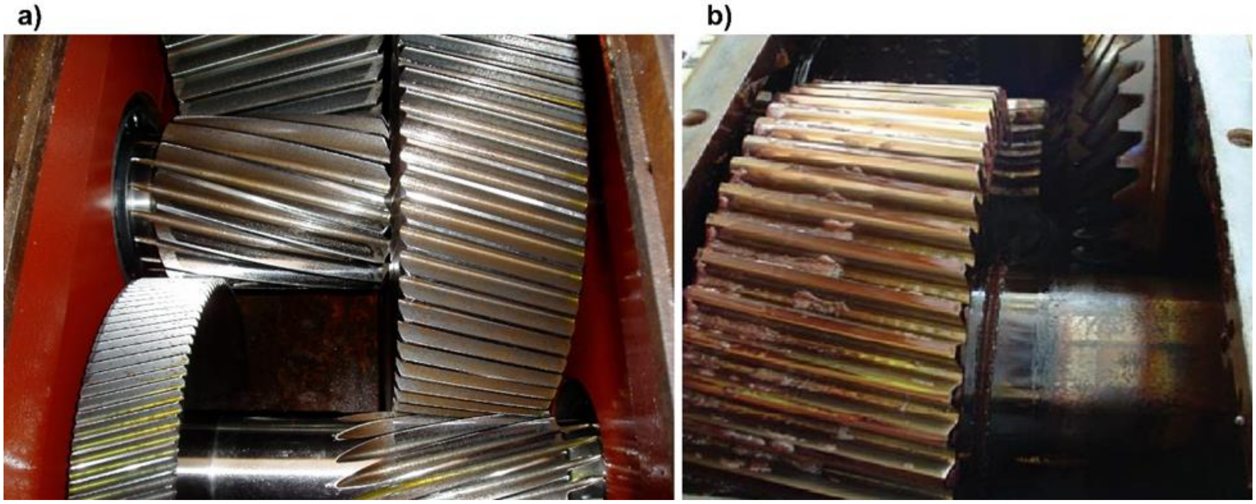


Figure 2–37. Helical gearbox

e. Gearing should be made from high-strength alloy steel, ground after gear cutting to ANSI/AGMA Quality 11 or better, according to AGMA 2015/915-1, and carburized or case hardened after machining. Pinions gears are often cut integrally on the pinion shaft. Spiral bevel gears should be made from high-strength alloy steel with case-hardened teeth, crown lapped for quality and smooth operation. Reducer shafts should be made from high-strength alloy steel and should be of sufficient size to ensure rigid alignment.

f. All keyways should have fillet radii and the mating keys should have chamfers as recommended in ASME B17.1. Keys should be provided for all shafts and be of standard keyway design, according to ASME B17.1. All fabricated dimensions of the keyways and keys should be included in submittal requirements for government review.

g. All speed reducers should be equipped with anti-friction bearings. Overhung loads on speed reducer shafts should be discouraged unless available space is severely limited by design circumstances. If overhung loads cannot be avoided, the designer must coordinate with the gearbox manufacturer to confirm that the shaft and bearings within the speed reducer can tolerate the overhung loads.

h. The designer should use EM 1110-2-1424 and INDC TR 2018-01 for selecting gearbox lubricants. Speed-reducer lubricants for the bearings and the gear sets should be chosen for operation in the existing ambient conditions. Where ambient temperatures fall below the normal lubricant recommendations for the type of speed reducer required, a thermostatically controlled unit heater, or heaters, should be provided in the reducer enclosure. Well-type, non-immersion heaters are recommended to avoid localized overheating, or cooking, of the oil and to facilitate replacement without removing the gearbox from service. Heating elements should have a maximum watt density of 1.5 W/sq cm (10 W/sq in.).

Figure 2–38. Miter gate speed reducer

i. Synthetic hydrocarbon lubricants with a higher viscosity index are an acceptable oil alternative, as approved by the speed reducer manufacturer for the normal loads and speeds encountered in service. These are used often in cold weather applications.

j. A separate lubricating oil pumping system, which sprays all gears and non-greased bearings before startup and during operation, should be provided for speed reducers that operate infrequently, start under loaded conditions, or will be placed in extended storage.

k. Speed reducers should be specified with a lubricant thermometer, a level gauge, and a hygroscopic oil breather.

l. Condensation and moisture accumulation within gearboxes pose a significant challenge for the designer. Water bleed-off ports, desiccant breathers, and water-separating filtration are some of the different methods the designer might elect to incorporate. Connection ports for portable filtering should be furnished on the gearbox to aid in routine filtering of the oil and moisture removal.

m. Worm gears are used when large gear reductions are needed in a limited space and a very high mechanical power rating is necessary. They are adaptable to applications where high shock loading is required. All of the 94 roller gate drives on the Upper Mississippi River locks and dams, for example, use the same basic worm gearbox, with some slight variation from site to site.

(1) With a single-reduction worm drive, the worm gear advances only one tooth for every 360° turn of the worm. Higher reduction ratios can be created by using double and triple-reduction ratios. It is common for worm gears to have reductions of 20:1 and even up to 300:1. Worm gearboxes can also generate high heat inside the gearbox and are among the least efficient of gearboxes.

(2) Therefore, the lubricant viscosity required is much higher than for a helical gearbox. This is often ISO 460 or higher. Many worm gears (but not all) have a property that no other gear set has in that it can be self-locking. The worm can easily turn the gear, but the gear cannot turn the worm. This self-locking feature is usually applicable for worm drives with a lead angle less than 5°. This is because the angle on the worm is so shallow that when the gear tries to spin it, the friction between the gear and the worm holds the worm in place. The self-locking feature of a worm gearbox, however, should never be used to replace a brake in the drive system. A brake system is still working for electromechanical drives.

(3) Operation of worm gears is also analogous to a screw. The relative motion between these gears is sliding rather than rolling and requires higher lubricant viscosity. The uniform distribution of tooth pressures on these gears enables using metals with inherently low coefficients of friction, such as bronze wheel gears with hardened steel worm gears.

(4) Another significant difference from helical gears is that worm gears are usually made of dissimilar materials, which reduces the chance of galling and reduces friction. Extreme pressure (EP) additives in the lubricant usually are not required for worm gears and may be detrimental to a bronze worm gear. Worm gears also have lower starting efficiency. Therefore, worm gear systems require motors with high starting torque. Efficiencies of worm gear sets typically range from 50% to 90%, depending on the amount of reduction. It is recommended to factory test worm gear drives at the factory to verify efficiency.

2–16. Machinery components wire rope

The designer should use EM 1110-2-3200 and the Wire Rope User’s Manual (2005) for wire rope design and selection. Wire rope is a common product used for gate-operating machinery.

a. Round wire rope is typically defined as multi-wire strands laid helically around a center core. The individual wires are woven together to form strands of wire. The strands are wound around the center core to form the finished wire rope. The wire material, the method by which the wire is woven, the core construction, and any wire rope coatings all influence the properties and strength of the wire rope.

b. It also determines the appropriate application for different wire rope types and sizes offered. Each round wire rope is constructed to close dimensional tolerances. The round wire ropes generally have a higher resistance to wear and mechanical damage than flat wire rope (woven wire rope with a rectangular cross section).

c. For new or rehabilitated machinery, a minimum factor of safety of 5, based on the nominal breaking strength of the rope, must be applied to the maximum working load. Wire rope must not exceed 70% of the breaking strength at the locked rotor torque of the motor.

d. Wire rope constructions are available that resist rotation, abrasion, crush, corrosion, and fatigue.

e. Electromechanically driven wire rope systems are generally considered more amenable to longer periods of inactivity than systems operated by hydraulic cylinders and are easier to maintain.

f. More thorough wire rope selection criteria and discussion of topics mentioned here are in EM 1110-2-3200 and the most recent edition of the Wire Rope User's Manual. A multiple wire rope application is shown in Figure 2–39.

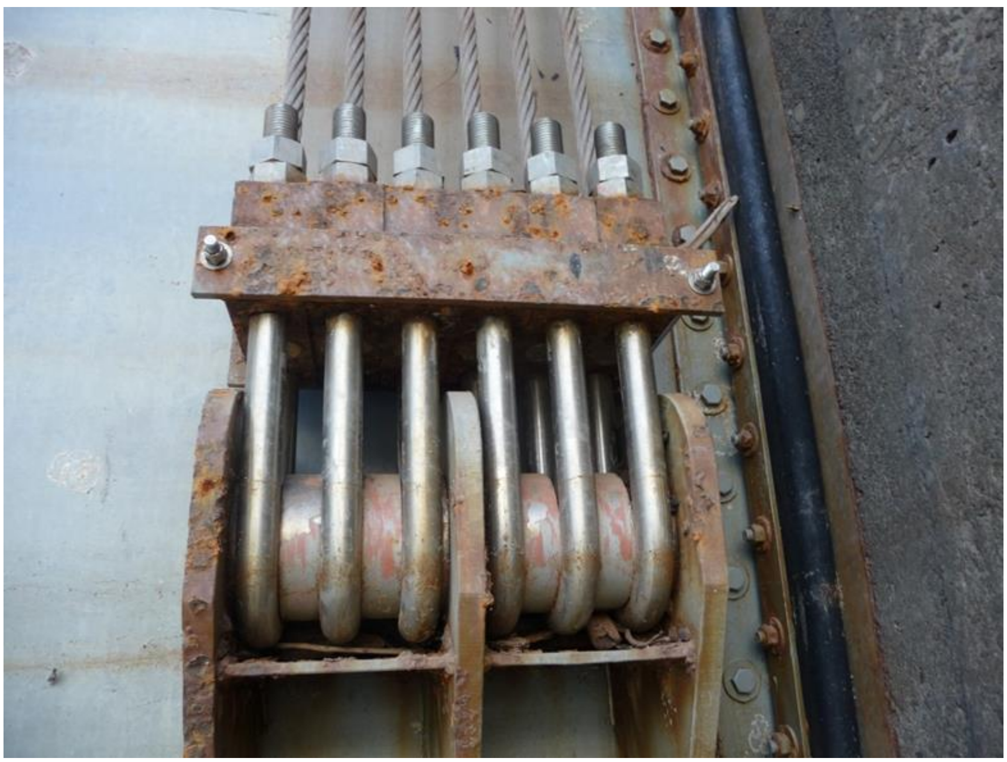


Figure 2–39. Multiple wire rope and gate connection detail for tainter gate lifting application

2–17. Machinery components anchor bolts

Anchor bolts should be designed for the maximum normal load and the locked rotor torque criteria. Anchor bolt groupings should be de-rated for concrete shear cone overlaps. All anchor bolts should be detailed on the contract drawings with type of material, threads, head, depth of embedment, and any special grouting or adjustment provisions.

a. Anchor bolts, even those only for shear conditions, should have hooks, bolt heads, chairs, or body deformations designed to resist pull-out to the limits of the bolt tension rating. Anchor bolts should be installed with a weather-resistant template made from the actual device to be anchored. The specifications should have detailed requirements or tolerances for leveling the machinery on the anchor bolts, grouting, and preloading the bolts.

b. Several types of lock operating machinery include devices designed to fail at a predetermined load to prevent overloading of other machinery components. The most successful method for performing this function is usually a fused bolt or bolts. Fused bolts can be designed to fail in tension or shear accurately. Bolts fail most predictably in tension. A standard manufactured bolt, of a particular manufacturing run of bolts from the same material stock, can be load tested to improve the accuracy of a design.

c. The designer, by calculating the approximate reduction in nominal diameter of the bolt required to fracture at a specific load, can test bolts machined to the reduced diameter to failure. Similar methods can be applied to shear connections made by bolts.

d. The designer must be careful to ensure that the maintenance personnel realize that replacement of the bolts with bolts of the same material and dimensions is critical. It is dangerous to replace these types of bolts with larger, stronger bolts, because of recurring failures. Regular failure indicates another problem with the machine or the original design load criteria. Larger bolts could move the failure to a more critical design component.

e. It is important to never use these devices on a gate that can fall, causing damage to the structure. Fused bolts have been used successfully on many miter gate machine items, such as operating struts and cone brakes.

2–18. Machinery components keys, pins, and splines

Keys, pins, and splines are important connections in lock operating machinery designed to transmit power and motion to the gate.

a. Keys and keyways should be designed according to ASME B17.1. With rare exceptions, these items should be fashioned for the general design criteria, not for failure at or near design operating loads. Any item that, by its failure, can cause a gate or machine to free wheel to impact with the concrete or steel structures should not be allowed to be the weak link in the system.

b. Splined connections should follow the requirements in ANSI B92.1 and AGMA 945-2-B20.

2–19. Lubrication

The designer should review the guidance provided in EM 1110-2-1424 for the proper selection of oils, greases, and fluids. The designer should also use and reference

INDC TR 2018-01. This TR provides specific selection criteria for greases, hydraulic fluids, and gearbox oils.

Chapter 3
Self-Lubricated Materials and Components, Performance, and Application

3–1. Introduction

Self-lubricated materials are used in many CW applications, and composition and properties can be tailored for each design. Typically, these materials are substituted for metallic materials to reduce maintenance, prevent conventional lubricants from entering waterways, and provide electrical isolation. This chapter provides a brief introduction to self-lubricated materials but primarily focuses on current and past applications of self-lubricated materials in CW projects and the successes and failures experienced during their use.

3–2. Self-lubricated materials in brief

This section is a brief introduction to self-lubricated materials. A deeper discussion of the theory and best practices for designing self-lubricated materials is provided in EM-1110-2-1424 (Chapter 12). The designer should also reference the INDC TR 2018-01. There is also a UFGS specification 35 05 40.17 to assist designers with specifying self-lubricated materials. Designers are also encouraged to reach out to the Mechanical Community of Practice (CoP), HQ CoP Leads, and INDC and to work with experienced designers to avoid some of the issues described later in this section.

a. The designer should be aware that self-lubricated materials have worked well in some applications and have failed in other applications. If the designer is considering self-lubricated materials, they must be evaluated for their potential use for the specific application. Involve and coordinate with manufacturers early in the design. Coordinate specification requirements with manufacturers. The designer must be aware of the consequence and cost of self-lubricated material failure. On a miter gate pintle, for example, the cost of emergency replacement can run into the millions of dollars.

b. As part of the design, water quality samples should be collected to assess conditions and convey in specifications to manufacturers of materials. This helps determine whether the proposed materials are suitable or not. Alternatively, a water quality program within the district could collect samples of water and provide in a data base. As a rule, most locks have lots of silt and debris. For in-water applications, the designer should also be aware of the dewatering intervals allowing inspection. In many cases, inspection cannot take place for 20 years or more. This does not allow inspection of the self-lubricated pintle, for example, on a regular basis.

c. There are three main types of self-lubricated materials commonly used in CW applications:

(1) Fiber-reinforced plastics (FRP), which consist of interwoven fibers impregnated with a resin like a fiberglass composite. However, softer fibers such as polyester are used to prevent damaging the shaft or pin, and a solid lubricant is incorporated into the resin near the running surface of the bearing.

(2) Thermally applied sprayed coatings applied to a roughened running surface with a solid lubricant embedded in the coating.

(3) Bronze bearings with embedded plugs of solid lubricant. This, along with sintered bearings, are some of the original self-lubricated materials and there are original installations at CW projects with these bearings.

d. Through strength and coefficients of friction, self-lubricated materials can meet or exceed the performance of a conventional greased bronze bearing. However, thermal expansion, moisture absorption, and dielectric strength can differ significantly from conventional bronze bearings and must be considered during design. As for bronze bearings, the designer should hold bearing pressures below 4,000 psi.

e. Self-lubricated materials are also more sensitive to grit, sand, and other foreign materials. A means of sealing out debris needs to be provided in any application where foreign materials may enter the journal surface. This is like the seals typically provided on conventionally lubricated bearings to retain lubricants and exclude debris.

f. FRP bearings are often anisotropic and have significantly reduced capacity when loaded perpendicular to the reinforcing fibers. FRP bearings can also have brittle failure modes if edge loading occurs due to excessive deflection in assemblies or initial misalignment.

g. Typical applications of self-lubricated bearings include:

(1) Slow speed and high load (except for hydrodynamic bearings).

(2) Locations where conventional grease or oil lubrication could cause undesired contamination of the waterway.

(3) Components that are difficult to access to apply grease or other conventional lubricants.

(4) Applications, such as tainter gate trunnions, where the high loads and low angle of rotation make it difficult to deliver conventional lubricants to the loaded zone of the bearing.

(5) Components that require galvanic isolation from surrounding materials such as stainless steel in contact with carbon steel. This is applicable only for FRP or thermal coated self-lubricated bearings, which are electrically insulating.

h. The designer must exercise judgement during the design process to identify the bearing as either a failure-critical bearing (FCB) or a non-failure critical bearing. The designer must use UFGS 35 05 40.17 for failure-critical bearings. A list of acceptable manufacturers is provided in the specification.

i. The specification for non-failure critical bearings should be tailored to remove the extra requirements and testing associated with FCBs unless certain requirements are required by other design parameters.

j. The designer can also consider having the manufacturer provide grease grooves in the self-lubricated bearing as a backup system. Ensure the grooves are deep enough to provide adequate lubrication. Sensors can also be incorporated into self-lubricated bearings such as miter gate pintles that would provide an indication of wear.

3–3. Current and past applications

Each of the following provides examples of applications where self-lubricated materials are currently installed at USACE facilities. They provide relevant details of each type of application to assist the designer as well as any issues observed and ways to mitigate those issues. The designer is encouraged to contact the INDC and the Hydroelectric Design Center (HDC) for more specific project details. Appendix D provides a memorandum for record of self-lubricated material failures at Peoria and LaGrange locks.

a. Tainter gate and valve trunnion bearings. Self-lubricating bearings are successfully used at many projects, including 25 tainter gates and 12 tainter valves in the Portland District, and have been operating successfully for 15 years at earlier installations. See Figure 3–1 through Figure 3–3.

(1) Details: A cylindrical bearing that is shrink-fit in the gate arm hub per the bearing manufacturer's recommendation. The fit and surface roughness between the pin and bushing should be coordinated with bearing manufacturer as well, to achieve the proper running fit since self-lubricated bearing materials may have different properties from conventional bronze bushings. These bushings are typically provided with grease grooves to allow supplementary lubrication if required. Ensure grooves are installed on the loaded side of the bearing. The grease port in the hub or pin is provided with a pipe plug that can be replaced with a lubrication fitting. See Figure 3–1. Includes energized seals at each end of the bushing to prevent debris intrusion and to help retain auxiliary lubricant if added.

(2) Issues: Early installations used an adhesive to attach bearings to hub and getting proper distribution of adhesive to allow proper bearing and resist torque due to friction was difficult. Tight clearances likely caused ongoing stick-slip issues at the Folsom Auxiliary Spillway Gate trunnions. Designers should work with self-lubricated bearing manufacturers to determine the appropriate clearances, given the varying thermal expansion coefficients of the self-lubricating materials.

b. Guide bearings for tainter valve operating linkages. Cylindrical bearing sliding along a bar driven by a push rod. No issues are currently noted. These are operating successfully at several tainter valve applications on the Columbia River in the Portland District.

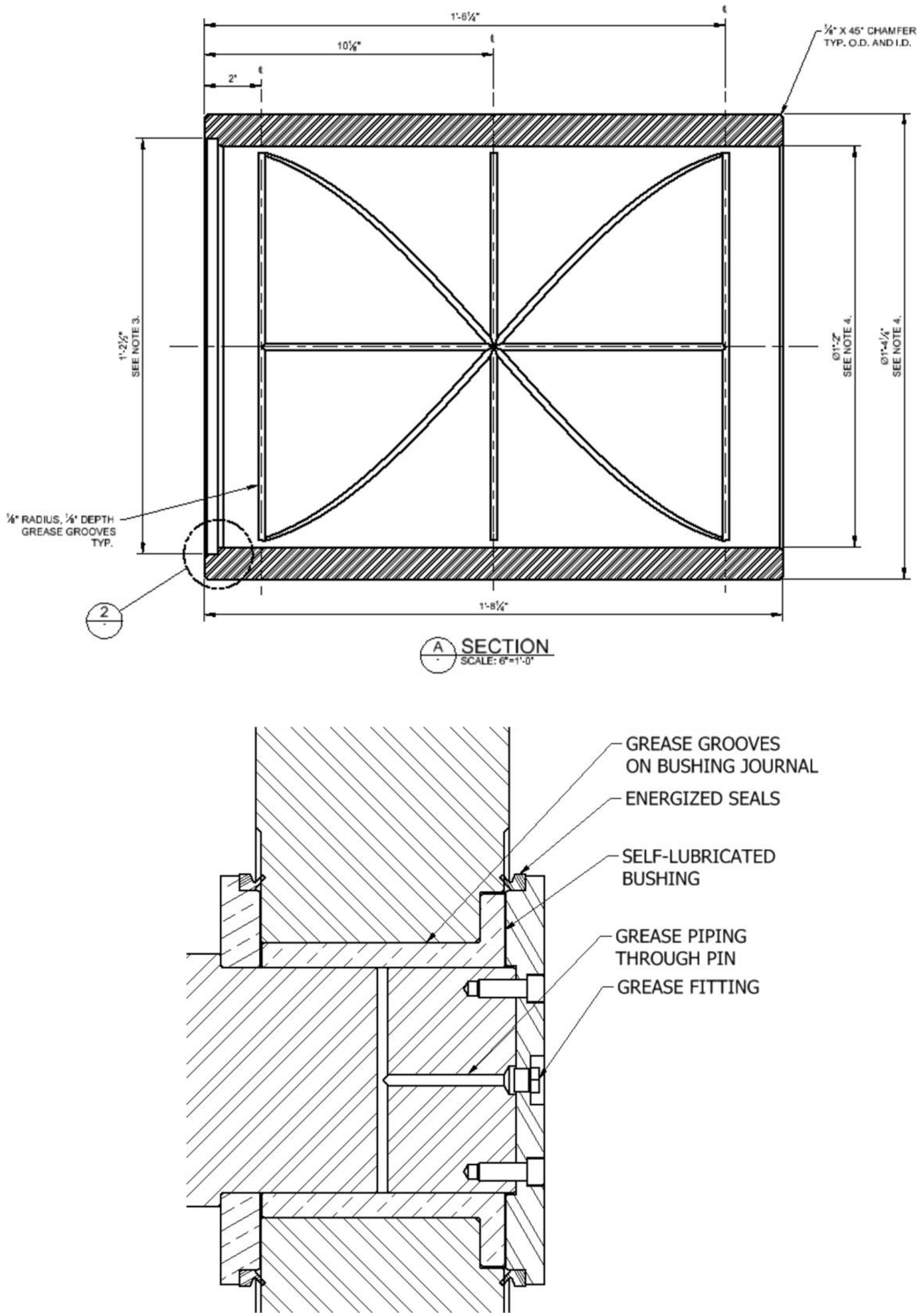


Figure 3–1. Self-lubricated bearing detail

Figure 3–2. Fiber-reinforced plastics trunnion hub installation

Figure 3–3. Fiber-reinforced plastics trunnion thrust washer installation

c. Miter gate gudgeon components, including in the St. Paul District. Cylindrical and spherical bushings, both thermal coated and FRP types, used in the fixed or collapsing gudgeon assemblies at the upper pivot point on miter gates.

(1) Issues: High allowable design pressures caused brittle failure of cylindrical FRP bearings at The Dalles Dam in Portland District, see Figure 3–4. These were replaced with a thermal-coated, self-lubricated bearing with higher load capacity. In future designs, the recommendation is to keep allowable pressures closer to typical bronze bearings as described in Chapter 2 of this manual. This is preferred even in applications that see little rotation to prevent the risk of brittle failure.

Figure 3–4. Brittle failure of fiber-reinforced plastics self-lubricating gudgeon pin bushing at The Dalles Dam in Portland District

(2) Thermal-coated bearings also failed at Lock and Dam 2 on the Mississippi River due to a combination of damage during installation and high loading, see Figure 3–5 below.

Figure 3–5. Chipped thermal coating on self-lubricating gudgeon pin bushing at Lock and Dam 2 in the St. Paul District

d. Miter gate pintles. Plate 21 shows a typical miter gate pintle. Self-lubricated pintles are typically a spherical bushing either with self-lubricated material spread over the full surface or in discreet pucks that are attached to the surface. These have typically been thermal-coated bearings mating with a bronze cup. Figure 3–6 through Figure 3–8 show examples of greaseless bearing pintle/bushing designs. Conductivity indicator wear pins are typically incorporated into the bearing surfaces to allow the project personnel to periodically test for bearing surface wear and to schedule replacement.

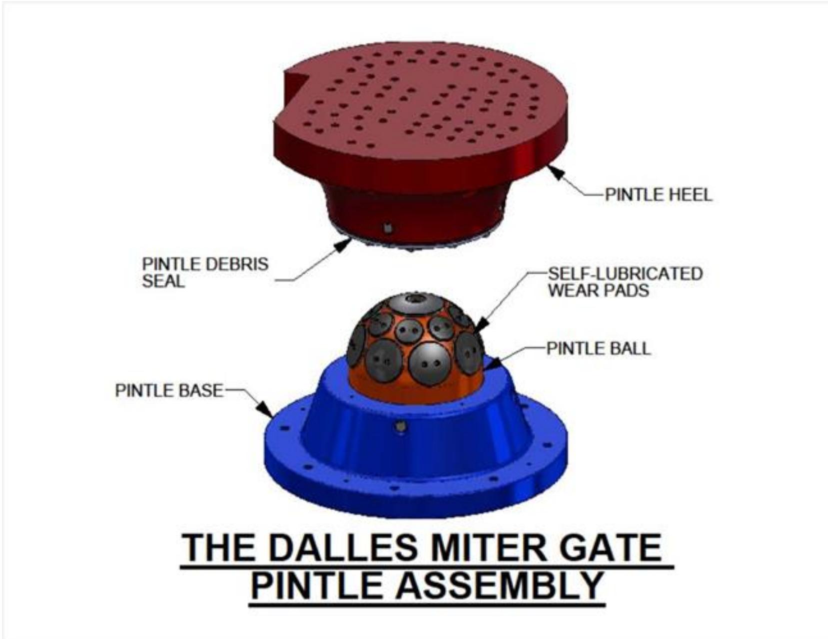


Figure 3–6. Greaseless pintle bushing

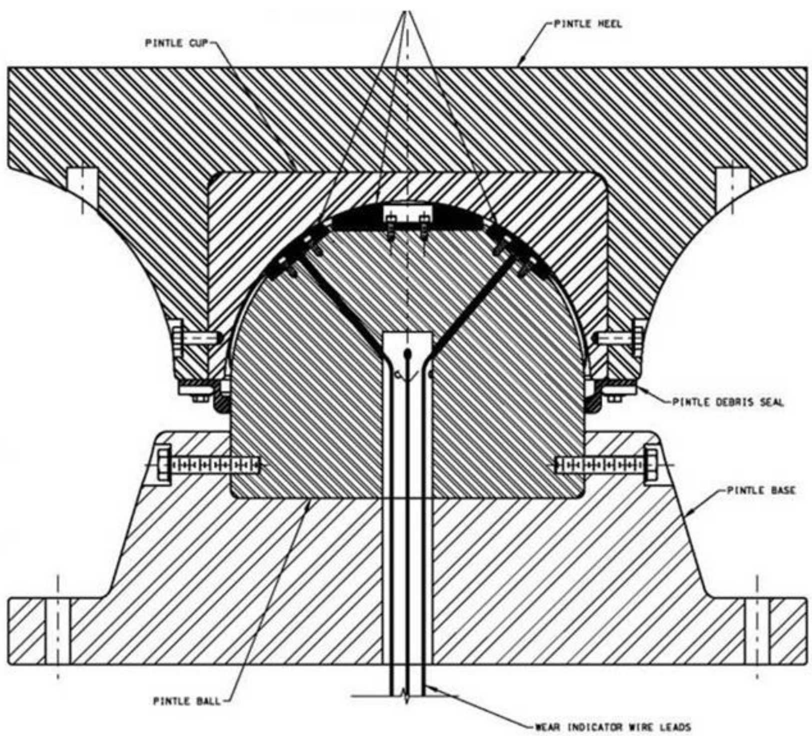


Figure 3–7. Schematic of a greaseless pintle bushing

Figure 3–8. Miter gate pintle at The Dalles Lock

e. Miter gate pintle issues: There have been several failures of self-lubricated pintle bearings. These have often occurred after short operating periods (less than 10 years), primarily related to sediment and debris damaging the bearing. The failures are broken out by type below. High sediment load in river and siltation and suspended solids must be considered. Seasonal flooding must be accounted for.

(1) Foreign debris: Thermal-coated, puck-style bearings have failed due to debris scoring or chipping off the self-lubricating coating at the Peoria and La Grange Locks on the Illinois waterway as well as Lock and Dam 6 on the Mississippi (Figure 3–9). See also Appendix D. These bearings did not have seals or O-rings to prevent debris intrusion. The designer must include seals in these applications. At Peoria and La Grange Locks, there was significant debris around the pintles, while at Lock and Dam 6, debris was present but in smaller quantities. Reference Memorandum for Record August 2020 from the INDC in Appendix D.

(2) Delamination: A contractor-designed bearing self-lubricated coating failed after the coating delaminated from the pintle ball after only a year of operation at McAlpine Lock (Figure 3–10).

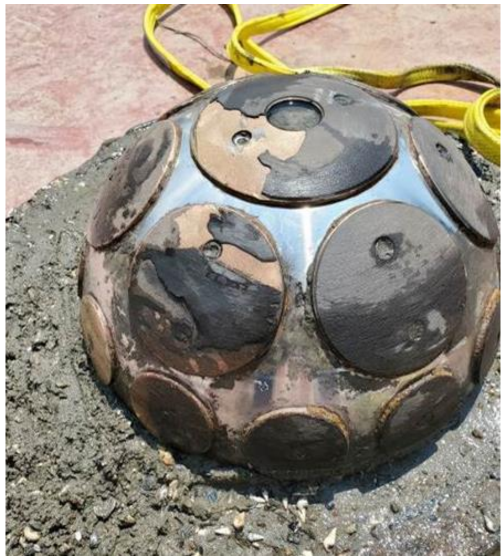


Figure 3–9. Failed pintle ball at Peoria Lock

Figure 3–10. Failed pintle at McAlpine Lock

f. Traditional low-speed pillow blocks. Self-lubricated pillow blocks have been used at several spillway gate hoists on the line shaft connecting near and far sides of the hoist. These bearings are typically a plastic bushing with solid lubricant suspended in the bushing material.

(1) Issues: These have operated successfully at several projects in Portland District, but there have been issues where a lower-grade, self-lubricating material was specified.

(2) In those cases, the heat buildup during extended operation caused the bearing material to expand and pinch the shaft. In some cases, the plastic bushing material melted.

g. Wear blocks. Self-lubricating material has been used for guide blocks on lifting beams and mooring bitts to help keep the component aligned in their slots. No issues have been noted with this application.

h. Slide gate bearings. FRP self-lubricating sheet has been used to replace existing bronze on stainless seals for regulating outlet slide gates in Portland District. These have operated successfully for the side seals but there has been some jetting damage at the top seal as this area is subjected to flow when the gate is open. In future applications, a plugged bronze seal may be preferable.

i. Isolation bushings. FRP self-lubricating plain bushings have been used to isolate stainless pins from carbon steel in several applications, including wire rope connections on spillway gates and sheaves on block assemblies. No issues have been noted where the bearing pressures have been kept to the values listed for bronze bushings in Chapter 2.

j. Wicket gate bushings for hydropower. FRP self-lubricating bushings have been used consistently on turbines at numerous USACE hydropower facilities. More discussion is provided in EM 1110-2-3006. Self-lubricated wicket gate bushings have been used to mitigate environmental concerns with grease getting into the waterway.

k. Sector gate pintle and hinge bearings. Plate 31 shows typical sector gate hinge and pintle details. Self-lubricated materials have been used on both hinges and pintles for sector gates. These have been used successfully in multiple sector gate installations in the New Orleans District. This includes the West Closure Complex and the sector gates in St. Bernard Parish (144 and 149). All these installations have worked well. The West Closure sector gate is a 225-ft gate and has a 36-in. diameter pintle ball and a 38-in. diameter hinge ball. See Figure 3–11 through Figure 3–13.

l. Gate rollers. FRP and thermal coated self-lubricating bushings have been used on lateral guide rollers on spillway tainter gates. No issues have been noted with these bushings.

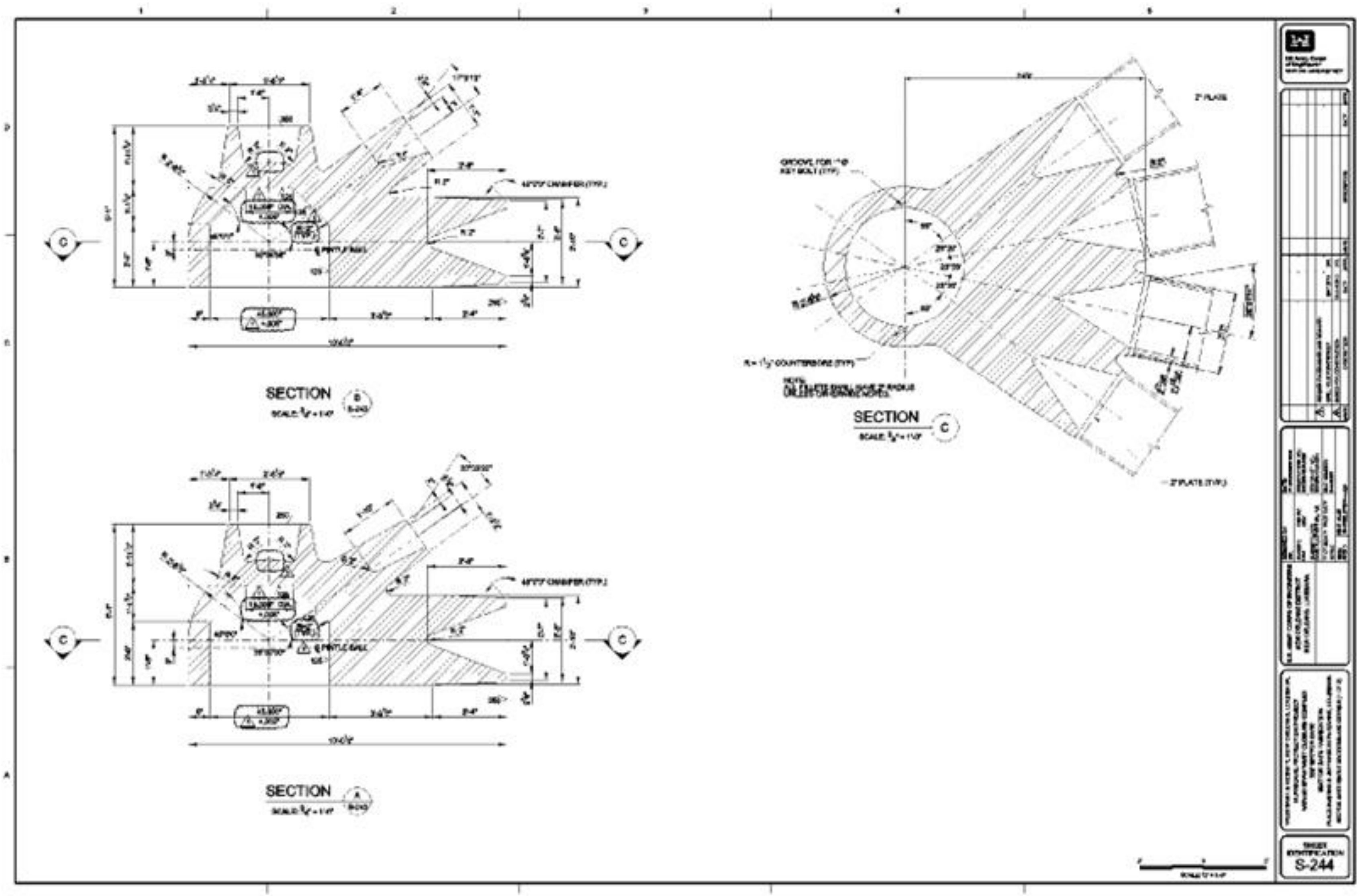


Figure 3–11. West Closure sector gate pintle casting

Figure 3–12. New Orleans 144 sector gate pintle

Figure 3–13. West Closure pintle

Chapter 4
Hydraulic Drives

4–1. Description and application

Hydraulic fluid power systems pressurize, transmit, and control hydraulic fluid to apply power at devices that perform work. This includes, for example, hydraulic cylinders and hydraulic motors. Power is generated by an HPU consisting of one or more pumps, valves, and controls mounted on a fluid reservoir. Pipe, tubing, hose, and manifolds transmit the fluid to the output devices and back to the reservoir or pump. Valves control the direction, pressure, and volume of the fluid flow.

a. Actuators, such as hydraulic cylinders and hydraulic motors, are the typical output devices. Hydraulic fluid power output devices often are used to operate lock gates, spillway gates, and culvert valves.

b. UFGS provides detailed assistance in preparing contract specifications of hydraulic fluid power systems, see UFGS 35 05 40.14 10. Other industry design standards covering hydraulic fluid power systems include the National Fluid Power Association and ISO including ISO 4413. Many European-based companies and organizations also use the DIN (German) Standards.

c. Chapter 5 provides design guidance for hydraulic cylinder coating systems and measuring systems.

4–2. Hydraulic systems

There are two types of hydraulic systems: open circuit and closed circuit. Drawing plates 7 to 10 in Appendix B provide some basic hydraulic circuits.

a. Open-circuit systems.

(1) Overview. Open-circuit systems generally have a high-pressure supply line from the pump to the actuator and a low-pressure return line from the actuator to the reservoir. The reservoir is vented to atmosphere and breathes as the reservoir level changes due to the volume differential from stroking a linear actuator (cylinder).

(a) Open systems usually have a directional valve and continue to circulate the fluid when in neutral. Open systems have been the most common type used on locks and dams and FRM projects. They are generally less complex, have wide industry support, and one pump system can handle multiple actuators. In general, hydraulic system designs for locks, spillway gates, or FRM projects are variations of open-circuit systems.

(b) These variations for lock applications include centralized power unit design, local power unit design, dedicated power unit design, and a self-contained hydraulic actuator design. The designer needs to evaluate all these options for the application. A typical centralized system has a single power unit location with piping and valves transmitting the fluid power to different locations.

(c) A typical local power unit design places an individual power unit near the actuators to be operated at one corner of the lock. A typical dedicated power unit design has a single power unit adjacent to each actuator such as for a miter gate and culvert valve. A self-contained hydraulic actuator is further discussed below.

(2) *Centralized power unit*. A typical centralized system has the power unit located in a lock control building, a dam building, or shelter above the flood of record. The building usually is located on the middle wall of a dual-chamber lock but can be on either wall of a single-chamber lock. On a dam, the central power unit can be located at one end of the dam. An extensive piping system connects the power unit to the gate and valve actuators. The piping system is installed in covered trenches or galleries on each wall and in crossovers to adjacent walls.

(a) A typical arrangement for a single chamber has two separate power units, with each dedicated to the actuators on one lock wall. The two power units are adjacent to each other for cross connection. Cross-connecting the main pressure, pilot pressure, and return piping system allows the use of either system as backup for the other during malfunctions. Under normal operating conditions, each power unit operates one miter gate or one culvert valve. If one pumping system is damaged, the remaining system can operate two miter gate leaves or two culvert valves at a reduced speed by pumping through the cross-connection system to the appropriate control system.

(b) A typical arrangement for dual chambers consists of a reservoir and three electric motor-driven, variable-volume pumps. Two pumps are selected for service and one for backup. Selection is rotated monthly. The two variable-volume service pumps operate in tandem and can supply multiple actuators on both chambers at the same time. Proportional valves are normally used to provide variable speed control of the miter gates.

(c) The principal advantages of centralized systems are reduced initial cost of power units, centralized maintenance, and smaller space requirements on the lock walls. The principal disadvantages are increased cost for piping, increased piping friction, cost for lock piping crossovers, high vulnerability to leakage, reduced speed and load capacity during backup operation or extremely cold weather conditions, and increased noise level when in a control building. Access to crossover piping for repair or replacement is also a consideration.

(3) *Local power unit*. A typical local system has a power unit at each corner of the lock walls. Each unit is used to operate the adjacent gate leaf and culvert valve. It is often prudent to furnish each power unit with an extra main pressure pump, mounted on the same reservoir, to provide backup power. The principal advantages of the local system are a reduction in initial cost of piping, reduced piping friction, no cost for piping crossovers, reduced leakage, and lower noise levels in personnel areas. The principal disadvantages are increased initial cost, decentralized maintenance, no special provisions for flood protection, and larger total space requirements.

(4) *Dedicated power unit*. Dedicated power units take the local system approach even further. A typical dedicated system has a separate power unit at each miter gate and each culvert valve. The system at Bonneville Lock is shown below in Figure 4–1. The hydraulic pump and motor are on the left side in the figure. There is one HPU at each corner of the lock to power the tainter valve cylinders.

(a) Each power unit is normally dedicated to operating its adjacent miter gate or culvert valve cylinder, but it also can be cross-connected with another nearby power unit to provide emergency backup.

(b) The principal advantages of the dedicated system are a reduction of initial cost of piping, reduced piping friction, no cost for piping crossovers, reduced leakage, full speed/load capability during backup operation, and lower noise levels in personnel areas. The principal disadvantages are increased initial cost, decentralized maintenance, no special provisions for flood protection, and larger total space requirements.

Figure 4–1. Tainter valve hydraulic power unit at Bonneville Lock

(5) *Self-contained hydraulic actuator*. Some manufacturers also refer to these units as electric hydraulic actuators, or EHA. These units feature a system that combines an HPU with a hydraulic cylinder to form a self-contained actuator that is sealed and submersible. Instead of directional valving, a self-contained hydraulic actuator uses a bi-rotational gear pump mounted inside a sealed reservoir and driven by a submersible electric motor attached to the reservoir. See Figure 4–2. The speed and direction of the cylinder rod are controlled by a VFD that controls the speed and direction of the electric motor.

(a) The principal advantages of a self-contained system are significant space savings, zero initial cost of piping, negligible piping friction, no cost for piping crossovers, minimal leakage, quiet operation, low maintenance, and a submersible design.

(b) Since there is no reservoir, the design must ensure the oil doesn't become overheated. Also, the expertise to maintain these systems are limited throughout USACE. At least one backup spare actuator of each size used on the lock should be provided. See Chapter 6 for additional information and photographs. Also, manufacturers may have load limits for these actuator units. The designer also needs to ensure they offer a way to relieve stress from a sudden overload, such as from a barge impact.

(c) Self-contained hydraulic actuators eliminate the volume difference between the rod and blind ends found in traditional cylinders. This allows the oil reservoir to be eliminated. These systems use significantly less oil, and the oil is sealed in a closed system. Position indication is built into the actuator.

(d) Self-contained hydraulic actuators reduce field installation requirements. The system is fully assembled and tested at the factory.

Figure 4–2. Self-contained hydraulic actuator (courtesy of Van Halteren Technologies)

(6) *Compact hydraulic drive unit*. Recently introduced in Europe, a compact hydraulic drive (CHD) unit is like a self-contained hydraulic actuator, except it is not attached to the actuator it operates. The compact modular unit is mounted near the actuator and connected with a pipe or hose. See Figure 4–3. A CHD also uses a sealed reservoir with a VFD for speed control. Quick-release hydraulic couplings and electrical plugs permit speedy replacement.

Figure 4–3. Compact hydraulic drive, Germany

(7) *Spillway gate power unit*. Spillway gate power unit design should be a function of the maximum normal operating requirements of the dam. A centralized system might be adequate where only one or two gates need to be moved in a single operation and the length of piping is manageable. Dedicated systems are the most practical solution for large dams with many simultaneous operations or remote-control capabilities.

(8) *Hydraulic power systems*. Hydraulic power systems for FRM structures should use redundant motor/pump units or other interconnection between units to provide adequate redundancy. Non-submersible components should be located within a protective enclosure or building at an elevation above the level of protection to minimize flood risk to the equipment. Arrangements for floodgates or locks using sector gates typically use a local/dedicated arrangement (generally lacking culvert valves) but may use integral power units or CHDs. Otherwise, FRM water control gates are similar in design to spillway gate applications.

b. Closed circuit systems. In a closed circuit, hydraulic fluid is returned from the actuator directly to the pump. Closed circuits are generally used only in applications with a rotary actuator or hydraulic motor. These systems have a high- and low-pressure side and a small, sealed reservoir to collect pump and motor leakage. Leakage normally is returned to the system by an auxiliary pump. Closed systems are limited to one pump per actuator applications. Closed systems have been widely used for mobile hydraulics. Their application to locks that use linear actuators or cylinders is limited.

4–3. Component parameters

Hydraulic system components are generally specified by parameters of flow rate, pressure rating, and optional features. Pressure and flow volume are intimately related to temperature and viscosity of the hydraulic fluid. The system design operating pressure can be best determined by requirements for reliability, efficiency, safety, maintainability, and life cycle cost analysis. The system flow rating is generally based on the required gate operating times. Gate operating times should be computed based on established experience and safety considerations.

a. System cycle speed. Increasing the operating speed of a gate increases the inertial and drag forces, and thus increases the required capacity of the drive machinery. Time of operation should consider the type and size of the gate. For mid-sized 25.6-m (84-ft) wide navigation locks, a full open or closed cycle for miter gates should take approximately 90 seconds or slightly slower and 120 seconds for a sector gate lock. For larger 33.5-m (110-ft) wide locks applications, 120 seconds is appropriate. Reduced speeds at the end of travel should be used to reduce forces and improve control. Flood gates may use substantially longer operating cycles (20 minutes) to reduce drive machinery and eliminate the need for slower end-of-travel speeds.

b. System operating pressure. Design system operating pressures are usually determined by balancing the requirements of the hydraulic pump, hydraulic actuator, piping friction, control valve ratings, and the potential for shock loading. System pressure for navigation projects and FRM projects should be designed to be under 21 MPa or 3,000 pounds per square inch gage (psig). Working pressures are recommended to be under 14MPa or 2,000 psig.

(1) Typical operating pressures for centralized power units are 14 MPa (2,000 psi) or less. Typical operating pressures for local, dedicated, or integral power units are 21 Mpa (3,000 psi) or less. Many modern piston pumps are capable of trouble-free operation up to 34.5 Mpa (5,000 psi) for the volumes needed for lock and spillway service.

(2) Increased system pressure, however, increases the risk of leakage and the size of some transmission components. Increased size translates to increased life-cycle costs. Bending and/or buckling loads often govern when sizing the cylinders (bore and rod diameter), which sometimes reduces the required operating pressure.

c. System component ratings. The manufacturer's published pressure, volume, friction, temperature, and fluid compatibility ratings should be used for selection of all system components. They should have a normal minimum pressure rating equal to at least twice the maximum normal operating design pressure. Components should be specified to deliver the maximum design volume flow rate at a cumulative pressure loss of less than 1 Mpa (150 psi), including main system valves, piping, hose, filters, and manifolds. The operating temperature ranges of hydraulic system components and the oil used are important considerations because parts of the system are normally in machinery trenches and subject to ambient temperatures.

4–4. Hydraulic cylinders

Hydraulic cylinders convert fluid power to linear motion. The three types of hydraulic cylinders used in typical lock and dam machinery applications are the tie rod type, telescoping type, and mill type.

a. Types of cylinders.

(1) *Tie rod cylinders*. Tie rod cylinders are commonly used in sizes below 10-in. bore. These cylinders are more prone to problems caused by field maintenance than other types of cylinders. They are typically designed for lower overall pressure requirements than the mill-type cylinder.

(2) *Telescoping cylinders*. These cylinders are commonly used in situations like an elevator, where installation space is limited and loading is relatively minor, but the cylinder stroke required is very long. Since each stage of the cylinder must be enclosed within another stage, the available force is limited. These are rarely used for lock and dam applications and not recommended.

(3) *Mill-type cylinders*. Mill-type cylinders are generally rated for higher pressures than the other designs. The cylinder heads are mounted with bolts or cap screws. The designer should use this type of cylinder for most lock and dam and FRM applications.

b. Cylinder features. Cylinders consist of an outer pressure vessel shell, the cylinder tube, which is divided into two volumes by the piston. One side of the piston is attached to a piston rod that exits the cylinder through a sealed orifice. This end is generally called the rod end, and the opposite side, the cap end. For a typical double-acting cylinder, there are fluid connections at either end. Force is exerted by applying hydraulic pressure to either side of the piston while allowing fluid on the opposite side to leave or enter the cylinder, depending on if the cylinder is actuating or retracting. Figure 4–4 shows a typical miter gate drive system using a hydraulic cylinder.

Figure 4–4. Upper St. Anthony Falls Lock

(1) All hydraulic cylinders should be provided with SAE, four-bolt, flange connections for the supply ports at the top or side of each end. All cylinders should be furnished with air bleeds and oil drains at the high and low points, respectively, at each end. Flexible hose sections may be used to isolate cylinders from rigid hydraulic lines where movement or vibration may adversely impact the cylinder hydraulic connections. All flexible hydraulic hoses should be routed and arranged with appropriate fittings to adhere to SAE J1273 or alternate standard to avoid excessive bends or premature failure.

(2) All cylinders should be provided with zero-leakage sealing systems to prevent drift and environmental contamination. Split-rod seals that can be replaced without disassembling the cylinder can also be considered by the designer. Metallic versus elastomeric piston seals/rings can also be evaluated by the designer. See discussion below. It is important in this case that the metallic piston rings are longer lasting and the increased leakage around the piston is inconsequential. The sealing system should be appropriate for the cylinder rod coating, hydraulic fluid characteristics, and operating conditions expected.

(3) On FRM projects, some designers and engineers prefer to use metallic piston rings, which are not zero leakage. They are preferable because they are less likely to have a catastrophic failure compared to polymer seals, which causes unintended gate closure. In the typical vertical cylinder application, they can last a very long time. Some current applications in USACE are 70 years old without being replaced since they are not side loaded. In some applications, a hybrid system is used with polymer and metallic piston seals.

(4) Piston rods should generally be either nickel chrome-plated steel or chrome-plated stainless steel. Newer laser cladding systems have worked well and are further discussed in Chapter 5. Refer to Chapter 5 regarding acceptability of other coating systems.

(5) Column buckling resistance is highly dependent on section moment of inertia. The standard Euler equation is typically limited to columns of uniform section (constant moment of inertia) and, depending on the design, may not be directly applicable to hydraulic cylinders with intermediate trunnion and cap-end mounts. However, the Euler equation should still be used as discussed below. The AASHTO method may also be used as discussed below.

(6) The cylinder rod should be designed with a minimum factor of safety of 3.0 to resist a buckling load under compression. End connections are usually analyzed as pin-pin, with the rod end connection almost always pinned, but the cylinder end could be guided or fixed depending on the design used. It is most common to use the Euler column method, assuming the entire length between supports has the cross-sectional properties of the rod.

(7) This method is conservative and secondary effects, such as self-weight bending, are usually not included. Other methods, such as found in AASHTO's LRFD Movable Bridge Design Specifications, or ISO/Technical Specification (TS) 13725, may be used, but care should be taken to follow all the requirements for determining cylinder load for buckling, secondary effects, and not simply using the buckling equation in isolation.

(8) AASHTO provides a vetted approach to evaluate hydraulic cylinder buckling resistance in critical civil infrastructure applications. The approach is published in AASHTO's LRFD Movable Bridge Design Specifications (second edition, section 7.5.12.3). AASHTO's method is based on Euler's standard equation and substitutes column length (L) with an effective column length (Lmod) that accounts for the increased rigidity (moment of inertia) of the cylinder barrel.

(9) The ISO/TS 13725 document specifies a method for evaluating the buckling load, which considers a geometric model of the hydraulic cylinder, meaning it does not treat the hydraulic cylinder as an equivalent column.

(10) All cylinder mounting features, including trunnions, should be attached by the manufacturer at the factory. The cylinder stroke should be designed with sufficient overtravel to facilitate installation tolerances for proper adjustment.

(11) Optional features may be obtained with the initial purchase of cylinders. The cylinder may be furnished with local control manifolds mounted directly to the cylinder, adjustable cushions to assist in deceleration when approaching the stroke limits, and a stop tube or double pistons to assist in resisting side loading of the piston rod.

(12) Internal sensors are available to provide continuous cylinder position or integral limit switches. Single-acting cylinders that are vented at one side or double ended

cylinders that have a cylinder rod at both ends also exist for specialty applications. There are other options, such as position indication, bleed ports, rod seal leakage collection chambers, rod heaters, and lifting lugs. Some long cylinders can also be designed and built with two-piece barrels.

(13) The factors of safety of the cylinder should be based on the maximum operating pressure. Using the maximum operating pressure, design all hydraulic cylinders with a factor of safety of 5 based on the ultimate strength of the material or 2.5 based on the yield strength of the material.

c. Regenerative circuits. It is common to have an application where the required operating pressure to extend a hydraulic cylinder is significantly less than that required to retract it. This may be because of the reduced working area on the rod side of the piston, and because the loads on retracting are higher, such as in the case of a suspended gate, or a sector gate opening under reverse head.

(1) In such instances, a regenerative circuit may be used to reduce operating time in extension without increasing pump capacity or hydraulic line sizes. A regenerative circuit is arranged such that pressure is applied to both ends of the cylinder, and only the net differential area between the cap and rod side of the piston is used to extend the piston, requiring higher pressure for the same load.

(2) The fluid in the rod end is displaced to the cap end during extension rather than returning to the tank. This decreases the line velocity and volume of fluid pumped from the HPU and increases extension speed.

d. Packaging for shipping, handling, and storage. All cylinders must be packaged for the maximum storage time and conditions anticipated under the contract duration, including shipping conditions.

(1) Cylinders should be shipped with the piston rod(s) retracted and restrained from movement. The contractor must follow the manufacturer’s recommendations for cylinder storage and maintenance while stored. Unless specified otherwise by the manufacturer, cylinders stored horizontally should be rotated 90° every six weeks.

(2) Periodic rotation is not required for cylinders stored vertically with the rod up. Small cylinders shipped without oil must have a vapor phase inhibitor added to prevent corrosion, and then be flushed and filled with clean system fluid before being put into service. Large cylinders should be shipped from the manufacturer, filled with the required system fluid, and remain filled with fluid while in storage. Temporary accumulators, standpipes, or similar expansion devices should be installed by the manufacturer before filling to accommodate oil expansion due to temperature changes during shipment and storage.

e. Mechanical linear actuators. Mechanical linear actuators have made adequate advancements to provide a mechanical cylinder alternative to hydraulics in many applications. Also sometimes called “electrical cylinders” or “electromechanical cylinders," this type of actuator uses a screw drive with a lead nut mounted on a threaded piston rod.

(1) The lead nut is driven by an electric motor through a gearbox. On the outside, mechanical cylinders resemble hydraulic cylinders, however, they do not contain hydraulic fluid or require additional HPU components.

(2) Older linear screw actuators were typically vulnerable to wear and corrosion. Modern mechanical actuators are generally protected against contamination and exposure. As with the self-contained hydraulic actuators, the designer also needs to ensure they offer a way to relieve stress from a sudden overload such as from a barge impact. Otherwise, they could pose a risk of damage to a miter gate.

4–5. Hydraulic motors

Hydraulic motors convert fluid power into rotary motion. Pressurized fluid from the hydraulic pump turns the motor output shaft by pushing on the gears, pistons, or vanes of the hydraulic motor. Hydraulic motors can be used for direct drive, where sufficient torque capacity is available, or through gear reductions. Most hydraulic motors must operate under reversible rotation and braking conditions. See Figure 4–5. Motors are often required to operate at relatively low speed and high pressure. Motors can experience wide variations in temperature and speed in normal operation. There are three types of hydraulic motors: gear, piston, and vane.

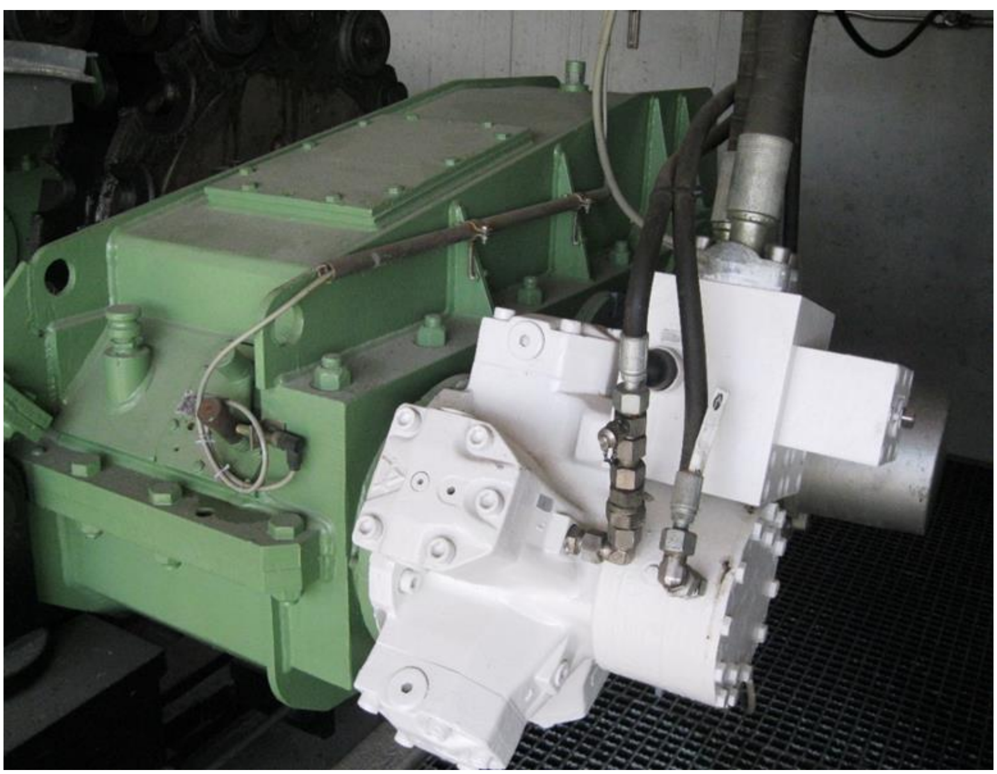


Figure 4–5. Hydraulic motor driving a gearbox

a. Gear motors. Gear motors are compact, basic in design, provide continuous service at rated power levels with moderate efficiency, and are reliable with high dirt tolerance. There are several variations of the gear motor, including the gerotor, differential gear motor, and roller-gerotor; all produce higher torque with less friction loss.

b. Piston motors.

(1) *Axial piston motors*. The most common type of motor available is the axial piston type. Axial piston motors have high volumetric efficiency, which permits steady speed under variable torque or fluid viscosity conditions. This permits the smoothest, most adaptable approach to variable loading conditions. Axial piston motors are available in two types of design, swash plate and bent axis. The swash plate design is the most commonly available hydraulic motor. The bent axis design is the most reliable and the most expensive.

(2) *Radial piston motors*. Radial piston motors are extremely reliable, highly efficient, and rated for relatively high torque. Radial piston motors are less commonly available, which might require extensive investigation into availability to ensure adequate procurement competition. Piston motors are available in fixed- and variable-volume versions. Large, direct-connected, low-speed, high-torque (LSHT), radial piston hydraulic motors have been used at multiple locations for sector gate rack and pinion gear drives. See Figure 4–6 below.

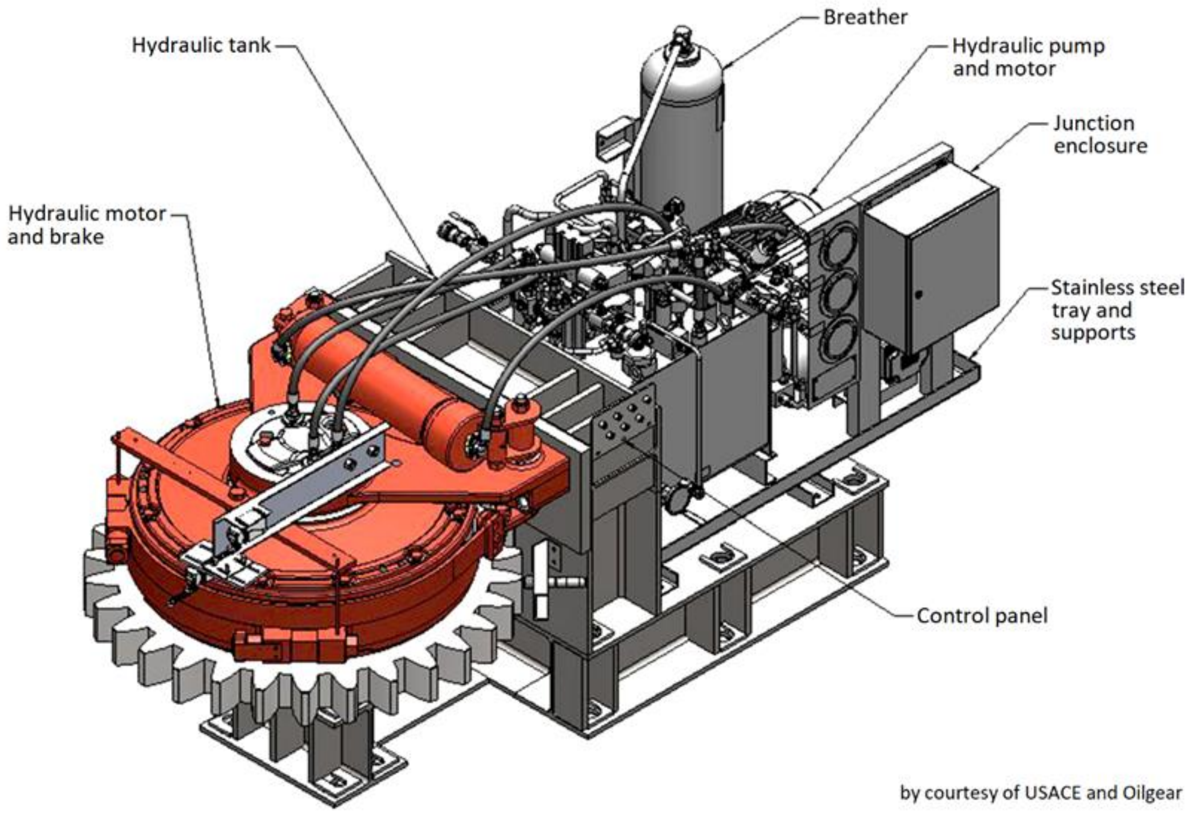


Figure 4–6. Sector gate hydraulic drive and hydraulic motor (courtesy of Oilgear)

c. Vane motors. Vane motors are compact, simple in design, reliable, and have good overall efficiency at rated conditions. Vane motors use springs or fluid pressure to extend the vanes. Vane motors generally use a two- or four-port configuration. Four-port motors generate twice the torque at approximately half the speed of two-port motors.

d. Rotary actuators. Where extremely high torques are required, large partial-turn rotary actuators, operated by pairs of hydraulic pistons, are available with torque capacities up to 5,650 kN-M (50 million in-lbs). This style of sealed actuator has been used to directly operate miter gate strut arms, replacing hydraulic cylinder-driven open rack and gear systems. The rotary actuator at La Grange Lock is shown in Figure 4–7.

Figure 4–7. Rotary-actuated miter gate machinery La Grange Lock

4–6. Hydraulic pumps

Hydraulic pumps convert electrical energy into fluid power. The fluid power is in the form of hydraulic fluid delivered to operating devices at a pressure and volume required to perform the work of the system. Gears, pistons, or vanes are used to compress the hydraulic fluid to the conditions required by the system. Hydraulic pumps generally operate at higher speeds and pressures than hydraulic motors without significant thermal shock, speed, and load variations. While some systems use reversible pumps, most lock operating systems use a unidirectional pump with a directional control valve to reverse the operation of the actuators. Hydraulic pumps generally have three basic types: gear, piston, and vane.

a. Gear pumps. The gear pump is a simple, rugged, positive-displacement design with a large capacity for a small size. Gear pumps have a high tolerance for fluid contamination, good overall efficiency, and are relatively quiet. While these pumps are fixed volume at a given rpm, their flow rate/rpm characteristics are linear within their efficiency ranges. Speed and direction control of an actuator therefore can be provided by driving a reversible gear pump with a variable speed electric motor, which makes them ideal for integral type power units. Gear pumps also are commonly used for pilot pressure applications. Gear pumps generally are restricted to less than 24 Mpa (3,500 psi) service.

b. Piston pumps. The piston pump is the type most often recommended as the main pressure pump for hydraulic power systems. It has the highest volumetric efficiency, highest overall efficiency, highest output pressures, and longest life expectancy. This type of pump is available in variable displacement models with a large variety of control systems for pressure and capacity. It is recommended that the drive motor speed be designed for 900 to 1,200 rpm, if possible, to reduce noise and increase pump life. Piston pumps generally are restricted to less than 42 Mpa (6,000 psi) service.

(1) *Axial piston pumps*. Axial piston pumps are used for high-pressure and high-volume applications. The two basic types of axial piston pump are the swash plate and the bent-axis designs. The bent-axis design is considered to be a higher quality pump with less noise, vibration, and wear than the swash plate design. Swash plate pumps can be designed to drive a separate pilot pressure pump from a shaft extension, while bent-axis pumps require a separate electric motor/pump arrangement for pilot pressure.

(2) *Radial piston pumps*. Radial rolling piston pumps are an extremely reliable, simple design. A typical design includes solenoid controls for up to five discreet operating speeds. Each of the operating speeds has a variable adjustment range from zero to full volume capacity to permit field adaptation to operating conditions. The typical pumping system includes an integral pilot pump, internal pressure relief valves, and associated control devices for speed of shifting between pumping rates.

c. Vane pumps. Variable-volume vane pumps are efficient and durable if a clean hydraulic system is maintained. In a simple circuit, the pressure compensation feature of the vane pump reduces the need for relief valves, unloading valves, or bypass valves. Vane pumps generally are restricted to less than 14 Mpa (2,000 psi) service.

4–7. Control valves

Various types of valves are used to control pressure, volume, and direction of fluid flow in a hydraulic circuit. Typical operating elements of these valves are poppets, sliding spools, springs, stems, and metering rods. Valves can be controlled manually (with a hand wheel, lever, joystick, etc.), mechanically (with a cam, roller, toggle, etc.), hydraulically (with pilot pressure), or electrically (with a linear variable differential transformer, solenoid, etc.).

a. Circuit types. Control valves are used in two basic types of hydraulic circuits: closed loop and open loop.

(1) *Closed-loop circuits*. Closed-loop circuits use a feedback system that generates input and output electrical signals to track system performance. The electronics

continually compare the input and output signals and automatically adjust the system to the required performance level. Control valves for closed-loop circuits are typically proportional and servo valves. Proportional valves are also used in open-loop circuits.

(2) *Open-loop circuits*. Open loop circuits rely on the performance characteristics of the individual valve components to meet the system requirements. Basic pressure-control valves, flow-control valves, and directional control valves are used to alter the pressure, flow, and direction of the fluid power using only simple electrical solenoids for control in an open-loop circuit.

b. Valve types. The following valve types can be used on either open or closed-loop circuits, although the servo valve is typically used in closed-loop circuits.

(1) *Proportional valves*. These valves can assume any position between their minimum and maximum settings in proportion to the magnitude of an electrical input signal. They can control direction, flow rate, and pressure. Since they can assume multiple positions, the directional valve spools can be designed to throttle the flow rate in each direction of motion. Actuator force or torque can be controlled by varying the pressure. Pressure is often a function of actuator speed in lock and dam operating equipment. Where pressure cannot be related to actuator speed, pressure-control valves must be used in the circuit. Proportional valves are mass produced with interchangeable spools and valve bodies. This can lead to slight misalignment, which results in center position overlap or no flow to the outlet ports. This flow dead band, while not a problem in flow control-type circuits, can cause errors and instability in closed-loop feedback positioning circuits.

(2) *Servo valves*. Servo valves are made to closer tolerances than proportional valves. These valves have superior response, repeatability, and threshold response. They are, however, considerably more expensive than proportional valves. Repeatability is a measure of the number of times a valve can produce the same flow rate with repeated signals of the same magnitude. Threshold response is the smallest variance in input signal that produces a corresponding change in the flow rate. Meticulous construction is required to produce precise alignment of the spool lands with the valve body ports. The higher cost of servo valves usually is justified when more sophisticated performance requires a high load stiffness, good stability, precise positioning, good velocity and acceleration control, good damping, and predictable dynamic response.

(3) *Pressure control valves*.

(a) Pressure control valves are used in hydraulic systems to control power and to determine pressure levels at which various operations or actions can occur. Pressure control valves can limit the maximum pressure in a circuit, reduce pressure levels from one part of the circuit to another, provide alternate flow paths for fluid at selected pressure levels, provide resistance to fluid flow at selected pressure levels, and modulate transient pressure shock in a hydraulic circuit.

(b) Pressure control valves include pressure relief valves, sequence valves, counterbalance valves, holding valves, unloading valves, reducing valves, and shock suppressors. All these valves have some method of pressure-setting adjustment. Valves operating in enclosed areas should be furnished with key-locked handles to discourage casual adjustment. Valves exposed to weather, such as in grated pits, may be furnished with lock nuts to maintain final settings.

(4) *Pressure relief valves*. A pressure relief valve limits upstream pressure to a preset value by returning part, or all, when sized correctly, of the fluid flow to the reservoir until the upstream pressure drops below the relief setting. The two principal types of pressure relief valves are the spool type and the poppet type. The poppet type has the shorter response time, but the spool type has more stability and accuracy of operation and adjustment. Most main pressure relief and pilot relief valves should be the balanced piston (spool) type with an appropriate adjustable pressure range. Pressure relief valves should be furnished for the main pressure pump, pilot pressure pump, and each actuator line between the directional valve and actuator inlet ports.

(5) *Sequence valves*. Sequence valves direct flow to a circuit in a predetermined logical sequence by sensing that adequate pressure was developed in one circuit before allowing flow in another. Sequence valves might have to actuate two or more spools or poppets to connect primary and secondary passages. Sequence valves are generally used in circuits where one actuator must complete its operation before another actuator, at a higher pressure, can begin its operation.

(6) *Counterbalance valves*. A counterbalance valve is a normally closed pressure control similar to a relief valve but has a reverse free-flow check valve. Counterbalance valves are used to control an overrunning or overhauling load. They are commonly used on culvert valve control circuits to prevent the open valve from drifting downward when main pump pressure has been blocked by the directional control valve. Counterbalance valves can be used with an internal pilot or a remote pilot actuation. Using a remote pilot can significantly reduce the power required to lower the load at a controlled rate. Selecting the proper pilot ratio for a given application is important. In general, higher pilot ratios are suitable for stable and constant loads, while lower pilot ratios are suitable for unstable and varying loads.

(7) *Holding valves*. A holding valve is a special type of counterbalance valve, functionally like a pilot-operated check valve. Pilot-operated check valves trap fluid to prevent actuator movement but, during actuator travel, produce little resistance. Counterbalance valves, in addition to preventing movement, add resistance during travel, which increases the power required to operate. Holding valves avoid the objectionable features of both the counterbalance and pilot-operated check. Holding valves also provide built-in, thermal-relief protection.

(8) *Unloading valves*. The straight unloader and the differential unloader are two basic types of unloading valves. The straight unloading valve is a two-stage relief valve, with its pilot port connected externally to a separate signal source. The differential unloading valve operates on an area differential between the control poppet seat and a

pilot piston of 10 to 20%. Unloading pressure is controlled by the spring force on the control poppet. The pilot piston is actuated by external pilot pressure such that it unseats the poppet at a preselected pressure. When the poppet opens, the main valve spool shifts to the open position. The pilot piston then prevents the poppet from reseating until the pressure drops below the required differential.

(9) *Reducing valves*. A reducing valve is a normally open valve that modulates, or blocks, flow at a preset pressure. They control downstream pressure by restricting flow due to the positioning of the spool, with respect to the outlet port.

(10) *Shock suppressors*. Sometimes called safety valves, shock suppressors are two-way valves that snap open to relieve hydraulic shock. Hydraulic shock is an excessive pressure applied instantaneously to the circuit. When high-pressure, high flow rate events occur, the two-way valve snaps open to allow the fluid to pass from the inlet to the tank. The small amount of fluid bypassed decreases the rate of pressure rise, thus preventing the shock.

c. Valve positioning.

(1) A central valve block or manifold at the HPU provides a convenient arrangement for locating and servicing valves as well as protecting them from exposure. However, there are some instances that may warrant placing valves elsewhere in the system.

(2) Where actuators are located at a significant distance from the HPU and may potentially see shock loads or external loading when not actuated, shock suppressors or relief valves may be needed closer to the actuators to adequately protect them. Where counterbalance or holding valves maintain position of suspended or hydraulic loads, placement near the actuator reduces exposure to line breakage. Additionally, if these valves have manual bypass valves to allow emergency gravity lowering, these should be placed where there is a line of vision to the actuator, if possible.

d. Flow control valves.

(1) Flow control valves control the rate of fluid flow from one part of the hydraulic system to another. These valves can:

(a) Limit the maximum speed of the actuating devices.

(b) Limit the maximum power available to sub-circuits.

(c) Proportionally divide or regulate the flow to different branches of a circuit.

(d) Control the speed of pilot-controlled valves.

(2) Flow control valves operate in three general configurations: meter-in, meter-out, and bleed-off. Meter-in and meter-out methods use a throttling approach to restrict the size of the fluid path, while bleed-off bypasses the flow to tank or a lower pressure area

of the circuit. Flow control valves can be compensated or non-compensated. Compensated valves automatically adjust to provide uniform pressure drop across the valve to furnish constant flow rates.

(a) Meter-in circuits. Meter-in flow controls should be used when the load might kick back, when the circuit power or pressure level must be retained when the actuator pressure level falls off, and for dividing flows to multiple branch circuits.

(b) Meter-out circuits. Meter-out flow controls should be used when the load is overhauling or overrunning, the load can decrease and cause lunging, and when a back pressure is desired for rigidity in motion.

(c) Bleed-off circuits. Bleed-off flow controls should be used when a soft circuit is desired, and when the power to be controlled is a fraction of the circuit power to the actuator.

e. Directional control valves. Directional control valves do one or more of the following by providing a choice of flow paths:

(1) Control direction of actuator motion.

(2) Select alternate circuits.

(3) Perform circuit logic functions.

f. Check valves. The check valve is the simplest of all directional controls. Other directional controls are described by the number of primary ports available for control. They are usually referred to as two-way, three-way, or four-way valves. Check valves can be used for a wide variety of functions in a circuit. They can prevent flow in one direction, while permitting free flow or pilot-controlled flow in the other. They can be piloted externally to provide an actuator-locking function. They can be used in pilot lines to provide rapid release of a pilot-operated spool.

g. Two-way directional valves. Two-way valves generally perform logic functions such as AND, OR, and AND/OR decisions. These valves allow flow in one position and no flow in the other. These valves can be in the normally open or the normally closed position until actuated by levers, solenoids, pilot pressure, etc. Two-way valves perform interlock or safety functions.

h. Three-way directional valves. Three-way valves have a pressure supply port, a tank port, and one actuator port. These valves are generally used with an actuator designed with springs or other means of returning to a rest position, because they can address only one actuator inlet port. This type of valve is generally not recommended for normal lock and dam machinery design, because it is important to use pump flow to control operation in both directions of travel.

i. Four-way directional valves. The typical directional valve used on lock and dam projects is the four-way, three-position, directional valve. This valve has four main ports:

main pressure, tank, actuator A, and actuator B. This permits the valve to reverse actuator direction in a controlled manner with the main pump flow. These valves can be furnished with a wide variety of spools for controlling flow. The directional control valve is usually the single greatest pressure loss point in a hydraulic circuit. Therefore, to minimize system losses, it is customary to design this valve for 1.5 to 2.0 times the maximum system flow rate.

j. Spools.

(1) The typical spool used for modern lock and dam hydraulic systems is the blocked-center, solenoid-controlled, pilot-operated, spring-centered spool. This type of spool is used successfully in hydraulic systems that can be operated remotely with a series of interlocks to prevent conflicting machinery behavior.

(2) A solenoid-operated, pilot-pressure, four-way valve applies pilot pressure to shift the pilot-operated spool in the main pressure four-way valve. The pilot pressure to each side of the spool is usually passed through a combination flow control-reverse free flow check valve to permit adjustment of main pressure spool actuation speed. The spring-centered feature is used in the pilot valve and the main pressure valve to return the system to blocked center when the solenoids are not energized to permit machinery operation. The tandem center-type spool has been used with some success when proper pressure control valves are included in the circuit to prevent actuator drift after main pressure pump shutdown.

k. Controls. Solenoid-controlled pilot operators are usually used on the more modern open loop-type systems to allow remote, or centralized, operation with appropriate electrical or electronic interlocks. Direct solenoid-operated valves are generally available in smaller flow rate capacities. All solenoids should be equipped with manual operating pins for troubleshooting and emergency operation. Lever or other manual-type operators should be used only on the most basic systems, or where human observation of the operation from the local controls is essential.

l. Mounting systems. Control valves should be mounted on steel block-type manifolds. Manifold systems are economical, reduce leakage, minimize piping fabrication costs, and reduce space requirements. See paragraph 4–9.

4–8. Reservoirs

a. Overview. A general rule for the initial sizing of a hydraulic reservoir is that it should have a minimum capacity of approximately 3 times the pump discharge rate (gallons per minute). The actual capacity required is determined by other factors such as the number and size of actuators served, long lengths of large-diameter piping, or excessive thermal expansion. The reservoir and HPU at Olmsted Dam is shown in Figure 4–8.

Figure 4–8. Olmsted Dam Hydraulic power unit and reservoir

(1) Since the typical hydraulic cylinder has substantially more fluid per length of stroke on the cap-end side than on the rod-end side (the rod takes up volume as it retracts into the cylinder), more fluid will be returned to the tank when a cylinder is retracted. Where multiple hydraulic cylinders are served, an analysis of all potential operating cases (number of cylinders that can be extended or retracted at the same time) should be performed to determine the maximum and minimum reservoir levels required for the complete system.

(2) The reservoir should have sufficient capacity to provide a flooded pump suction without vortex formation under all operating conditions. After the reservoir size is determined, its heat-dissipation capacity should be checked to see if it is adequately sized to dissipate heat generated by the individual components of the system and any ambient or solar heat gain. The reservoir should be fabricated from annealed and pickled steel or stainless steel plate, designed for the loads applied by all accessories and pumping equipment. Stainless steel construction is recommended. Coating the interior of reservoirs not made of stainless steel with an epoxy system is no longer recommended by many hydraulic system manufacturers.

(3) The reservoir should be internally reinforced, as required, with vertical baffles to separate the return oil from the pump suction. The baffles must be designed to prevent turbulence at the pump suction. External pumps are recommended for ease of maintenance, and each pump/motor group should be mounted with vibration isolators and connected with flexible hoses and conduit to prevent noise and vibration transmission to the reservoir and fluid. If internal pumps are required, D-flange motors

should be used to allow easy motor removal without removing the pump from the reservoir.

(4) The reservoir should be equipped with appropriate oil level gauges, low- and high-level shutoff switches, magnetic particle collector, drain valves, removable clean-out plates for suction and return sides, suction filters (if required for pumping unit design), breathers, and reservoir heaters (if required by the hydraulic fluid design).

b. Oil level gauges. Oil level gauges should be one or more sight gauges, placed to show the full normal operating range of fluid levels within the middle 80% of the gauge range. The lowest sight gauge installed must have a thermometer designed for the maximum normal hydraulic fluid operating range.

c. Shutoff switches. Float-type shutoff switches have proven reliable. Switches can prevent low suction level and overfill, as well as issue alarms when approaching fault conditions.

d. Magnetic particle collectors. These devices are permanent magnets immersed in the hydraulic fluid that collect metal particles that can cause pump damage. Periodic inspection and cleaning of these devices is essential in the early identification of pump wear problems.

e. Drain valves and cleanouts. Reservoir drain valves should permit easy access for draining the hydraulic fluid to the bottom of the reservoir. This includes placing the location well above the surrounding floor level sufficient to place a disposal container of modest size for collection of the fluid. Cleanouts should be properly sealed, bolted, or clamped, and placed for easy access when in service.

f. Reservoir heaters. Reservoir heat is not required for most installations. There are many viscosity-stable hydraulic fluids, designed for aircraft and missile service, and also synthetic hydraulic fluids that are usable with piston pumps at temperatures as low as -40 °C (-40 °F). Where it is determined necessary, the reservoir heating elements should not exceed a watt density of 1.5 W/sq cm (10 W/sq in.) of element to eliminate charring of the fluid.

g. Breathers. Hydraulic systems typically use a replaceable filter-breather device that permits atmospheric air to be drawn into the reservoir. These devices can be furnished with a desiccant-type filter for moisture control. Recent experience indicates the best method of breather protection for hydraulic systems in the damp, lock and dam environment, which is a bladder-type breather system.

(1) Where sufficient space is available, a flexible bladder-type breather system, usually called a reservoir isolator, should be used. Reservoir isolators recycle the air to and from the reservoir, sealing it from dirt, water, and other contaminants.

(2) Water in the hydraulic system is one of the primary reasons for hydraulic component failures. Water usually infiltrates the system from the moisture in the air that is exchanged in the reservoir through the breathers.

(3) A bladder is an elastomeric air chamber that is connected to the reservoir. The bladder expands and contracts as the air volume changes in the reservoir, eliminating the need for a breather. Reservoirs using bladders should be pressure tested and equipped with relief valves. Where installation of a reservoir isolation bladder is not available, a desiccant breather may be employed, though frequent replacement of the desiccant might be necessary in humid environments. Another option is to install the reservoir in a climate-controlled room with dehumidification.

h. Control valve manifolds. For convenience of adjustment and maintenance, it is beneficial to mount any control valves associated with the pumping system on a control manifold mounted on the reservoir. In some cases, the directional control valves, pressure controls, and flow controls can be mounted on the reservoir to conserve space.

i. Secondary containment. Some method of secondary containment for the contents of the fluid reservoir should be provided to eliminate spills and waterway contamination. The reservoir can be specified as double-walled with leak detection electronics between the walls. The reservoir can be contained within a containment pit like above-ground fuel tanks with leak detection electronics within the pit. This is required for any reservoir with direct drainage features to the waterway, such as floor drains, sump pumps, or lock wall recesses. Oil/water separators may be used to treat drainage prior to discharge into the waterway, but these devices should be tested thoroughly prior to installation to ensure that the effluent meets all state and local environmental pollution criteria.

j. Reservoir types. Separate reservoirs and sealed reservoirs are two basic types that should be considered.

k. Separate type reservoirs. Separate reservoirs are the most common design in industrial, or lock and dam, applications. A separate reservoir can be designed for a single pump/motor group serving one or more actuators, or multiple pump/motor groups serving many actuators. Some dual-chamber locks with centralized power units have one reservoir supplying three pump groups (two of the three are normally used), which operate all the actuators for both chambers. The three principal versions of separate reservoirs are rectangular, L-shaped, and vertical.

l. Rectangular reservoirs. These reservoirs use a rectangular steel box to hold the fluid and house the accessories. They can be designed with the pump groups mounted on top, underneath, or inside the reservoir. A short suction line with top mounting is required for each pump that extends below the minimum suction submergence of the fluid. The pump groups are provided with a flooded suction, with underneath mounting, that significantly improves pump operating conditions. The pumps are submerged, with inside mounting in the fluid, and the drive motors are mounted vertically on top of the reservoir.

m. *L-shaped reservoirs*. L-shaped reservoir packages have the pump groups mounted next to the reservoir on a common base. This arrangement provides good access to components for maintenance and repair.

n. *Vertical reservoirs*. Vertical reservoirs have the pump group in a vertical plane with the pump below a removable reservoir cover. While this arrangement is compact, with a low suction-lift requirement, the size is limited by the requirement for lifting the entire pump group, controls, and reservoir cover to service any equipment.

o. *Sealed reservoirs*. Sealed reservoirs are used primarily for the integral power unit of a self-contained actuator, which consists of a power unit attached directly to the hydraulic cylinder it operates. These actuators can be configured in different ways by changing the shape of the reservoir and where or how it is attached to the cylinder. The direct-connected miter gate actuators recently installed on several locks have long, slender reservoirs made from square structural tubing, bolted to brackets on the side of the cylinder.

p. *Tainter valve actuators*. Tainter valve actuators have also been designed with shorter reservoirs made from round structural tubing and permanently welded to the rear of the cylinder tube during fabrication. This arrangement allows the actuators to fit existing recesses without modification. Sealed reservoirs have a pump mounted inside and a submersible motor mounted outside. Since these reservoirs do not have breathers or accumulators, the air pressure inside varies with cylinder rod position and oil temperature. The actuator should be designed so the normal pressure range in the reservoir is between 3 and 10 psig. Make sure the pressure never goes below atmospheric or above 30 psig.

4–9. Manifolds

Predrilled steel manifold blocks have been extremely reliable for connecting control valve assemblies in hydraulic systems. Manifolds provide short, direct flow paths between controls, which reduces friction and response time. Stainless steel manifolds are recommended.

a. Aluminum manifolds should not be used with steel piping or steel-bolted SAE flange connections due to the localized yielding of the aluminum threads during installation, from shock, and from vibration. The specification should ask for detailed drawings of the drilled passages of the steel manifolds.

b. Sub-plate control valves are directly mounted, or stack mounted to the manifold, and cartridge-type valves screw directly into the manifold, eliminating excess piping and reducing leakage. Maintenance costs are reduced by eliminating piping connections. Manifolds can be sensitive to filtration problems, but proper preventive maintenance should yield excellent results. Test ports should be specified where required to provide convenient gauge connections for adjustment and troubleshooting.

c. It is essential to specify that all manifolds should be furnished with as-built fabrication drawings that document the dimensions and locations of all predrilled passages, including where fabricating passages have been plugged. A manifold of each different type, properly prepared for long-term storage, should be included in the spare parts.

d. Pressure-side and return-side filters should be provided on all hydraulic power units. Filters must be selected based on their Beta rating. Spin-on pressure line filters rated for full maximum discharge pressure of the pump should be furnished for the main supply and pilot supply pumps. A large, multiple-cartridge, return-line filter should be mounted adjacent to the reservoir.

e. Return-line filters should be the full flow-type, designed to pass all flow through the filtering elements. Return-line filters should, however, include a bypass relief valve system designed to shunt flow around the filter after a preset pressure drop is exceeded. Return-line filters should be provided with a maintenance indicator that clearly shows when the cartridges need to be replaced. Return-line filters need to be sized correctly so the inlet conditions into the pump are not adversely affected.

f. All filters should be rated for the minimum required by the manufacturer for the types of valves used. Modern proportional valves can require a particulate filtration rating as low as 5 microns. The system must be designed such that all hydraulic fluid passes through one or more of these filters during installation, testing, and normal operation.

g. The ISO standard for multi-pass filter testing (ISO 16889) has changed to require filter manufacturers to determine the average particle sizes that yield Beta ratios equal to 2, 10, 75, 100, 200, and 1,000, using the multi-pass test standard approach. The new standard gives a better interpretation of a filter’s overall performance. The higher the Beta rating, the higher the filter efficiency.

h. The efficiency of the filter is calculated directly from the Beta ratio. A Beta 1,000, 5-micron filter is said to be 99.99% efficient at removing 5 micron and larger particles. Filters should have a Beta rating of at least 200.

i. Accumulators store hydraulic energy in a manner similar to electric storage batteries. They store potential energy by accumulating pressurized hydraulic fluid in a vessel for later release into the system. Accumulators can improve energy efficiency, absorb shocks, dampen pulsation, reduce noise, prevent pump cavitation, compensate for leakage or thermal expansion, and provide emergency operation capability. Accumulators are nominally designated by their energy storage mode, either pneumatic, spring-loaded, or weight-loaded.

(1) *Pneumatic accumulators*. Pneumatic accumulators use compressed inert gas, such as nitrogen, to force hydraulic fluid back into the hydraulic system. Compressed air is not used due to the danger of explosive air-oil vapor. Accumulators should be the

separated type that uses bladders, diaphragms, or pistons to separate the hydraulic fluid from the compressed gas. Bladder designs are the most versatile.

(2) *Spring-loaded accumulators*. These accumulators use a spring compressed by a piston to force fluid into a hydraulic circuit. They are typically used for energy storage in applications below 3.5 Mpa (500 psi) and are not recommended for shock absorption.

(3) *Weight-loaded accumulators*. These accumulators use a heavy weight to push the piston down, forcing fluid into the circuit. They are typically very large, with installation and maintenance problems, and, therefore, not recommended.

4–10. Piping

All piping must be designed and selected according to ASME B31.1 based on the maximum normal operating pressure. Identification of pipe systems must follow ASME A13.1. This should also provide adequate design tolerance for shock and vibration. Proper design of hose assemblies should include adequate length, swivels, end connections, and outer coverings to account for exposure to the environment, equipment movement, and adjacent hazards.

a. Piping options. Stainless steel piping is recommended in nearly all applications. Black steel pipe should be furnished in the pickled and oiled condition. Stainless steel pipe, however, has been found economically justifiable on a life cycle basis to reduce maintenance and leakage due to corrosion. Many galleries for running hydraulic piping are prone to high moisture and flooding. Stainless steel piping should be considered in these applications. Hydraulic tubing can be used for diameters below approximately 40 mm (1-1/2 in.). All pipe hangers should be furnished with phenolic shock-absorbing inserts to accommodate hydraulic system shock and vibration.

b. Required design features. All piping systems must have air bleed valves at the high points in the system. All piping systems must have drain valves at low points in the system. An analysis should be performed at sufficient intervals to locate shutoff valves in the piping system and to permit localized drainage of piping for pipeline repairs. Gauge and pressure transducer connections should be furnished at appropriate locations for future system troubleshooting. Piping must be tested to the maximum normal working pressure rating of the pipe, tubing, or hose in the system.

c. Fluid velocity requirements. Main pressure lines should be designed for a velocity of 3 to 4.5 m/sec (10 to 15 ft/sec). Hydraulic return lines should be designed for a velocity no greater than 3 m/sec (10 ft/sec). Pump suction lines should be designed for a velocity of 0.6 to 1.5 m/sec (2 to 5 ft/sec). Pilot and drain lines should be designed for a velocity of 3 to 4.5 m/sec (10 to 15 ft/sec).

d. Piping layout. The piping system should be arranged to permit convenient removal of all valves, pumps, filters, actuators, and associated appurtenances. Shutoff valves should be placed around equipment that might need to be removed from the circuit for service. Piping should be sloped slightly to encourage complete drainage during servicing. Expansion and contraction should be considered in any design with long pipelines, with the inclusion of accumulators and hoses as required.

e. Hydraulic tubing. Hydraulic tubing should have a factor of safety of 6 against the burst pressure. Tubing is specified by outside diameter and wall thickness. Commercially available tubing is clean and easy to bend. Tubing provides easier installation, and fewer fittings are required. Stainless steel and carbon steel tubing is available in welded and seamless versions. Some difficulty has been encountered with the application of tube fittings to tubing above 40 mm (1.5 in.) outside diameter.

f. Hydraulic tube fittings. Fittings should be swaged type or flare type. Bite-type tube fittings should not be used. Non-welded pipe connecting systems have been successfully used to significantly reduce installation time and eliminate hot work. Pressure rating of such systems should be consistent with application design pressures.

4–11. Hydraulic hose

Hydraulic hose should have a factor of safety of 4 against the burst pressure. Hydraulic hose should be used to connect hydraulic components for which relative motion, or thermal expansion, must be accommodated.

a. Hose is specified by inside diameter and type of construction. Hose has three basic parts: the tube, which is the inner liner that carries the fluid; the reinforcement, which is the part that covers the inner liner with woven, braided, wrapped, or spirally wound materials for strength; and the cover, which is the exterior material that protects against abrasion, chemicals, weather, and UV rays.

b. Hydraulic hose should be specified as indicated in SAE J517. Plastic hose is lighter, smaller, and lower in electrical conductivity than synthetic rubber hose. Plastic hose is inert to most chemicals, hydraulic fluids, and ozone. Rubber hose is more resilient and flexible.

4–12. Piping fittings

Most piping system leaks occur at fittings or at the connection of fittings with valves, pumps, manifolds, or actuators. Leaks generally are caused by shock, vibration, thermal expansion/contraction. Or human impact at joints.

a. Piping fittings should match the type of pipe system in use, such as butt welded, socket welded, swaged or flare tube, and swaged or crimped hose. Swivel fittings should be used with hydraulic hose to avoid crimping and adverse bending.

b. Quick-disconnect couplers, which incorporate check valves to shut off flow, can be used for infrequent or emergency connection of equipment to the hydraulic system. Threaded fittings were once common on old locks with low system pressures. Since threaded fittings are prone to leakage, even at very low pressures, they are inappropriate for modern high-pressure hydraulic systems.

4–13. Hydraulic fluid

Hydraulic fluid generally is selected for compatibility with the main hydraulic pumping unit. The operating range of the pump is the primary consideration for system performance. EM 1110-2-1424 and INDC TR 2018-01 both provide extensive discussion of hydraulic fluid and its performance characteristics. Additives are typically rust and oxidation. Anti-wear additives are also sometimes utilized.

a. Most normal operating systems, which experience widely variable temperature and climate conditions, require the use of a petroleum-based fluid with a high viscosity index (VI). The permissible viscosity range varies with different manufacturers and types of pumps.

b. ISO 4406 cleanliness levels should be specified and maintained consistent with the requirements of the components used. Hydraulic fluids are covered in EM 1110-2-1424 and INDC TR 2018-01. The physical characteristics, quality requirements, use of additives, and types of hydraulic fluids are discussed in EM 1110-2-1424. EM 1110-2-1424 and INDC TR 2018-01 also have requirements for environmentally acceptable hydraulic fluids.

4–14. Gauges

All systems should have properly sized pressure and temperature gauges at locations near important system operating equipment such as the pumps, pressure control valves, actuators, and directional control valves. Pressure gauges should be rated for the maximum operating pressure of the system. Gauges with smaller scale ranges generally have higher accuracy. Manual pressure gauges should have minimum intermediate graduations of 0.35 Mpa (50 psi). Pressure gauges are essential for proper troubleshooting of system performance. All pressure gauges should be provided with pressure snubbers to protect against shock. Shutoff valves should be used to isolate the gauges until readings are required. Glycerin-filled pressure gauges are not required unless severe vibration is expected at the gauge location.

4–15. Special design considerations and lessons learned

a. Hydraulic power units. Conventional power units should be in areas that are not accessible to floodwaters. They can be placed in galleries, sealed pits, buildings, or on platforms that are protected from the flood of record, with appropriate freeboard. While submersible power units are available in some smaller sizes, they are a proprietary item. Secondary containment features, such as dams, pits, and piping penetration seals, should be coordinated with the structural design features. Secondary containment monitoring should be coordinated with the electrical control and power supply design.

b. Directional-control valves. Close coordination with the electrical controls designer is necessary when using proportional or servo-valves to provide feedback control.

c. Pressure-control valves. Pressure-control valve settings should be evaluated for the maximum setting that will cause damage to the gate. This could cause an increase in operating time but will prevent frequent damage to expensive repair items. Structural design items may have lower factors of safety than the mechanical equipment. Pressure-relief settings should protect all equipment in the system, including the gate.

d. Pressure transducers and gauge ports. Pressure transducers can be used to report, or record, pressures at key locations in the hydraulic system for troubleshooting purposes. Transducers can report to a PLC or personal computer (PC). Gauges can be used for less sophisticated control systems for which performance evaluations will be done manually. Push-to-read gauge devices permit quick installation of portable gauges.

e. Hydraulic cylinders. Most applications require coordination between the electrical control system and the cylinder design to provide accurate position sensing for the gate operations. The complexity of the position sensing system is dictated by the complexity of the control system. Fully automated operations require sophisticated systems. The actual length of stroke, or orientation of the cylinder, can restrict the type of system that will give accurate indication. See Chapter 5 for more discussion.

f. Cylinder tubes and rods. Guide specifications indicate cylinder tubes should be ASTM A519 Grade 1018 heavy wall seamless tubing. However, cylinder tubes fabricated from one-piece AISI 4340 steel with one-piece ASTM A36 steel trunnions have given satisfactory service for hinged crest gates. ASTM A106 Grade C can also be an option to consider.

(1) The most common problem occurring with hydraulic cylinders has been leakage of hydraulic fluid. This is generally caused by corrosion and scoring of piston rods. For this reason, the material and finish of the piston rods must be matched to the conditions in which the cylinder will be used. Various piston rod coatings have been developed for resistance to corrosion and abrasions. See Chapter 5 for more discussion.

(2) The guide specifications indicate piston rods should be either carbon steel (ASTM A108 Type C 1045 or Type CR 4140) with nickel and hard-chrome plating or stainless steel (ASTM A564/A564M or ASTM A705/A704M, Type 630, or Type XM-12), heat treated to a condition of H-1150 and hard-chrome plated. Cylinders should generally meet ASME Boiler & Pressure Vessel Code, though the specific requirement for U-stamping is generally waived for hydraulic cylinder manufacturers. Other cylinder rod coating systems are discussed in Chapter 5.

g. Pistons. Pistons should be precision fitted to the cylinder body bore. They should be fine-grained cast iron, unless otherwise recommended by the manufacturer for the specific service conditions. Pistons should be designed and equipped with seals and bearing rings as needed. And fabricated from materials as recommended by the contractor.

h. Seals. Dynamic seals should be suitable for frequent and infrequent operation and should be capable of not fewer than 500,000 cycles of operation in properly maintained systems. Cylinder tubes also should have the bore honed to a surface finish compatible with the seals being used to result in zero leakage past the seals. See discussion above on using split seals and metallic seals.

(1) All seals should be of material suitable for use with the hydraulic fluid specified. In the past, it was common for pistons to have only alloy piston rings. This has allowed too much bypass of hydraulic oil around the piston, and standard practice is now for all pistons to be provided with wear bands and seals. In addition to the rod seals, a rod wiper or scraper is usually provided to exclude contaminants from the interior of the cylinder.

(2) For rod seals, there has been success using stacks of the Chevron® style. These are supplied as continuous rings but, to facilitate changing the seals without disconnecting the rod, each ring has been split and installed with each split staggered. Doing this has shown that cylinders experienced no increase in leakage or decrease in service life.

(3) A recurring issue has been the compatibility of rod seals with the surface finish of hydraulic cylinder rods. This is particularly true of rehabilitated cylinder rods for which the shop has the capability to finish the resurfaced rods with a highly polished finish, but they are not as experienced with large cylinders and slow-moving applications typical of navigation locks. The rod seals can function too efficiently if the rod is too smooth, causing stick-slip due to high friction from the complete removal of the oil film on the cylinder rod.

(4) Many seal manufacturers claim an optimal range of 3 to 12 µin Ra, but, when questioned, will express a preference to stay to the upper end of that range. Above the manufacturer’s stated acceptable range, accelerated seal wear and leakage become a concern.

i. Piping. Piping should be pitched a minimum of 1/2 in. per 50 ft to provide high and low points, and accumulator tanks should be used in systems with long lines to minimize the effect of hydraulic surge.

j. Air bleeds and drains. To facilitate complete filling of the system, air bleed valves should be installed at all high points where air can be trapped. To facilitate draining of the system for maintenance, drain valves must be installed at all low points so that a particular section can be isolated and drained, and the complete system can be drained if required.

k. Design, coordination, testing, and commissioning. The hydraulic system supplier should verify the design by providing detailed computations and shop drawings for review and approval. To avoid compatibility issues between the hydraulic and control systems, one supplier should be responsible for providing both the hydraulic components and the control components as an integrated system. When possible, integrated shop tests should be conducted to pretest the hydraulic and control systems and provide initial component settings before shipment. Field tests and commissioning must be conducted to verify proper operation and document final field settings for all pumps, valves, and control components in the system.

l. Guarantees. Although an exception to DoD policy, designers of some installations have specified guarantee periods greater than one year. In some cases, the guarantee period for hydraulic cylinder parts other than the rods have been specified as two years from date of acceptance, and the hydraulic cylinder piston rod’s guarantee period has been specified as five years from date of acceptance. The warranty should be against defective materials, design, chrome plating or ceramic coating of the rod, and workmanship.

m. Supply contracts. Hydraulic systems are often a small part of a larger lock construction project. When advantageous, providing the hydraulic system using a supply contract should be considered. The design must be based on the conditions under which components will operate. The designer must consider, however, both the advantages and disadvantages of a supply contract.

n. Spare cylinders and parts. Spare hydraulic cylinders often are specified due to the long lead time for obtaining a replacement if damaged. If spare cylinders are specified, they must be stored and maintained properly.

(1) Some manufacturers recommend their cylinders should be stored vertically with the rod up, but this is impractical for large cylinders. Modern materials for bearings and seals have greatly reduced the seal compression problems associated with long-term horizontal storage of large cylinders.

(2) However, most manufacturers still recommend that stored cylinders should be protected from the elements and fitted with accumulators or standpipes to ensure they are completely filled with oil. Provisions for periodically exercising stored cylinders also are recommended. Exercising usually requires extending and retracting the rod a few inches periodically to prevent the seals from sticking. Spares also should be considered for other hydraulic system components such as control valves, protection valves, hydraulic pumps, motors, etc.

o. Contamination control during construction. Protecting the hydraulic system from contamination during assembly must be adequately addressed during the construction phase to prevent problems, as they are difficult to correct in the field. Manifolds must be completely cleaned before installing on the HPU. Modern proportional valves have stringent oil cleanliness requirements, and contamination can wreak havoc on a hydraulic system. Therefore, quality assurance and control personnel must be fully trained in the importance of contamination control and those requirements must be written into the contract specifications.

p. Other important design considerations. Facilitating ease of maintenance should be a primary consideration. This includes designing for quick and easy component replacement and, where possible, changing parts, including hydraulic cylinders.

(1) Also, designing for simplicity not only minimizes the potential failure points in the system but also minimizes the maintenance effort in the long term. The designer should make all attempts to minimize the number of components that will be susceptible to corrosion when subjected to the elements.

(2) Exposed manifolds can be fabricated from corrosion-resistant materials, but often valve bodies are carbon steel. They can be painted, but often corrode in a short time. Covering these components to protect them from the elements is often the best solution, not only for corrosion control but also for protecting electronic components from moisture. Finally, the designer should design the system for robustness and extreme weather/flood conditions.

Chapter 5
Hydraulic Cylinder Coating and Measuring Systems

5–1. General discussion

This chapter provides design guidance on hydraulic cylinder rod coating systems and measuring systems. The proper cylinder rod coating system is critical for long-term viability of the cylinder rod. Modern hydraulic and control systems have also necessitated the accurate feedback of gate or valve position.

5–2. Hydraulic cylinder rod coating systems

The designer should use the latest guide specification for hydraulic power systems UFGS 35 05 40.14 10 during design. Several coating systems are available in today's market and are discussed in this chapter.

a. Surface coating of cylinder rods is used extensively today. Coatings are applied to hydraulic cylinder rods generally for corrosion protection, wear resistance, and to provide a scratch and impact-resistant surface for the seals. The designer should use ISO 9223 to determine the corrosion category for the cylinder rod. This is also defined in UFGS 35 05 40.14 10.

b. Starting in the mid to late 1990s, there was a significant initiative to use ceramic oxide coatings over a carbon steel substrate for hydraulic cylinder rods within USACE and in European waterways. These ceramic coating systems also went by the name CERAMAX™ from the manufacturer Bosch Rexroth. Superior corrosion and wear resistance of the ceramic coatings was marketed as the primary advantage as compared to the more traditional coatings of chrome or nickel chrome.

c. Also, using the coating on a carbon steel rod allowed the use of a magneto-resistive position sensing system that is integral with the rod. Over time, however, piston rods subject to intermittent use and exposure to the weather allowed the evaporation of the protective oil from the pores of the coating, which led to some failures. Many of these failures were on gates operated infrequently or subject to impact damage from debris.

d. Subsequent generations of the coatings have improved on this initial design and now incorporate a metal matrix and are applied with the high velocity oxygen fuel (HVOF) process. These newer coating systems are discussed below and offer improved resistance to corrosion and higher impact and wear resistance.

e. Ceramic-coated rods are no longer allowed in USACE due to corrosion failures at several locks caused by the inherent porosity of ceramics, detailed in the ECB 2009-3. This includes Winfield Dam (tainter gates), Olmsted Lock (miter gates), and Braddock Dam (tainter gates).

f. There are sites where the ceramic coated CERAMAX™ rods have worked well. In these cases, the cylinder rods are exercised on a regular basis and the rods are lubricated regularly. This allows sealing the pores in the ceramic coating and limits the entrance of moisture by applying a thin coating of hydraulic fluid to the rod's surface. This is the case for the main lock at Chittenden and the Welland Canal Locks shown in Figure 5–1. The locks at Chittenden are among the most used in USACE and the ceramic coated rods have worked well in this application.

Figure 5–1. Miter gate ceramic-coated cylinder rod at Chittenden Lock, Seattle, and Welland Canal

g. The designer is cautioned against using chrome-plated cylinder rods in any saltwater or brackish water applications. This could be the case for a hydraulic cylinder operating a culvert valve with the lock exposed to salt water. The presence of wet and dry cycling in a chloride-containing environment may cause plating degradation.

h. The designer must coordinate with the cylinder manufacturer when selecting the rod base material and final coating system to verify there are no dissimilar metal corrosion issues. Coating failure because of electric potential difference could occur where either the piston rod or the coating acts as sacrificial anode. Selecting the hydraulic fluid also must be coordinated with the rod base material to ensure compatibility.

5–3. Hydraulic cylinder rod coating alternatives

The following coating alternatives were investigated as part of the Folsom Dam Cylinder Replacement project and detailed in a separate technical evaluation report (TER CS-3108). The cylinder rod coating alternatives were chosen to represent the standard offerings of cylinder rod types based on the market research performed. The TER CS-3108 report findings are incorporated and summarized in this manual.

a. Overview. These alternatives are not intended to represent an exact coating and material system offered by one manufacturer. Rather, the intent is to note the range of manufacturer products that the government could receive, considering the limitations of the Federal Government procurement restrictions. Specification requirements for coatings need to be general enough so that multiple manufacturers can meet the requirements.

b. Alternative 1: Hard chrome. Chrome-plated cylinder rods are the most common in USACE and have been used for decades. This is shown in Figure 5–2. The Lower St. Anthony Falls (LSAF) Lock in Figure 5–2 has been in service for over 50 years. Chrome-plated cylinder rods have demonstrated very good corrosion resistance and performance on lock gate, culvert valve, and spillway gate hoist cylinders, except in brackish or salt water applications. Spillway gate hoist cylinders are the most demanding in that the cylinder rods are extended for very long periods of time. The chrome-plated cylinder rods at Olmsted Dam are shown in Figure 5–3.

Figure 5–2. Lower St. Anthony Falls Lock hydraulic cylinder for miter gate

Figure 5–3. Olmsted Dam hydraulic, cylinder-operated tainter gates

(1) One issue today with chrome-plated cylinder rods are environmental concerns with the plating process. This has led to restrictions, especially in European markets, on the use of chrome plating. Chrome plating shops may also be difficult to find in the future because of environmental concerns. The chrome plating over stainless steel is covered in ASTM B254.

(2) The chrome-plating system assumes a stainless steel rod base material per ASTM A564 or ASTM A705, Type 630 (DIN 1.4542) or Type XM-12 with an electroplated hard chrome. Chrome plating thickness should be 0.003 in. to 0.005 in. thickness (76 micrometers to 127 micrometers thickness). Note that the specifications should clearly define the minimum and maximum allowable thickness range and not a range for an average thickness.

(3) Corrosion resistance of the stainless steel is good (with the exception of salt water), while the plating provides a smooth hard surface for sealing and exhibits good wear properties. The designer must not utilize chrome plating systems in any salt water or brackish water applications. Stainless steel alloys such as the precipitation hardening 17-4ph or Type 630 have provided high strength and good corrosion resistance in a relatively wide range of stock sizes. The surface roughness Ra of the finished cylinder rod is, on average, 0.2 μm.

(4) Alternatively, an alloy steel base material could be used (such as AISI 4140 or 4130) with a laser cladding made from ferrous-based stainless steel (such as Hunger Hydraulics' Chrome Plus™, Bosch-Rexroth Hard Chrome™, Parker-Hannifin Hard Chrome™).

(5) Position-sensing systems for chrome-plated rods require magneto-strictive, absolute, non-contact, linear-position sensors discussed below. Alternatively, a separate position-sensing system from the cylinder rod can be provided. This could include limit switches, encoders, etc. An example of this on the Soo Locks is discussed further below.

c. Alternative 2: Thermal spray over carbon steel (smooth). This alternative assumes an alloy steel base material (such as AISI 4140 of 4130) with a single high hardness (~1,000 Vickers) and a thermal-spray layer (such as chromium oxide or titanium oxide). The thermal-spray method varies by manufacturer but includes HVOF and plasma spray.

(1) This alternative assumes no position indication grooves are cut into the rod base material.

(2) An absolute rod positioning indication system such as the magneto-strictive is required. Alternatively, a separate gate limit switch or encoder can be provided.

(3) The designer should evaluate need for a sealer applied to prevent corrosion of the base rod material.

(4) The designer could also use a stainless steel base material for any applications that have significant corrosion concerns. This needs to be coordinated with the hydraulic cylinder manufacturer.

d. Alternative 3: Thermal spray over carbon steel (grooved). Same as Alternative 2 except that position grooves are used using a magneto-resistive system discussed further below. This alternative assumes an alloy steel base material (such as AISI 4140 of 4130) with a single high hardness (~1,000 Vickers) thermal-spray layer including HVOF. It assumes that position indication grooves are cut into the cylinder rod base material.

e. Alternative 4: Thermal spray over laser-clad, corrosion-resistant, barrier layer (grooved). This alternative assumes an alloy steel base material (such as AISI 4140 of 4130) with a laser-clad, non-porous barrier layer such as nickel or cobalt that prevents corrosion, followed by thermal spray such as HVOF. Even without a sealer on the thermal-spray topcoat, corrosion should not be a concern in most applications. However, the designer needs to investigate this for the specific application. The alternative assumes a base layer with a high hardness (1,000 Vickers). It assumes position indication grooves are used.

f. Alternative 5: Laser cladding/weld overlay over carbon steel or stainless steel (grooved). This alternative assumes an alloy steel base material (such as AISI 4140 of 4130). It assumes that position indication grooves are cut into the rod base material. It also assumes a corrosion-resistant alloy, laser-clad top layer that is impermeable (typically a cobalt-based, nickel-based, or stainless steel-based, cladding).

g. Alternative 6: Laser cladding/weld overlay over carbon steel or stainless steel (smooth). Assumes an alloy steel base material (such as AISI 4140 of 4130). Assumes no position indication grooves are cut into the rod base material (smooth). Assumes an absolute rod positioning indication system will be installed. Assumes a corrosion-resistant alloy, laser-clad top layer that is impermeable (typically a cobalt-based, nickel-based, or stainless steel-based, cladding).

5–4. Hydraulic cylinder rod coating evaluation factors

The following evaluation factors are considered the most important criteria and constraints for cylinder rod selection. Evaluation factors focus on how likely the rod coating system will perform successfully for a minimum 30-year service life under the specific operating conditions. The descriptions of these factors are provided below.

a. Corrosion resistance. How well the rod and coating system will perform with exposure to all weather conditions, water splash, water immersion, and bird excrement.

(1) Evaluation should account for the long durations of rod exposure between gate operations that would cause the hydraulic fluid film left on the rod to wash away and not provide corrosion protection.

(2) Evaluation should be supported with performance history from other installations and by manufacturer’s recommendations.

(3) Consideration should be given for rods and coatings that are the most corrosion resistant and have a strong history of successful performance.

(4) Low consideration should be given for rods/coatings with low corrosion resistance or for materials that do not have a proven history of successful performance.

b. Bending capacity. How well the rod and coating system complies with self-weight bending experienced in specific applications as well as additional bending under full closure, binding, and during installation.

(1) High consideration should be given for rods/coatings that are ductile and can resist cracking under self-weight bending loads.

(2) Low consideration should be given for rods/coatings that are brittle and have a high likelihood of cracking under self-weight bending loads.

c. Durability. How well the rod and coating system performs in the types of conditions that will be experienced in the specific application. This includes high UV light exposure. Some considerations include the following:

(1) If a retrofit application, ensure compatibility with the existing hydraulic fluid, including seals.

(2) If a new application, ensure coordination on selecting hydraulic fluid with manufacturer.

(3) Evaluate whether long periods between gate operations may cause hydraulic fluid films to wash off cylinder rod (dry operation past cylinder seals).

(4) Evaluate possible exposure to localized impact damage.

(5) Evaluation should be supported with performance history from other installations or by manufacturer's recommendations.

d. Maintainability. How well the cylinder rod/coating will accommodate maintenance over a 30-year service life. Specifically, this is an evaluation of:

(1) How repairable the rod will be in service damage that may be suffered (such as small impact-damaged areas)?

(2) How easily can the seals be replaced?

(3) How likely is a particular rod/coating to have other significant maintenance costs?

(4) High consideration should be given for rods/coatings that have lower overall maintenance requirements.

e. Life cycle cost. To evaluate this factor, a life cycle cost estimate should be created for each cylinder rod coating alternative. The major cost items for consideration include:

(1) *Piston rod cost*. Include estimated material costs for the different rod types.

(2) *Position system labor and material cost*. Includes material cost and installation cost for the position-indication devices. Includes costs to commission the position-indication system.

(3) *Rod end seal replacement cost*. Includes labor costs to perform seal replacements, assuming that the rod end seals would not last a full 30-year life cycle.

5–5. Alternative 1: Hard-chrome plating

The hard-chrome plating system is the most common in USACE. The hydraulic cylinder shown in Figure 5–4 for the Soo Locks has been in service for over 40 years. Chrome-plated cylinder rods have been used in a multitude of applications across USACE. The most significant concern is the availability of chrome plating in the future.

a. Corrosion resistance: Excellent in most applications. Exposure to salt water and brackish water can damage and degrade the chrome surface. The use of chrome plated cylinder rods must be avoided in brackish or saltwater applications.

b. Bending resistance: The stainless steel rod base material for this alternative will act in a ductile manner under bending loads. However, the hard chrome plating is brittle and could be susceptible to cracking under bending loads.

c. Durability: Hard chrome has been used in many industrial applications and lock and dam applications and has a proven performance history. Chrome is not as wear resistant as other rod coatings, however. Due to brittleness, hard chrome is susceptible to impact damage.

d. Maintainability: In-place repairs are possible for hard chrome, however, the repair method can be difficult and expensive.

Figure 5–4. Hydraulic cylinder for Soo Locks Poe Lock miter gate

5–6. Alternative 2: Thermal spray over carbon steel (smooth)

a. Corrosion resistance: Thermal sprays are inherently porous because of the HVOF application process. This alternative assumes a carbon steel rod base material, however, a stainless steel base material could also be used. The carbon steel base material is susceptible to corrosion without a sealer. Documented cases of similar corrosion issues with thermal spray-coated rods are discussed in ECB 2009-3. A porous thermal spray, without a sealer, and without corrosion protection from a film of hydraulic fluid, would provide low corrosion resistance and may require manual lubrication (more frequently than the cylinder would be cycled) to prevent corrosion.

b. Bending resistance: Thermal sprays are brittle and are susceptible to cracking from bending.

c. Durability: The thermal-spray coatings are brittle, which makes them susceptible to impact damage.

d. Maintainability: Manufacturers offer field repair options. However, the repair options are typically epoxy patches that do not match the mechanical properties of the thermal-spray coating. The long-term durability of these types of patches, especially after the rod experiences thermal and bending cycles, may be an issue. In addition, the thermal-spray coatings are porous and are susceptible to corrosion, which creates the possible need to manually lubricate the rods.

5–7. Alternative 3: Thermal spray over carbon steel (grooved)

a. Corrosion resistance: Similar to Alternative 2, this alternative assumes a carbon steel rod base material. This carbon steel base material is susceptible to corrosion without a sealer due to the inherent porosity of the thermal-spray rod coating. It was estimated that a porous thermal spray would provide moderate corrosion resistance and may require manual lubrication (more frequently than the cylinder would be cycled) to prevent corrosion.

b. Bending resistance: Unlike Alternative 2, this alternative assumes a grooved rod profile, which creates additional stress concentrations that the rod coating must be able to accommodate. The grooved rod profile creates more potential for cracking.

c. Durability: Again, the thermal-spray coatings are brittle, which makes them susceptible to impact damage.

d. Maintainability: The long-term durability of available field repair options may be an issue. In addition, thermal-spray coatings are susceptible to corrosion, which creates the likely need to manually lubricate the rods.

5–8. Alternative 4: Thermal spray over laser-clad barrier layer (grooved)

a. Corrosion resistance: Assumes a carbon steel rod material with a laser-clad, non-porous, barrier layer that prevents corrosion. However, a stainless steel base material could also be used. Added corrosion protection provided by the laser-clad barrier layer compared to other thermal-spray alternatives.

b. Bending resistance: Assumes that rod position grooves are machined into the laser-clad barrier layer with a thermal spray applied over top. Preference is given to overlay material systems that are soft and ductile. The material system must not form any cracks following welding and during normal piston rod operation. The laser-clad layer should be resilient against bending. However, the thermal-spray top layer will still have brittle behavior. In addition, the rod grooves added stress concentrations, which increased the likelihood of cracking from bending.

c. Durability: The improved corrosion resistance of the added laser-clad base layer improves the durability by giving less potential for failure of the thermal-spray coating.

d. Maintainability: The added laser-clad barrier layer prevents the need to manually lubricate, which reduces the maintenance burden. However, the thermal spray topcoat is still susceptible to impact damage that is difficult or impossible to field repair.

5–9. Alternative 5: Laser cladding/weld overlay over carbon steel (grooved)

a. Corrosion resistance: Laser cladding used as an outer layer is designed specifically for corrosion resistance in harsh environments such as offshore applications that require the highest level of corrosion resistance (corrosivity category CX per ISO 9223). Laser cladding should be utilized in any salt water and brackish water applications. Laser cladding is likely the direction for cylinder coatings in the future.

b. Bending resistance: Laser cladding is the most ductile of all the rod/coating options, according to cylinder manufacturers. Preference should be given to overlay material systems that are soft and ductile. Assume rod grooves are cut into the carbon steel rod base material, which may have a slight reduction in bending resistance (added stress concentrations).

c. Durability: Cylinder manufacturers indicate that the laser cladding is resistant to impact damage. In addition, the metal cladding material is naturally non-porous, and therefore, does not rely on sealer/penetrant or hydraulic fluid, which are susceptible to UV degradation, to fill porosity to maximize corrosion resistance.

d. Maintainability: Cylinder manufacturers indicate that maintenance is simple with a laser-clad rod coating. Specifically, a laser-clad coating does not require manual lubrication to maintain corrosion resistance. Laser cladding has good field repair (weld repair) options if localized impact damage occurs.

5–10. Alternative 6: Laser cladding/weld overlay over carbon steel (smooth)

a. Corrosion resistance: Manufacturers indicate that the laser cladding used as an outer layer was designed specifically for corrosion resistance in harsh environments (developed for offshore applications with a CX (Extreme) corrosivity category rating). Again, the laser cladding system should be utilized in salt water or brackish water applications.

b. Bending resistance: Cylinder manufacturers indicate that the laser cladding is the most ductile of all the rod/coating options. Assume rod grooves are cut into the carbon steel rod base material, which gives it very good bending resistance.

c. Durability: Manufacturers indicate that the laser cladding is resistant to impact damage. In addition, the metal cladding material is naturally non-porous, and therefore, does not rely on sealer/penetrant or hydraulic fluid, which are susceptible to UV degradation, to fill porosity to maximize corrosion resistance.

d. Maintainability: Cylinder manufacturers indicate that maintenance is simple with a laser-clad rod coating. Specifically, a laser-clad coating does not require manual lubrication to maintain corrosion resistance. Laser cladding has good field repair (weld repair) options if localized impact damage occurs.

5–11. Position-measuring systems

Systems integrated into the cylinder are the most popular and require little or no design effort for external mechanisms or linkages. They also offer the advantage of being included with the cylinder as a turnkey product. Integrated systems include the magneto-resistive systems and magneto-strictive systems that require the rod to be drilled from the piston end for a sensor rod.

a. Magneto-resistive systems. Magneto-resistive systems are available from all the primary hydraulic cylinder manufacturers and are available with different rod coating systems. They require that grooves be cut into the rod base material as shown in Figure 5–5.

(1) Limitations include the fact that the system does not provide an absolute indication of position or, in the case of power supply failure, can lose track of its position and require reset. The various types of magneto-resistive systems are discussed further below.

(2) Specially engineered grooves underneath the piston rod coating cause a variation in the magnetic field from a permanent magnet inside a Hall-effect sensor.

(3) The various magneto-resistive systems discussed below include brand name descriptions. This is not intended as an endorsement of any system. Rather, it provides the designer an overview of the primary systems currently in use.

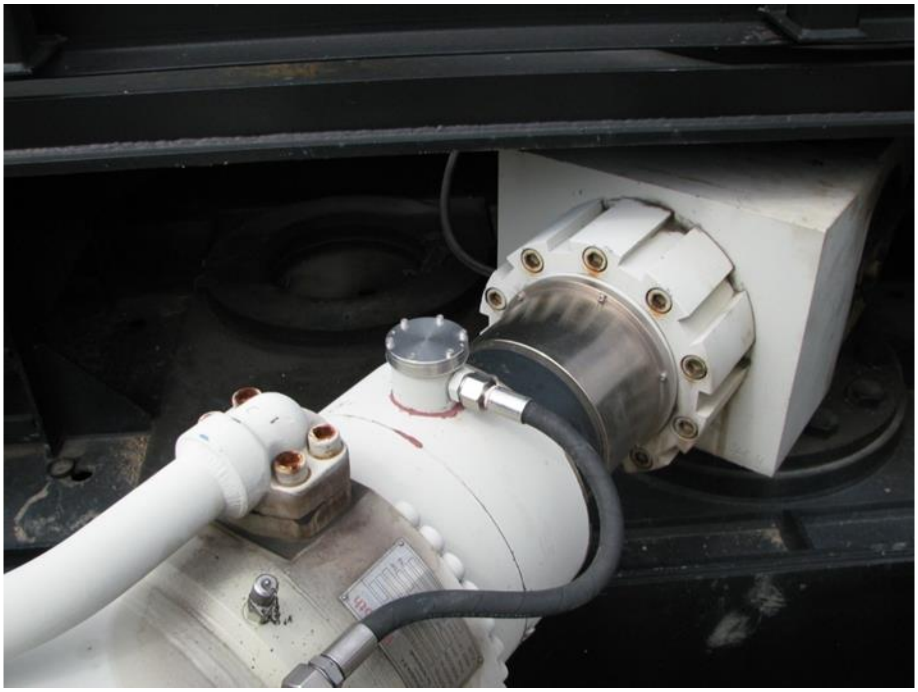


Figure 5–5. Magneto-resistive position sensor on rod end gland

b. Magneto-strictive systems. Magneto-strictive systems or linear displacement transducers (LDTs) provide an absolute indication of position but are limited to a maximum stroke of approximately 25 ft (7.6 m) because of the length of unsupported rod in the cylinder when extended. However, flexible magneto-strictive systems are also available on the market and could be utilized in some applications.

(1) Magneto-strictive systems require that the piston rod be bored for installation of the transducer. This typically has a small effect on the buckling strength of the rod and should be calculated.

(2) Within the sensing element, a sonic-strain pulse is induced in a specially designed magneto-strictive waveguide by the momentary interaction of two magnetic fields. One field comes from a moveable permanent magnet that passes along the outside of the sensor. The other field comes from an “interrogation” current pulse applied along the waveguide. The resulting strain pulse travels at sonic speed along the waveguide and is detected at the head of the sensing element.

c. Alternatives. Alternatives to integral-position sensors include retrofitting the hydraulic cylinder to externally drive either a rotary encoder or LDT, driving a rotary encoder or LDT directly from the gate or valve through an external linkage, or installing a moving target to trip multiple proximity sensors.

(1) Maintenance of external systems is independent of the hydraulic cylinders, possibly allowing a simpler and faster repair and a greater likelihood of the gate or valve remaining in service while repairs are being made.

(2) Examples of external systems at the Soo Locks are shown in Figure 5–6 and Figure 5–7. This system uses a drive shaft connected to the miter gate that, in turn, drives an encoder. Regardless of system type, moisture ingress issues should be mitigated with appropriate sealing precautions and care in placing junction boxes above anticipated flood elevations.

Figure 5–6. Soo Locks miter gate drive train for external position indication

Figure 5–7. Soo Locks miter gate encoder

5–12. String potentiometer (string pot) (absolute – smooth rod)

Since there are many different types and models of the string pot sensors, the Celesco™ model PT9420 is highlighted here for designer reference only. The designer must compare and evaluate all the different types on the market. The string pot has the resolution to measure and capture the change in rod position displacement.

a. Cable extension position transducer specifications (typical):

(1) Full stroke range options.

(2) Output signal options: 4 to 20 mA (2-wire) and 0 to 20 mA (3-wire).

(3) Accuracy ± 0.12% full stroke.

(4) Repeatability ± 0.05% full stroke.

(5) Resolution is essentially infinite.

(6) Measuring cable options, nylon-coated stainless steel or thermoplastic.

(7) Enclosure material powder-painted aluminum or 303 stainless steel.

(8) Sensor (plastic-hybrid precision potentiometer).

(9) Potentiometer cycle life 250,000, minutes before signal degradation occurs.

b. Electrical specifications:

(1) Input voltage typically 24 VDC (see ordering information).

(2) Input current 20 mA max.

(3) Circuit protection, 38 mA max.

(4) Impedance 100M ohms @ 100 VDC, min.

(5) Output signal adjustment.

(6) Zero adjustment from factory set zero to 50% of full stroke range.

(7) Span adjustment to 50% of factory set span.

c. Advantages:

(1) Absolute sensor, which will retain the data when losing power.

(2) Very accurate and has the resolution to detect miniscule change in rod position.

(3) Works in a variety of harsh conditions.

d. Disadvantages:

(1) Not easily accessible (if mounted inside rod cavity) for maintenance, repair, or replace purposes.

(2) Cable can stretch or break.

(3) Moving parts.

5–13. Acuity™ AR1000 laser distance sensor (absolute – smooth rod)

The AR1000 is a time-of-flight sensor that measures distance by a rapidly modulated and collimated laser beam that creates a spot on a target surface. Information is provided here for reference only for the designer. These laser sensors have been used in a multitude of industrial applications including cranes, drill rigs, and pipelines. They are not used currently in any USACE applications for hydraulic cylinder positioning.

a. Components. Components of the reflected light signal are collected by a lens and focused onto a photodiode within the sensor unit. The reflected light returns with a shift in phase compared with the reference signal.

b. Distance. From the amount of phase shift, a required distance is calculated with millimeter accuracy. The distance is transmitted through serial communications or analog outputs. Maximum ranges exceed 100 ft (30.48 m) with the optional use of reflectors. The AR1000H model has an automatic internal heater for sensor operation to -40 °F (-40 °C).

c. Features:

(1) Span – 4 in. (101 mm) min to 100 ft (30.48 m) max (targets of 85% diffuse reflectance) 500 ft (152.4 m) max (retroreflective targets).

(2) Output signal options: 4 ... 20 mA (2-wire) and 0 ... 20 mA (3-wire).

(3) Accuracy ± 0.12 in (3 mm).

(4) Repeatability >± 0.02 in (0.5 mm).

(5) Resolution is essentially infinite,

(6) Laser type 650 nm, 1 megawatt (MW) visible Red.

(7) Power 10 – 30 VDC, 50 – 150 mA draw (AR1000H 24W at 24 VDC with heater).

(8) Sampling rates 50 Hz maximum or sample trigger (serial command and analog).

(9) Operating temp 14 to 122 °F, -40 to 122 °F (AR1000H with internal heater).

(10) Environmental NEMA – 4, ingress protection rating 65 (IP65).

(11) Output serial RS232 full duplex, RS422 (optional) unterminated and terminated, analog 4 to 20 mA.

d. Advantages:

(1) No moving parts.

(2) Very accurate and has the resolution to detect miniscule change in rod position.

(3) External mounting, easy access for maintenance, repair, and replacement.

e. Disadvantages. Disadvantages include an unknown design concept for USACE. May require extensive testing and qualification in a simulation lab environment before real-life environment during commissioning testing phase.

5–14. HYPOS™ sensor (incremental – grooved rod), magneto-resistive

The position system is controlled by the HYPOS sensor system, which uses electronic pulse counting to determine position. The HYPOS sensor is widely used by many cylinder manufacturers and is installed in multiple applications. The designer should also investigate any other alternative sensors as they become available on the market.

a. Key features:

(1) Contactless measurement of linear or rotational movements.

(2) One or two channels.

(3) Magnetic measurement principle.

b. Other features:

(1) Can be used under very harsh conditions.

(2) Resolution = 0.16 in. (4 mm).

(3) Registers speed between 0 Hz and a maximum of 25 kHz.

(4) Large measuring distance (air gap) of up to 3 mm (depending on the gear module or the pitch of the target).

(5) Very precise duty and phase shift of the output signals.

(6) Stainless steel housing.

(7) Very high protection class ingress protection rating 68 (IP68).

(8) Wide temperature range from -40 °C (-40 °F) to +85 °C (185 °F).

c. Electrical signal outputs:

(1) Supply power 24 VDC.

(2) RS-422 output data protocol.

d. Processing rod position signals. Signals are generated based on the profile of the engraved grooves as shown below in Figure 5–8 (all measurements in millimeters).

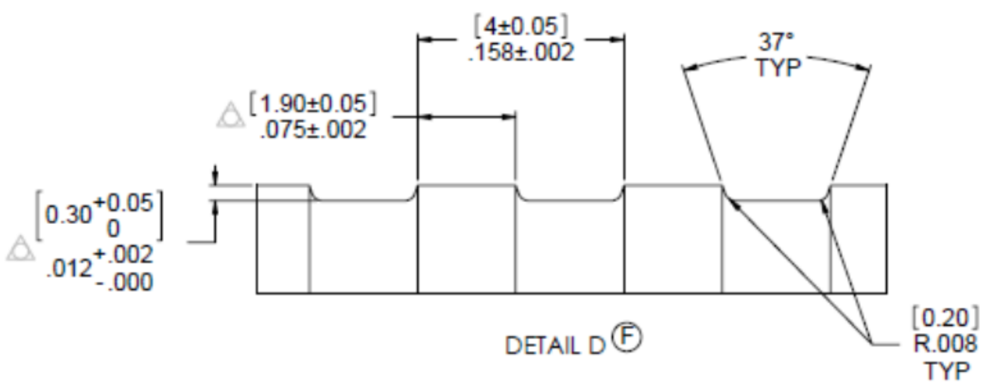


Figure 5–8. Groove detail

e. Programmable automation controller processor. These signals are fed to the PLC. The input module is part of the programmable automation controller (PAC) system to resolve two axes of rotating position information from quadrature encoder devices. The module outputs a pulse to the PAC processor at each change in quadrature state. The processor counts the module output pulses and tracks the direction and position.

f. Monitoring. Under software control, the PLC continuously monitors the position displacement of the two rods and scales the signals to generate the appropriate output voltages ranging from 0–10 VDC.

(1) These signals are then fed to the proportional valve driver cards to drive the HPU proportional valve system, a very critical circuitry to maintain the leveling and synchronization of the cylinder rods.

(2) The software implements the proportional integral derivative (PID) control feedback loop algorithm to provide the stability of two rods leveling and synchronization. This is a very complex process requiring both hardware and software working in unison to provide a working and stable system.

5–15. Cylinder Integrated Measuring System (incremental – grooved rod)

The Cylinder Integrated Measuring System™ (CIMS) is an integrated displacement measuring system for use on hydraulic cylinders with an *Enduroq 2000* series piston rod coating or the previous capillary electrochromatography (CEC) coatings. It was developed by Rexroth and is trademarked.

a. Overview. Grooves underneath the piston rod coating cause a variation in the magnetic field from the permanent magnet inside the *CIMS*. The *CIMS* Hall-effect sensor elements measure the magnetic field and its variations. Their signals are fed into a micro-controller, which calculates the position inside the groove and generates the incremental RS422 output signal. The sensor and electronics are protected by a stainless steel housing, which can be installed into the head of the cylinder.

b. Features:

(1) Contactless operation; no contact between sensor and cylinder rod; no-wear parts; no-slide pad; no-rod diameter, depending on components; and a completely closed housing.

(2) Easy commissioning/easy installation: plug and play; no (manual) calibration necessary; CIMS will automatically compensate for mounting tolerances, magnetic disturbances, and temperature effects.

(3) Status CIMS can be monitored. Simplified failure analysis possible: diagnostic output, through a PC or PLC, can be retrieved for sensor status, error codes, and sensor identification.

c. Specifications. Electrical specifications include a supply power 24 VDC and RS-422 output data format protocol.

d. Concept advantages:

(1) Well-proven design concept.

(2) External mounting on cylinder head. Sensor is easily accessible for maintenance, repair, or replacement purposes.

(3) Accurate and reliable.

(4) No moving parts.

5–16. Hunger™ (incremental – grooved rod)

Hunger™ has developed a sensing system used by many cylinder manufacturers. Hydraulic cylinders with *CERAPLATE™* coating can be equipped with the incremental transducer system *CIPS* (CERAPLATE with integrated positioning system). Grooves are placed under the rod coating system. Again, the designer should investigate these systems as they get further developed and new systems come into the market.

a. Sensor outputs. One sensor with two integrated sensor elements (displace by 90°) detect the direction of the movement and count the grooves under the coating. The sensor elements work according to the Hall effect and provide rectangular output signals, which are processed by the consecutive electronic pulses. A phase discriminator quadruples the pulses and thereby provides a four times higher density in comparison to the width of the grooves on the piston rod.

b. General specifications:

(1) Groove width and spacing: 2 mm/2 mm.

(2) Layer thickness: 300 µ m (over grid).

(3) Surface finish Ra: < 0,1 µm.

(4) Surface hardness: 950 HV.

(5) Gap between sensor and layer: 0.4 mm.

(6) Phase displacement of sensors: 1 mm (90°).

(7) Density of measuring system: 1 mm.

(8) Max. output frequency: 25 kHz.

(9) Max. measuring length: 20 m.

(10) Max. piston rod diameter: 1 m.

(11) Max. piston rod weight: 15 tons.

(12) Supply power 24 VDC.

(13) RS-422 quadrature output data format protocol.

c. Concept advantages:

(1) Well-proven design concept.

(2) External mounting on cylinder head. Sensor easily accessible for maintenance, repair or replace purposes.

(3) Accurate and reliable.

(4) No moving parts.

(5) Retaining existing cable hardness infrastructures.

5–17. Magneto-strictive, non-contact, linear-position sensors (absolute – smooth rod)

Temposonics® linear-position sensors are the largest supplier of this system. A piston rod is bored into the cylinder for installation of the transducer. The design utilizes time-based magneto-strictive position sensing principle developed by the Materials Tests Systems company. The culvert valve at Chittenden Lock uses this system and is shown in Figure 5–9. Flexible systems from *Temposonics®* are also available.

a. Sonic-strain pulse. Within the sensing element, a sonic-strain pulse is induced in a specially designed magneto-strictive waveguide by the momentary interaction of two magnetic fields. One field comes from a moveable, permanent magnet that passes along the outside of the sensor. The other field comes from an “interrogation” current pulse applied along the waveguide. The resulting strain pulse travels at sonic speed along the waveguide and is detected at the head of the sensing element.

b. Positioning. The position of the magnet is determined with high precision and speed by accurately measuring the elapsed time between the application of the interrogation pulse and the arrival of the resulting strain pulse with a high-speed counter. The elapsed time measurement is directly proportional to the position of the permanent magnet and is an absolute value. Therefore, the sensor’s output signal corresponds to absolute position instead of incremental, and never requires recalibration or rehoming after a power loss. Absolute, non-contact sensing eliminates wear and guarantees the best durability and output repeatability.

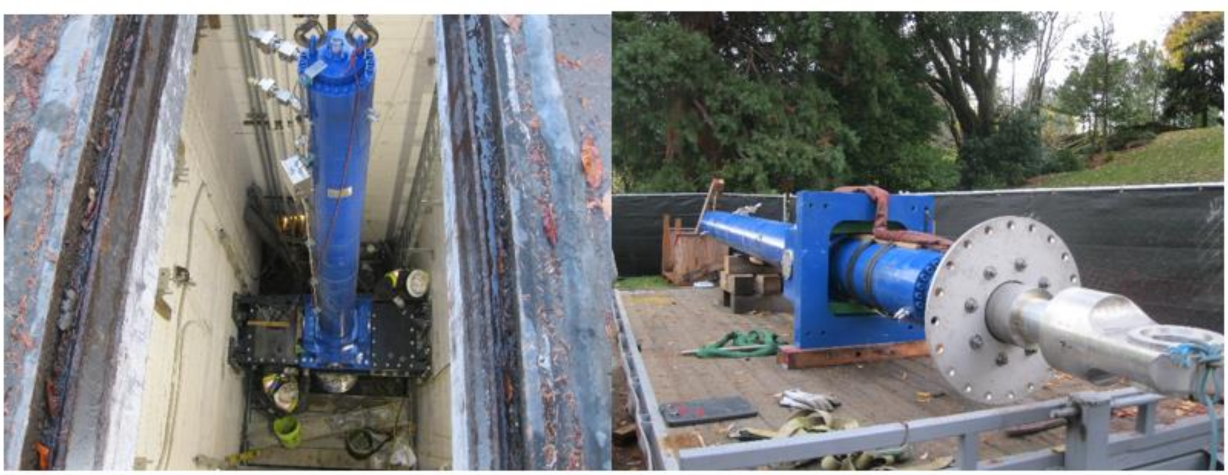


Figure 5–9. Chittenden Lock culvert valve cylinder

c. Features:

(1) Linear, absolute measurement.

(2) LEDs for sensor diagnostics.

(3) Non-contact sensing technology.

(4) Linearity deviation less than 0.01%.

(5) Repeatability within 0.001%.

(6) Direct 24/25/26-bit Synchronous Serial Interface (SSI) output, gray/binary formats.

(7) Synchronous measurement for accurate velocity/acceleration calculations.

(8) Superior accuracy.

(9) Rugged industrial sensor.

(10) High-speed update options.

(11) Linearity correction options.

(12) Velocity output option.

d. Resolution. The resolution of the magneto-strictive system is like the string pot resolution. This assumes the magneto-strictive option selected is a 4-20 mA unit, therefore, the resolution will be (0.027 in./microA) x (0.8microA) = 0.021 in. The magneto-strictive sensor has the resolution to measure and capture the change in rod position displacement and can easily meet the minimum specs for accuracy.

e. Advantages:

(1) Absolute sensor, which will retain the data when losing power.

(2) Very accurate and has the resolution to detect miniscule change in rod position.

f. Disadvantages:

(1) Not easily accessible for maintenance, repair, or replacement since it is bored inside of the rod cavity.

(2) Requires a pressure transducer to be installed into the bored rod to protect the magneto-strictive element from the increased internal hydraulic cylinder pressure.

5–18. Linear variable differential transformer and linear variable induction transformer non-contact, linear-position sensors (absolute – smooth rod)

Linear variable differential transformer (LVDT) and linear variable induction transformer (LVIT) are electromechanical devices used to convert mechanical motion or vibrations, specifically linear motion, into a variable electrical current, voltage, or electric signals, and the reverse.

a. A linear transducer provides voltage output quantity, related to the parameters being measured (for example, force) for simple signal conditioning. LVDT and LVIT sensor devices are sensitive to electromagnetic interference. Reduction of electrical resistance can be improved with shorter connection cables to eliminate significant errors. An LDT requires three to four connection wires for power supply and output signal delivery.

b. Physically, the LVDT and LVIT construction is a hollow metallic cylinder in which a shaft of smaller diameter moves freely back and forth along the cylinder’s long axis. The shaft, or pushrod, ends in a magnetically conductive core which must be within the cylinder, or coil assembly, when the device is operating.

c. In common practice, the pushrod is physically attached to the moveable object whose position is to be determined (the measurand), while the coil assembly is attached to a fixed reference point. Movement of the measurand moves the core within the coil assembly; this motion is measured electrically.

d. Operating temperatures include: > -32 ºF, -32 to 32 ºF, 32 to 175 ºF, 175 to 257 ºF, 257 ºF and up. These make up the range of temperature within which the device must accurately operate.

e. Since it is a transformer, the LVDT and LVIT requires an AC drive signal. A dedicated electronics package or signal conditioner is typically used to generate this drive signal, and to convert the device’s analog AC output to +5VDC, 4-20mA or some other format compatible with downstream equipment. This circuitry may be external, or it may be housed within the transducer body. Internal electronics allow the user to feed the transducer a DC signal of only moderate quality, often a benefit in battery-powered and onboard vehicular applications. However, external electronics offer higher quality and may provide optional features such as calibration to enable direct readout in engineering units.

f. *This advantage results in a v*ery accurate transformer that has the resolution to detect miniscule change in rod position.

g. Disadvantages include:

(1) Sensitive to electromagnetic interference.

(2) Requires AC signal source for primary excitation winding.

(3) Not easily accessible for maintenance, repair, or replacement since it is bored inside of the rod cavity.

Chapter 6
Miter Gate Operating Machinery

6–1. Linkages and components

a. General description of linkages and components. The miter gate is the most frequently used gate on navigation locks. The miter gate linkage provides the connection between the drive system and the gate itself. Mechanical linkages traditionally have been used to open and close miter gates. Many of the lock sites built in the 1930s on the Mississippi and Ohio rivers used mechanical linkages. Recently, direct-connected hydraulic cylinders have become more prevalent and are used at both new locks and for rehabilitation of existing locks. This manual does not dictate which drive system to utilize.

b. Operating linkages. Five types of miter gate operating linkages have been used.

(1) The Panama Canal linkage, which has no angularity between the strut and sector arms at either the open or closed positions of the gate, is shown in Figure 6–1 and Figure 6–2.

(2) The Ohio River linkage, which has angularity between the strut and sector arms at both the open and closed positions, is shown in Figure 6–3 through Figure 6–5.

(3) The modified Ohio River linkage has angularity between the strut and sector arms at the recess, or open, position and no angularity at the mitered or closed position. This linkage is shown in Figure 6–6 and Figure 6–7.

(4) A direct-connected cylinder is considered a linkage in the sense that it provides the connection between the drive system and the miter gate. A direct-connected cylinder, shown in Figure 6–8 and Figure 6–9, consists of a hydraulic cylinder and rod connected to a pin on the gate and a pin on the lock wall. The piston force is transmitted directly from the piston rod to the gate. A self-contained hydraulic actuator, shown in Figure 6–10, is a variation of the direct-connected cylinder.

(5) Rotary actuators are an enclosed hydraulic rack that is direct connected to the strut arm acting as a Modified Ohio linkage or Ohio River linkage. This is one way to use hydraulics to actuate the miter gates in a way that is very similar to electromechanical gearboxes. See Figure 6–11.

c. Mechanical drives. Miter gate mechanical drives usually consists of a large gear wheel, typically called a bull gear or sector gear (this manual uses the term sector gear), and a sector arm revolving in a horizontal plane. The sector gear and sector arm are connected to the miter gate leaf by a strut, which then connects to the miter gate. The sector gear is typically driven either by an electric motor located in a recess in the lock wall or by a hydraulically operated cylinder using a toothed rack gear (Figure 6–5). The latter method is used when the locks are subject to flooding due to high river stages.

d. Panama Canal linkage. The Panama Canal linkage has been used primarily where electric motor operation was feasible, that is, at locations where high water will not overtop the lock wall. The operating machinery for this linkage generally consists of a high-torque, high-slip, alternating-current motor driving the gate through two enclosed speed reducers, bull gear, sector arm, and spring-type strut. As the name implies, these linkages were used on the original Panama Canal lock gates. See Figure 6–1 and Figure 6–2.

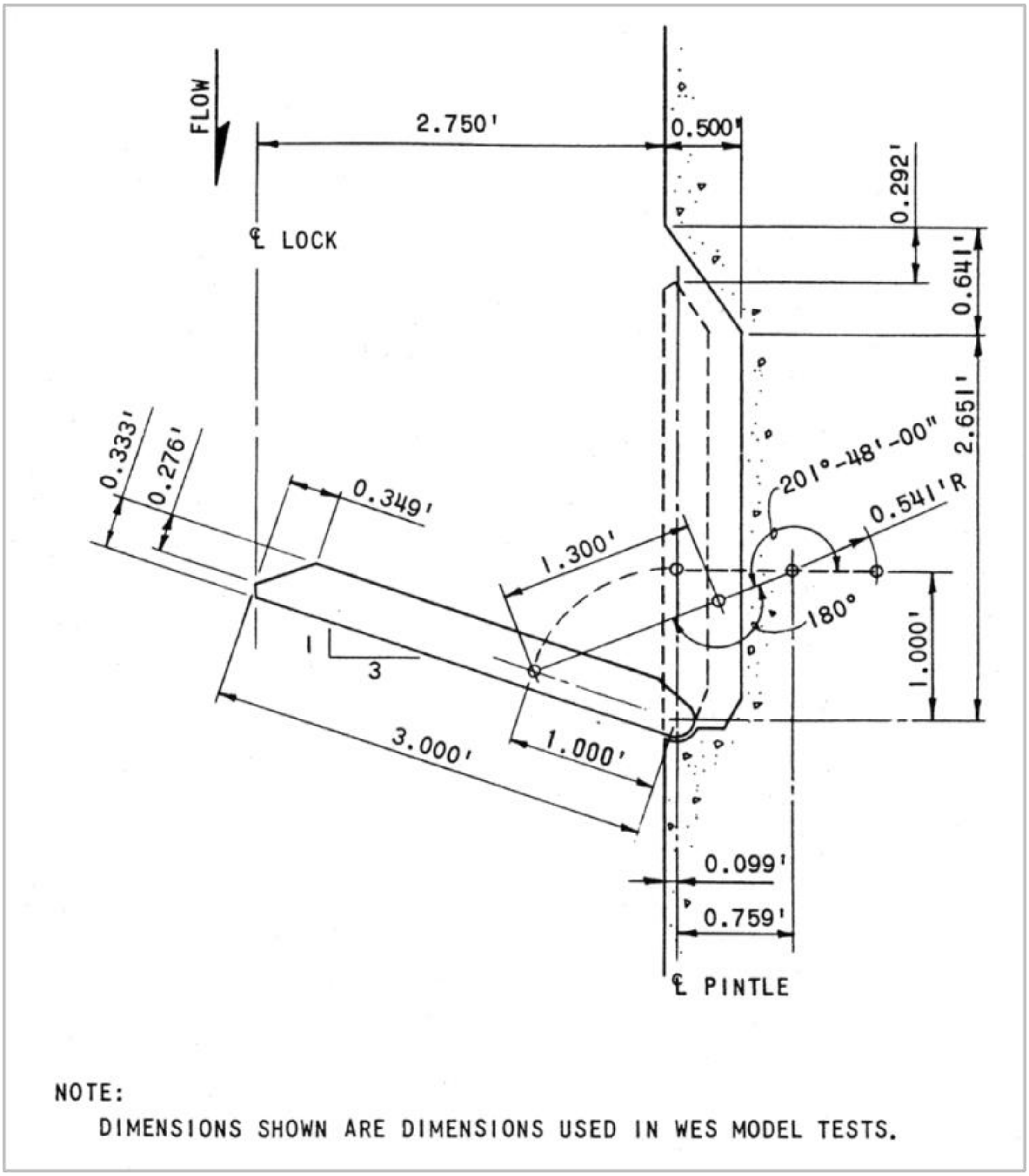


Figure 6–1. Panama Canal linkage (USACE 1964)

(1) This linkage permits the gate to be uniformly accelerated from rest to the midpoint of its travel, then uniformly decelerated through the remainder of its travel, thus eliminating the need for motor speed control. This is accomplished by locating the operating arm and strut on dead center when the gate leaf is in both the open and closed positions. The strut must be at a higher elevation than the sector arm to pass over the arm and become aligned for the dead center position when the gate is fully open.

(2) Special consideration must be given to the design of the eccentric connection between the strut and sector arm. This eccentric connection is shown in Figure 6–2 at Dresden Lock on the Illinois Waterway. The strut passes over the top of the sector gear. An assembly layout of the Panama-type linkage is shown in Plate 11 in Appendix B.

(3) The kinematics of the operating cycle are such that the elimination of all angularity between the strut and sector arm reduces the velocity of gate movement near the limits of gate travel for uniform rate of movement (constant travel) of the operating machinery. This, in turn, reduces the peak loads on the operating machinery. However, this reduction cannot be obtained at each end of the operating cycle unless the sector arm is raised above the sector gear to permit passage over the central axis.

(4) The eccentric connection is one of the primary disadvantages of the Panama Canal linkage and is one reason the Panama linkage is generally not used anymore for new lock construction. Speed control now can be obtained through multispeed motors or VFD systems.

Figure 6–2. Dresden Lock, Illinois River, Panama Canal linkage

e. Ohio River linkage. The traditional Ohio River linkage consists of a hydraulic cylinder, piston rod, toothed rack meshed with a sector gear, and a sector arm. The spring-type strut is connected to the gate leaf and sector arm (see Figure 6–5). A typical machine is shown in Plate 13. The traditional Ohio River drive system with a hydraulic cylinder driving a toothed-rack gear is seldom used, replaced primarily by a direct-connected cylinder. The exception is in a lock that is submerged a significant amount of time each year.

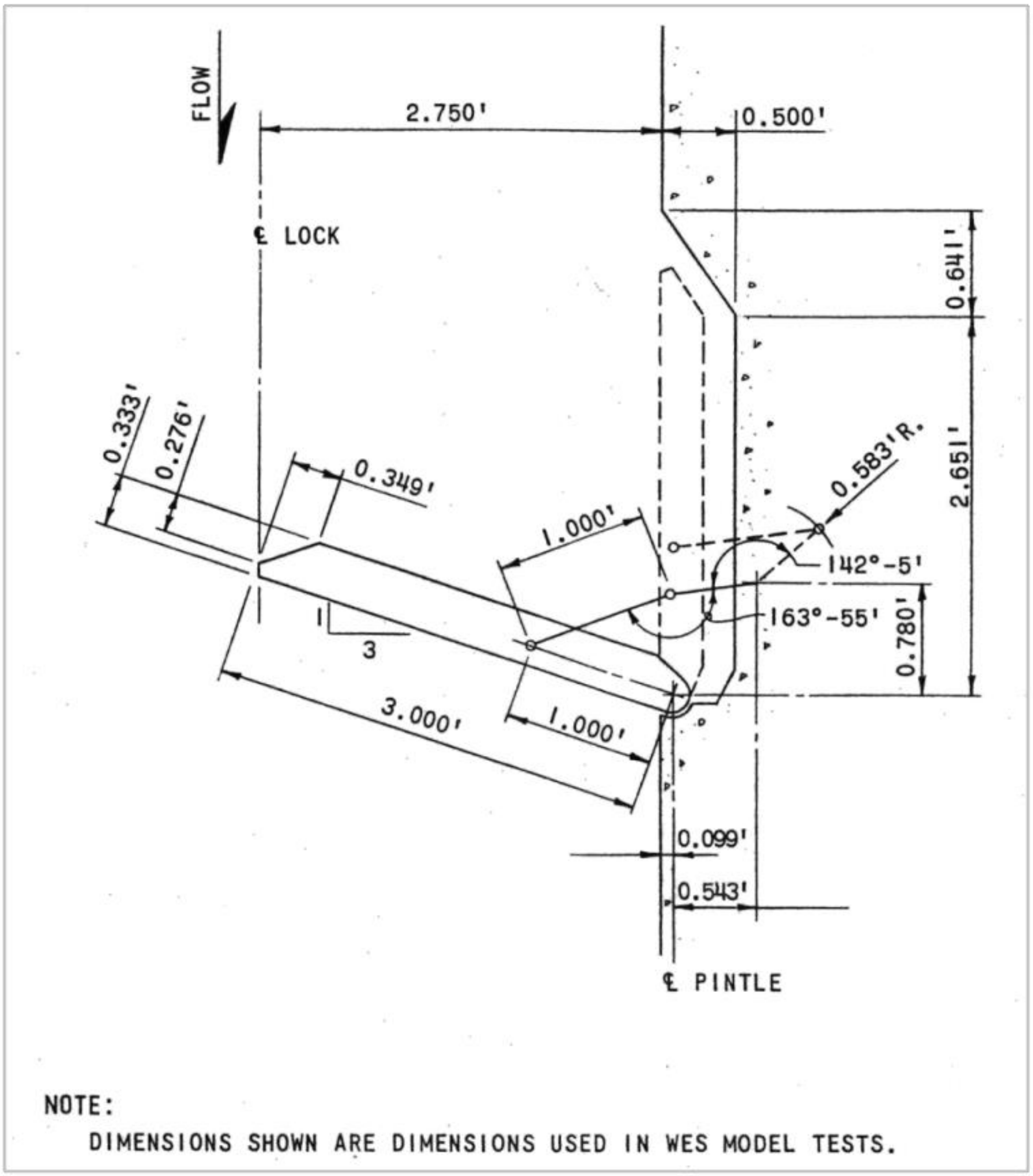


Figure 6–3. Ohio River linkage (USACE 1964)

(1) The Ohio River linkage may be a mechanical drive with an electric motor and gear reducer, which drives the sector gear/sector arm assembly (Figure 6–4). If the lock

is prone to flooding, the mechanical drive system can be raised above the lock wall. A strut arm, which usually includes a buffer spring, connects the gate leaf and sector arm.

(2) With the traditional Ohio River drive using a hydraulic cylinder (and the direct-connected cylinder linkages), load analysis for all components is possible. Overloads due to surges or obstructions are carried through the piston and converted to oil pressure, which is released through a relief valve. In this way, all machinery component loads can be determined based on the relief valve setting.

(a) Advantages. The Ohio River linkage offers several advantages because of its unique geometric configuration relating to the acceleration and deceleration of the miter gates. The sector arm and strut arm can absorb impact loading from debris better than a direct-connected cylinder. They are less susceptible to damage than a direct-connected hydraulic cylinder.

(b) Disadvantages. The disadvantages of this system are wear, bearing forces, and mechanical inefficiencies associated with the geared rack, sector gear, sector arm, and strut.

Figure 6–4. LaGrange Lock, Illinois River, Ohio linkage

(3) For lock sites whose machinery may be submerged during high water, the traditional Ohio linkage offers some benefits. The designer can specify a sealed hydraulic cylinder and components driving the toothed rack gear to be sealed, preventing water from getting into the hydraulic system. This hydraulic arrangement

allows the possibility that electrical motors may be located out of wet areas, such as inside of a gallery.

Figure 6–5. Lock 52, Ohio River, traditional Ohio linkage with toothed rack gear

f. Modified Ohio linkage.

(1) The modified Ohio linkage is like the Panama type, except that the dead center alignment is attained only when the gate is in the mitered (fully closed) position. With the modified Ohio linkage, the strut and sector gear are at the same elevation, thus eliminating the eccentric strut connection but preventing the linkage from attaining the dead center position with the gate recessed. (See Figure 6–6.)

(2) The operating machinery for this linkage has been built either for electric motor drive, as with the Panama linkage, or hydraulic operation, as with the Ohio River machine. The operating machinery also can be raised above the flood elevation, as shown in Figure 6–7. An assembly layout of the modified Ohio linkage with electric motor drive is shown in Plate 12.

(a) Special consideration should be given to the strut length and/or cylinder stroke, which become critical at the gate-closed position (mitered). Generally, some means of adjusting strut length should be provided to ensure that the gate leaves are fully mitered when the sector and strut arms are fully extended. If the gates do not miter completely

at this position, additional travel provided by the cylinder or motor only will pull the gates farther apart.

(b) As this linkage approaches the mitered position, the sector arm and strut move near the dead center position. If an obstruction is encountered, the force in the strut becomes indeterminate. Although this linkage provides restraint against conditions of reverse head in the dead-center position, it must be designed with an easily repaired weak link to limit the maximum loads that can be placed on the machinery components.

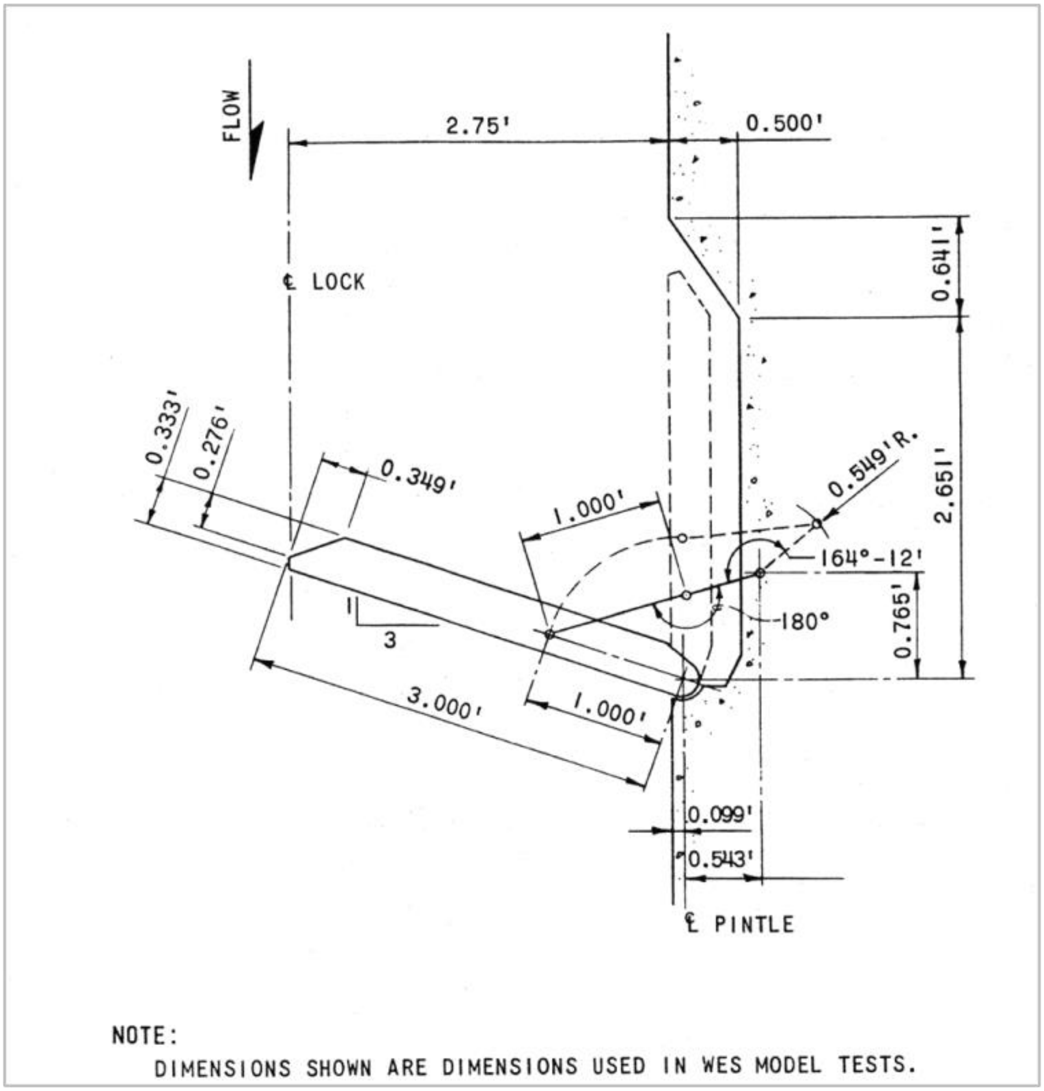


Figure 6–6. Modified Ohio River linkage (USACE WES 1964)

Figure 6–7. Modified Ohio River linkage with raised machinery

g. Hydraulic cylinder direct-connected linkage.

(1) The direct-connected linkage consists of a hydraulic cylinder with its shell (or body) supported in the miter gate machinery recess by a trunnion and cardanic ring assembly (or gimbal), and its rod connected directly to the miter gate with a spherical bearing-type clevis. The layout of the cylinder and cardanic ring minimizes any damage from a barge impact. See Figure 6–8 and Figure 6–9. The INDC is currently writing a technical report to determine the ideal location for the direct-connected cylinder connection to the miter gate. A connection point too close to the pintle end can create high loading on the anchorage assembly. It is recommended currently to install the cylinder connection at approximately 25% to 35% of the miter gate length (from the pintle) with 33% being ideal.

(2) The size of the piston rod is determined by the bending and buckling load criteria. Since the piston rod is used as a strut, it is generally larger in diameter than the rod of the Ohio-type machine (with a toothed-rack gear). This larger rod also increases the ratio of time of opening to time of closing, since the net effective cylinder volume on the rod end is smaller relative to the volume of the cap end. This variation in opening

and closing times can be easily eliminated by using adjustable flow control valves or a regenerative circuit in the hydraulic system.

(3) The direct-connected cylinder linkage is becoming more widely used (Figure 6–8). The arrangement of the direct-connected type machine is shown in Plate 14. The direct-connected type of machine has been used satisfactorily on both 84-ft wide (25 m) and 110-ft wide (33.5 m) locks in the United States and similar size locks in Europe. Experience has shown that the direct-connected cylinder design will have lower initial costs than traditional mechanical drive systems. Chapter 4 provides more detail for hydraulic drive systems and hydraulic cylinder design.

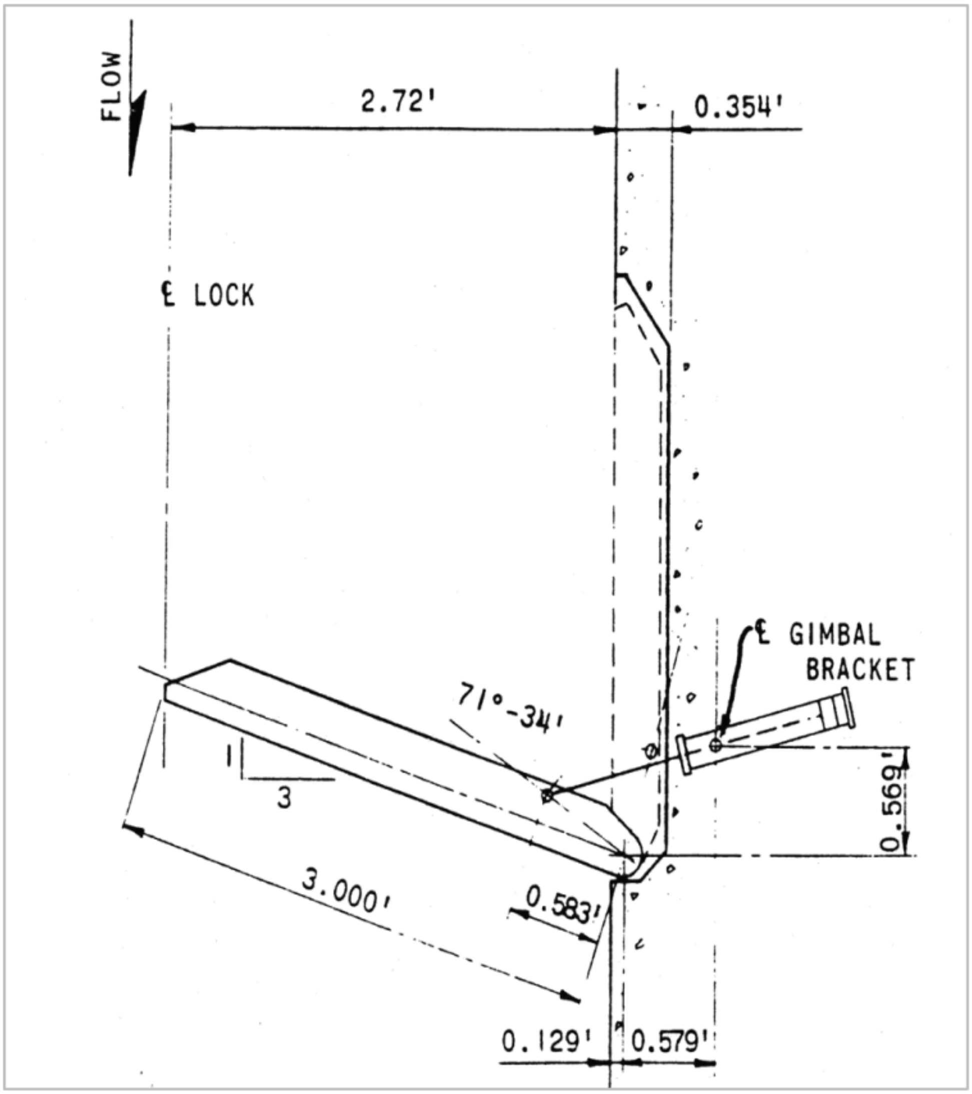


Figure 6–8. Direct-connected linkage isometric

Figure 6–9. Direct-connected linkage for miter gate, Soo Locks

h. Self-contained hydraulic drives. A self-contained hydraulic drive system is like the direct-connected cylinder. These types of drives have been used at several Pittsburgh District lock sites on the Allegheny River (Figure 6–10). This design will also be used at the Chittenden Lock (small lock). The drive combines an HPU with a hydraulic cylinder to form a self-contained actuator that is sealed and submersible. The gear motor and the entire drive are designed to be submerged. More details on this system are in Chapter 4.

Figure 6–10. Self-contained actuator – USACE, Pittsburgh District

(1) The self-contained actuator provides several advantages over the traditional direct connected cylinder:

(a) Completely self-contained, meaning there are no external piping, motors, or hydraulic power units, and it is sealed from dirt and moisture.

(b) No piping friction losses.

(c) Reduced total space requirements.

(d) Low maintenance.

(e) Easily replaceable (plug and play).

(f) Fully adjustable thrusts and speeds for each direction of travel.

(g) Smooth, vibration-free operation.

(h) Weatherproof and can be provided as an explosion-proof unit and can be installed in various mounting configurations.

(2) The primary disadvantage of the self-contained actuator is the lack of manufacturers to fabricate the unit. The units are generally custom-built to allow them to be submerged. They may also be limited in the amount of torque necessary to move the gate.

i. Rotary actuators. This option allows a compact means of using hydraulics to actuate a miter gate. This arrangement is suitable for sites which frequently flood on an annual or biannual basis. The system is totally sealed, and there are no gearboxes to inundate with water or hydraulic rods that are vulnerable to debris damage. See Figure 6–11.

j. Linkage selection. The final decision for selection of the drive system and linkage should be based on several factors, including cost, maintainability, and availability of components. See Chapter 1 for more discussion. The life cycle cost of any drive system must be calculated before a final drive system is selected. When possible, rehabilitation and replacement should be done on a system-level basis. The drive system must be operated at a slower speed near the mitered and recessed positions. This is especially critical for hydraulic drives to reduce loading on the miter gate anchorage.

(1) Designs for a waterway system should be standardized as much as possible. The direct-connected cylinder design likely will provide the lowest initial cost. This arrangement, when properly designed, is the simplest to maintain, repair, and replace.

(2) The direct-connected hydraulic cylinder linkage is common in Europe and is becoming the drive system of choice in the United States, both for new lock construction and for rehabilitation. Some of the disadvantages of the direct-connected hydraulic cylinder drive system include a lack of simplified methods for position measurement and

a lack of manufacturers. Hydraulic cylinders for a miter gate drive generally will be custom built.

(3) Although mechanical drives and linkages have been in service for more than 50 years on many locks, they are becoming less common in new lock construction and rehabilitation of existing locks. One of the advantages of mechanical drives and linkages over hydraulic drives is the proven design and reliability. They are robust and generally have a longer life span than the direct-connected hydraulic cylinder systems. They can be installed at locks subject to flooding.

(4) Mechanical drive systems have been in place since the 1920s and 1930s in the United States, and originally were installed at the Panama Canal. Even though mechanical linkages can provide inherent speed control, new mechanical drive systems should be provided with two-speed motors or VFD systems.

(5) Disadvantages of mechanical drives, as compared to hydraulic drives, include a more complex operating machinery linkage. There is limited adjustment possibility in the strut connection. Components and gearboxes require maintenance and periodic replacement of oil. The mechanical drive system is labor intensive for routine maintenance and for replacement. Components can be difficult to replace, remove, and acquire since they’re often custom built with long lead times. Alignment is critical and, if not done properly, the life of the machinery is shortened.

(6) Mechanical drives are generally more susceptible to shock load and barge impact (although barge impact also is an issue for direct-connected hydraulic cylinders).

Figure 6–11. Rotary actuator rendering

k. Struts. Mechanical drive systems and linkages require a strut arm at the connection to the miter gate (Figure 6–13). Spring-type miter gate struts are commonly used with the Ohio River and modified Ohio River linkages. Springs built into the strut assembly act as a shock absorber to soften the loads transmitted to the operating machinery.

(1) Two types of struts have been used for the above mechanical linkages. One type uses several nests of helical coil springs installed into a cartridge and attached to a wide-flange, structural steel fabricated member. The other type of strut uses a spring cartridge housing and tubular steel strut. Ring springs are used in the spring cartridge to provide the necessary deflection. Spring boxes can be arranged to provide compressive and tensile deflection to protect linkages from all types of failures as shown in Figure 6–12.

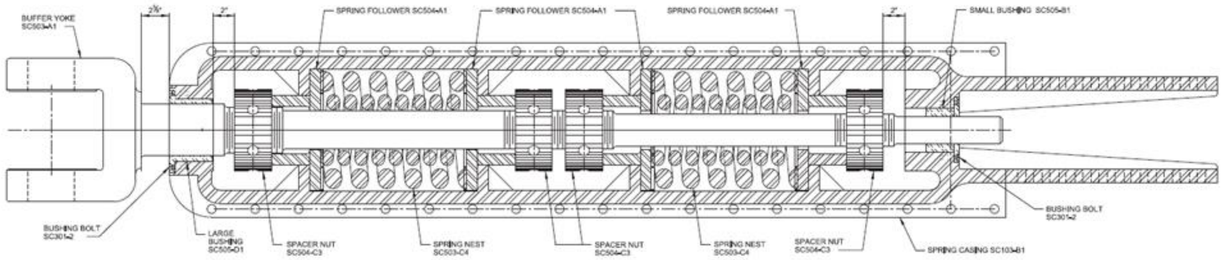


Figure 6–12. Two-way, nested spring box – tension or compression

(2) The springs, when compressed, act as a shock absorber. In the case of electric motor operated machines, the compression in the springs permits the operation of a limit switch to cut off current to the motor when the gates are mitered or recessed. This switch also serves as a torque limit switch to protect the machinery. The limit switch is set to open the motor circuit at a point immediately preceding the maximum spring compression in the strut. This type of strut is shown in Plate 15 in Appendix B.

(3) Excessive maintenance and repair costs have occurred with the spring cartridge. In addition, ring springs are available only from limited manufacturers. Use of the ring spring-type strut is not recommended. Recently, Belleville springs have been used in struts and appear to function satisfactorily. The Belleville spring strut is shown in Plates 16 and 17. However, several failures have been reported for the Belleville spring design. This design should consider the extreme loading conditions and need for proper lubrication and sealing.

l. Sector gear anchorage. Mechanical drives and linkages require a sector gear or bull gear (both names are used). The sector gear support and anchorage is one of the more critical items to be considered in the design of miter gate machinery. For proper machine operation and long component life, the sector gear must be maintained in rigid and proper alignment. The recommended arrangement consists of a sector base anchorage, sector base support, and a sector base.

(1) The sector base is a heavy steel casting or fabrication and contains the sector pin on which the sector gear turns. An important feature is the bearing choice and lubrication design for the bearings that allow the sector gear to rotate around the pin. The design is such that the final post-tension rod force is enough to resist the horizontal sector pin load by friction between the concrete and sector base support. In addition, compression blocks are welded to the bottom of the sector base support to provide additional resistance to horizontal motion.

(2) The sector gear can also be supported (roller supports) on its outer perimeter to provide additional support. This is suggested for new installations. The sector gear pin should be restrained to prevent rotation in the sector base.

Figure 6–13. Miter gate strut arm

6–2. Design criteria

For mechanical linkages, the designer should utilize the model study described in Waterways Experiment Station (WES) TR 2-651 (USACE 1964). Details of this testing report are further described in this section. See Appendix C provided separately from this document for additional information on example calculations. New and updated model studies are currently being planned and executed at the writing of this EM. However, the 1964 model report is the only current guidance. An analytical means to calculate gate operating forces is provided in USACE WES TR 74-11 (USACE 1974).

a. Design loads.

(1) Miter gates are not suitable for operation under other than essentially balanced conditions or equal head on both sides of the gate. The lock chamber must be filled or emptied by means of a culvert system prior to operation of the gate leaves. Thus, the water level on each side of the gate is equalized, or almost equalized, before movement of the gate leaves is undertaken. The forces to be overcome by the gate-operating machinery are friction, wind loads, surges, hydraulic drag forces, and head differential created by the gate leaves moving through the water.

(2) Friction and wind loads can only be estimated but are generally small in comparison to the hydraulic loads. Evaluation of operating forces caused by hydraulic drag and head differential could be made through tests on existing lock gates. In practice, however, it has been found difficult to make accurate load measurements in the field. Furthermore, it is not practical to vary field operating conditions such as gate speed and gate submergence (height of water on gate).

b. Normal loads.

(1) Gate operating machinery should be designed to conform to the criteria in this section. Operating loads on the miter gate machinery should be derived by hydraulic similarity from test data obtained from model studies. The model study available for design is described in WES TR 2-651 (USACE 1964). See Appendix C for more information on how to access the calculation details from this study.

(2) The WES TR 2-651 model study report includes test data on the Ohio River, modified Ohio River, and Panama Canal linkages. This report contains necessary data for conversion to prototype torque for all three of the different types of linkages. This report is summarized as follows:

(3) "Tests to determine operating forces on miter-type lock gates were conducted in a 5.5-ft-wide, 66.5-ft-long, 4.25-ft-deep flume equipped with a single set of miter gate leaves located approximately in the center of the flume. The length of the model gate leaf was 3 ft. Three linkages, with different kinematics of the operating machinery, were studied: modified Ohio River, Panama, and Ohio River."

(4) "For each linkage, tests were conducted at gate submergences of 1 to 4 ft and at operating times of 10.1 to 40.2 seconds. The effects of chamber length, bottom clearance of gates, presence of barges in the lock chamber, and non-synchronous operation of the gate leaves also were investigated."

(5) "Peak hydraulic resistance to operation of the miter gate was observed as the leaves entered and left the mitered (closed) position with the maximum resistance occurring as the leaves entered the mitered position."

(6) "Peak torques were actually observed as the leaves left the recesses (began closing) with the Ohio River and modified Ohio River linkages, but these torques were created by sudden application of loads to the rigid model linkages and, thus, were not considered representative of those of prototype gates that are equipped with shock absorbers."

(7) "The modified Ohio River and Panama linkages resulted in peak resistances in terms of torque at the pintles, which were approximately equal and about 40% less than the peak torques obtained with the Ohio River linkage."

c. Direct-connected cylinder loads. For direct-connected hydraulic cylinders, prototype tests were made at Claiborne Locks. Results of these tests are included herein and Appendix C for the determination of gate torque for any proposed direct-connected lock machine of similar proportions. Details regarding a curve of gate torque plotted against percentage of gate closure are provided in Appendix C so that torque at any submergence or time of operation can be computed by application of Froude's law, adjusting the submergence and time to suit the new conditions.

d. Temporal loads. In addition to the above-normal loads, design miter gate machinery at the miter position, to hold and withstand forces produced by a 0.38-m (1.25 ft) and not exceeding 30 seconds duration temporal load. This temporal load is only in a static condition and not included in the operating forces. Normal machinery operating loads from the WES 2-651 report govern the machinery design for gate travel in the intermediate positions. Components such as strut arms and sector arms are allowed to reach 75% of yield strength under temporal loading conditions.

e. Temporal load definition. A temporal load can also be considered a surge load and acts on the submerged portion of the miter gate to account for temporary and sudden pool level changes. Temporal hydraulic loads or surges are temporary changes in water level resulting in a differential water level on opposite sides of a lock gate. These surges or differential heads may be caused by overtravel of water in the valve culvert during filling or emptying, wind waves, ship waves, propeller wash, etc. The machinery must be designed to maintain control over the miter gate when the gate is at miter position. Temporal loading should also be evaluated for gates in the recess position but in this case gate latches can be provided.

f. Operating time. A time of operation should be selected and based on the size of gate. For smaller gates (25.6-m or 84-ft lock), an average time of 90 seconds should be used. For larger gates (33.5-m or 110-ft locks), an average time of 120 seconds should be used.

(1) Any decision to increase the operating time from 1.5 to 2 minutes for smaller gates or 2 to 3 minutes for larger gates should be made only after considering the economic impact of the increased time required for navigation traffic and barges to transit the lock.

(2) Mechanical drive systems using two-speed motors should be operated at slow speed when approaching miter or recess. This needs to be considered in the overall operating time. Hydraulic drive systems must also provide for reduced speed at miter and recess positions.

g. Submergence. The submergence of the gate has the most significant impact on the required pintle torque. The design of the gate operating machinery should be based on the submergence of the upper or lower gate, whichever is greater. The submergence of the gate is the difference in elevation of the tailwater on the gate and the elevation of the bottom of the lower seal protruding below the gate.

(1) A submergence selected for design of the gate machinery should be the tailwater on the gate that would not be exceeded more than 15 to 20% of the time.

(2) The design should be the same for all four gate machines, because there would be no savings in designing and building two different size machines. The increased design cost would offset the reduced cost of the material used in constructing the smaller machine.

(3) Use the submergence curves in the WES TR 2-651 (USACE 1964) for determining pintle torque as outlined below.

h. Direct-connected cylinder force. For direct-connected hydraulic cylinders, the operating cylinder size should be selected to provide a force to operate the gate using approximately 6-17 Mpa (900-2500 psi) effective pressure where a central pumping system is used. Where local or integral pumping units are used, an operating pressure of 10-17 Mpa (1,500-2500 psi) will be satisfactory.

(1) Gate operation time will increase when the required gate torque exceeds the available gate torque from the machinery. This condition might occur during starting peaks or periods of higher submergence.

(2) This condition causes the pressure in the hydraulic cylinder to rise above the relief valve setting, which, in turn, reduces oil flow to the cylinder, slowing down the gate and reducing the required pintle torque. This increases the total time of operation; however, this slower operation will generally be experienced for only 15 to 20% of the lock's total yearly operating time.

(3) Use the submergence curves in WES TR 2-651 (USACE 1964) for determining pintle torque as outlined below.

i. Non-synchronous gate operation. Peak torque can be reduced by non-synchronous operation of the gate leaves. A considerable reduction in peak torque can be obtained by having one leaf lead the other by approximately 12.5% of the operating time. The time of opening would be increased by the amount of time one gate leads the other. It has been found that, in actual practice, very few gates are operated in this manner.

j. Under-gate clearance. Model tests revealed an increase in gate torque values as the bottom clearance decreased, regardless of the length of operating time. When model similarity is used to compute gate loads, an adjustment should be made according to Figure 6–14 and WES TR 2-651.

k. Machinery components and factor of safety. General design criteria applicable to the various machine components are presented in Chapter 2.

6–3. Load analysis

a. Normal loads. New model studies to replace WES TR 2-651 are being developed as of the writing of this EM and expected to be published in 2027 or 2028. Normal operating hydraulic loads on miter gates are caused primarily by submergence, speed of gate, and clearance under gate. The submergence of the gate and the speed of the gate are the two most significant factors. An increase in submergence or an increase in speed will increase the required pintle torque. For additional information and explanation, the designer should review WES TR 2-651. Some general observations and summary from the report:

(1) An increase in submergence of the gate leaves or speed of operation resulted in increased hydraulic resistance.

(2) Hydraulic resistance increased as the bottom clearance of the gate leaves was decreased.

(3) Hydraulic resistance decreased as the length of the lock chamber was increased.

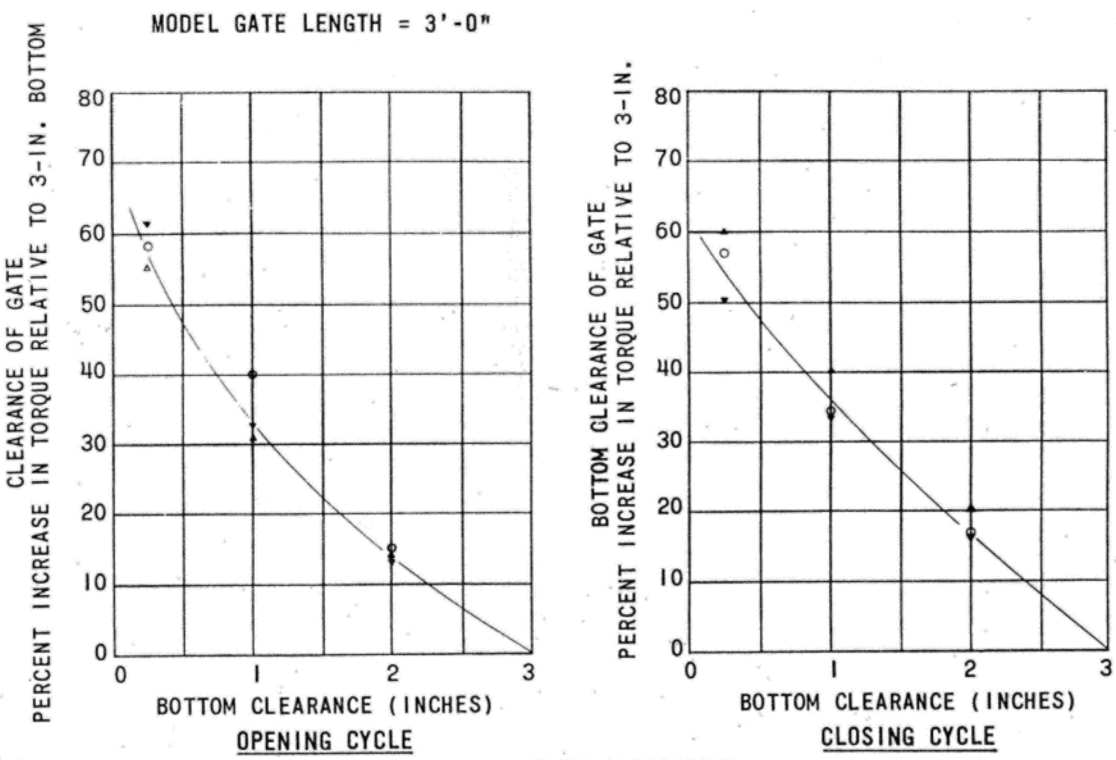
(4) Non-synchronous operation of the gate leaves resulted in a slight reduction in peak torque.

(5) Limited tests conducted with barges in the lock chamber showed no appreciable effect on torque values.

b. Torque and under-gate clearance. Tests reveal that gate torque increases when the clearance under the gate leaf is decreased, regardless of the length of operating time. Data from these tests, presented in Figure 6–14 and taken from WES TR 2-651, indicate the percentage increase in model torque for various bottom clearances relative to the torque observed with a 3-in. bottom clearance. These data can be used to adjust the proposed lock torque values using the bottom clearance factor discussed below.

c. Non-synchronous operation of miter gates. Non-synchronous operation of miter gates results in slightly lower forces on the leading leaf. Forces on the lagging gate leaf are greater during most of the closing cycle and less during the opening cycle than similar forces recorded for synchronous operation of the gate leaves. The greatest reduction in torque appears to occur when one gate is leading the other by approximately 12.5% of the total operating time.

d. Barges. Barges in the lock chambers are found to have negligible effect on gate operating forces.



OPERATING TIME TORQUE, LB-FT (3-IN. BOTTOM CLEARANCE)

SEC.	OPENING CYCLE	CLOSING CYCLE	SYMBOL
13.4	40	35	○
20.1	29	20	△
26.8	18	12	▼

Figure 6–14. Relative effect of gate bottom clearance on torque, 4.0-foot submergence

e. Chamber length. The chamber length affects the gate torque in that the longer the chamber, the less the torque. As the length of time is increased, the less the chamber length affects the gate torque. Insufficient data are available to set up any definite adjustment factors for correcting for chamber length.

f. Pintle friction. Torque caused by gate pintle friction is generally of small magnitude. The WES TR 2-651 (USACE 1964) incorporates pintle torque in the model tests. These are based on traditional grease-lubricated pintle bearings. The model tests do not account for any binding or seizing of the pintle bearing.

g. Calculation options. Two options are provided below for direct-connected cylinder torque calculation. One is from the Claiborne Lock model, and one uses a simpler method of applying a 6-in. differential head on the miter gate while it is operating. Generally, it is recommended for the design to consider whichever choice produced the highest load in either of the cases.

(1) When operating torque for a direct-connected, hydraulic cylinder-type miter gate drive is being computed, the curves shown in Appendix C can be used. The curves

are results of prototype tests made on Claiborne Lock and show gate torque plotted against percentage closed. The torque from these curves can be adjusted to suit new conditions by the application of Froude's law. Since the curves were based on using a three-speed pump to slow the gate travel at beginning and end of cycle, it will be necessary to make similar assumptions on the proposed lock.

(2) For the three-speed motor mentioned above, the fast rate would be 100% of output speed, the medium rate would be 80% of output speed, and the slow rate would be 30% of output speed. A normal cycle would be to first operate 10% of the gate angular travel at 30% speed, then the next 10% of travel at 80% capacity, the next 60% of travel at 100% speed, the next 10% of travel at 80% capacity, and the last 10% at 30% capacity.

(3) A study comparing this type of operation and the Panama-type linkage indicates that the direct-connected machine, if operated as stated above, will compare favorably with the Panama machine in angular gate velocity (degrees per second) at all positions. Assuming the angular velocities compare with the Panama-type machine, the maximum torque will vary as the 1.5 power of the submergence (closing) and 1.7 power of the submergence (opening). The operating time should vary as the 1.1 power for closing and the 1.3 power for the opening cycle.

(4) Another method of sizing direct-connected miter gate machinery is to simply utilize a differential head. Compute opening the gate against a 0.15-m (6 in.) differential head. This condition then needs to be compared to the case for the torques computed using model forces.

h. Temporal loading. Temporal loads typically affect the design of the gate machinery components when the gate is at the mitered position and not moving. However, temporal loading should also be evaluated at the recess position. These forces do not affect the machinery power requirements since the evaluation is done for a static condition. These forces have been known to fracture gate struts and shear sector pins. In hydraulic systems, these temporal loads can lead to excess system pressure causing pressure relief valves or load holding valves to bypass. This can cause uncontrolled gate drift, which is undesirable and unsafe.

i. Miter gate loading discussion from Waterways Experiment Station (1964). The peak hydraulic resistance to operation of the miter gate occurs as the leaves enter the mitered position. This suggests that head differential on the two sides of a gate leaf is the primary cause of loads on the operating machinery.

(1) If drag forces were the predominant influence, it is expected that the peak load would occur simultaneously with the maximum rate of angular movement. This happened for all linkages when the gate was about 45% open.

(2) If inertial forces were major factors, the torque should have been greatest as the leaves moved away from the mitered position and were accelerating, but the reverse was found to be true.

6–4. Determination of machinery loads

a. Table 1 summarizes the methodology required to determine model pintle torque for a mechanical linkage and a 110-ft-wide (33.5 m) lock and a 60-ft (18.2-m) miter gate leaf. The detailed discussion follows the table. The methodology for a direct connected hydraulic cylinder is similar.

Table 6–1
Methodology for machinery loads 110-foot-wide lock by 600-foot long and a 60-foot miter gate leaf and 90-second total time operation – modified Ohio linkage

Step 1	Determine the type of mechanical linkage – modified Ohio example
Step 2	Determine scalar ratio $L_R = L_1/L$ = 60 ft/3ft = 20. The gate leaf in the WES TR 2-651 (USACE 1964) report is 3 ft.
Step 3	Determine time scalar adjustment = $L_R{}^{½}$ = 20 ^{½} = 4.472. Therefore, the ratio between the WES model and the actual lock prototype is 1:4.472. For a 90 second time of operation, the WES model curve to utilize would then be 20.1 seconds (90 seconds divided by 4.472).
Step 4	Determine the correct WES model curve to utilize for the lock chamber length. In this case, there is a 600-ft lock chamber. The scalar ratio is 1:20 so the correct WES model curve would be a 30-ft model chamber (600/20).
Step 5	Determine which model curve to utilize in the WES report. Utilize the WES model curve for 20.1 second operation and 30-ft chamber length. The correct curve in this case would be on Plate 22 in the report.
Step 6	Utilize the model curves closest to submergence. The actual submergence is scaled using the scalar ratio.
Step 7	Determine bottom clearance correction factor C.

b. When using data from the model tests, it will be necessary to adjust the data based on the scalar ratio between the model and the proposed lock. The length of the gate leaf normally is used for determining the scalar ratio. The lock chamber length is directly proportional to the scalar ratio. From the scalar ratio, Froude's law comparing prototype to model would be:

Scalar ratio = $\frac{\text{length of prototype leaf}}{\text{length of model leaf}} = L_R$

Volume, weight, and force = $(L_R)^3$:1

Time and velocity = square root of L_R:1 or $(L_R)^{1/2}$:1

Torque = $(L_R)^4$:1

c. When machines having the Ohio linkage, the modified Ohio linkage, or the Panama-type linkage are used, miter gate pintle torque can be obtained from curves plotted in WES TR 2-651 (USACE 1964) and Panama Canal model tests. Readings from the curves must be factored according to Froude's law for submergence, time of operation, and clearance under gate.

d. After the type of linkage is identified, the designer must determine which USACE (1964) plate and submergence curve to use to calculate pintle torque. The plates and curves selected should be those in which the scaled model most closely matches the design.

e. For the modified Ohio-type linkage, USACE (1964) has plates representing six different operating times and four different chamber lengths. Based on the calculated time ratio (t_R) and scalar ratio (L_R), the designer should select the plate that most closely matches both design operating time and design chamber length.

f. For the Ohio-type linkage, USACE (1964) has plates representing six different operating times. There is only one chamber length represented in the USACE (1964) plates for the Ohio-type linkage, so chamber length is not considered when the design uses this type of linkage. Therefore, based solely on the calculated time ratio (t_R), the designer should select the plate that most closely matches the design operating time.

g. For the Panama-type linkage, USACE (1964) has plates representing six different operating times. There is only one chamber length represented in the USACE (1964) plates for the Panama-Type Linkage, so chamber length is not considered when the design uses this type of linkage. Therefore, based solely on the calculated time ratio (t_R), the designer should select the plate that most closely matches the design operating time.

h. Once the correct USACE (1964) plate is selected, the appropriate submergence curve must be identified. To do this, the designer must scale down the design submergence by the scalar ratio (L_R). On the selected plate, the designer should use the next highest submergence curve to obtain pintle torques. For example, if the scaled down submergence is 3.1 ft, the 3.5-ft curve should be used. It should be noted that several of the USACE (1964) plates for the Modified Ohio-type linkage do not have data corresponding to 1.0 ft–2.0 ft scaled submergences. In cases where the scaled design submergence is lower than 2.0 ft, the next highest available curve (2.5 ft) should be used.

6–5. Computation of pintle torque for Panama Canal and Ohio-type linkages

a. *Pintle torque*. If the proposed lock gate is in the same scalar ratio, with respect to length of gate, and the submergence and time of operation, as shown on curves, and the type of linkage are the same, the pintle torque would equal the pintle torque at each position indicated on the curves, multiplied by the ratio of gate leaf lengths to the fourth power. See equation 6–1.

$$P_1 = P(L_1/L)^4 \tag{6–1}$$

where:

P_1 = pintle torque of proposed lock gate at selected position
P = pintle torque shown on curve of WES model study at selected position
L_1 = leaf length, pintle to miter end, proposed lock gates
L = leaf length, pintle to miter end for curves that have been plotted on model study

b. Formula adjustments. In the event the ratios of gate lengths (L_1/L), submergence (S_1/S), and the square of the time of operation (T_1/T) are not of the same scalar ratio, the formula should be expanded as shown in equation 6–2:

$$P_1 = CP(L_1/L)^4 (S_1/S_2)^x (T_2/T_1)^y \quad (6\text{–}2)$$

where:

P_1, P, L_1, and L are the same as in equation 6–1

S_1 = submergence of proposed lock gate

S = actual submergence of model gate on which curves are based

S_2 = adjusted submergence of model lock gate = $S(L_1/L)$

T_1 = time of operation of proposed lock gate (see arc of travel adjustment in equation 6–3)

T = actual time of operation of model gate on which curves are based

T_2 = adjusted time of operation of model lock gate = $T\sqrt{L_1 / L}$

x = power to which submergence must be raised, for the particular type linkage see Table 6–2

y = power to which time must be raised, for the particular type linkage see Table 6–2

C = correction factor for bottom clearance from USACE (1964) Plate 33

Table 6–2
Summary of submergence and time powers

Linkage	Opening or Closing	Factor	Power
Ohio	Closing	Submergence	x = 1.5
Ohio	Opening	Submergence	x = 2.1
Ohio	Closing	Time	y = 1.0
Ohio	Opening	Time	y = 1.0
Modified Ohio	Closing	Submergence	x = 1.9
Modified Ohio	Opening	Submergence	x = 2.2
Modified Ohio	Closing	Time	y = 1.1
Modified Ohio	Opening	Time	y = 1.5
Panama	Closing	Submergence	x = 1.5
Panama	Opening	Submergence	x = 1.7
Panama	Closing	Time	y = 1.1
Panama	Opening	Time	y = 1.3

Note: If only one ratio for either submergence or the square of the operating time is not of the same ratio as gate leaf length (L_1/L), then only the ratio not in agreement with L_1/L need be considered in the equation.

c. Operating time adjustments. If the arcs of gate travel differ from that shown on model curves, it will be necessary to adjust the operating time of the proposed lock (T_1) to use in equation 6–2:

Let T_A = adjusted operating time, then:

$$T_A = T_1 \frac{(arc\ of\ travel, proposed\ lock)}{(arc\ of\ travel, on\ model\ curves)} = T_1(K_1/K) \qquad (6–3)$$

Note. T_A must be substituted for T_1.

d. Motor slip. Using equations 6–1, 6–2, and 6–3 results in a pintle torque, which makes no allowance for motor slip since all the model curves were based on uniform speed of hydraulic cylinder or constant rpm of the motor. If a portion of the required gate torque curve overloads the motor, the resulting time of gate operation would be slower, which, in turn, would result in lower gate torque during this period.

e. Cylinder overload. The same would occur when operating the gates with a hydraulic cylinder. Overloading the cylinder would result in some of the oil bypassing through relief valves, slowing the gate during the overload period. When Ohio-type linkages and torque data from WES TR 2-651 (USACE 1964), are used, the pintle torque should be adjusted for under-gate clearance in addition to submergence and time. The percentage increase can be obtained from curves in Figure 6–16.

f. Bottom clearance. The procedure to calculate the proper bottom clearance factor for each type of linkage begins with utilizing the scalar length ratio to scale the proposed bottom clearance to Plate 33 found in the WES TR 2-651. Plate 33 indicates a 3 in. bottom clearance. Scale the proposed lock gate bottom clearance using the gate length ratio as follows:

$$C_{scaled} = C/L_R \qquad (6–4)$$

where C_{scaled} is the scaled bottom clearance of the proposed lock, C is the original and uncorrected bottom clearance of the proposed lock gate, and L_R is the scalar ratio.

g. Bottom clearance adjustment. If the proposed lock gate is not a direct connected cylinder, plot the scaled bottom clearance on Figure 6–14 (taken from WES TR 2-651 Plate 33) and determine the bottom clearance factor for opening and closing. The proposed bottom clearance factor will be a percentage from the graph. For example, if the value is 20%, then C will equal 1.2. If the scaled bottom clearance is equal to or greater than 3 in., then C will equal 1.0.

h. Report submergence. Note that the submergence value of the WES TR 2-651, Plate 33, is 4 ft. The Plate 33 in the WES TR 2-651 is the only one provided for bottom clearance adjustment, however. The WES TR 2-651 report held that submergence constant and varied the bottom clearance to see what happened to the torque. They used bottom clearances of 1/4”, 1 in., 2 in., and 3 in. All the other model tests in WES

TR 2-651 that measured torques for different submergences and different speeds were done with a bottom clearance of 3 in.

i. *Electric motor design*. Electric motor operation with Panama-type, Ohio-type, or modified Ohio-type linkages should be designed for several factors.

(1) Motors and gearboxes should be elevated above flood levels to the extent possible.

(2) A high-torque, high-slip motor should be used and selected so that the normal full load torque available would not be exceeded by the required torque of the machine more than 15 to 20% of the time. As such, a motor service factor of 1.15 or 1.2 should be provided.

(3) Motors should be two-speed to allow slower operation at the miter and recess positions.

(4) Peak torque during the overload period should not exceed 150% of full load torque. This can be determined by plotting the required torque based on curves computed from model tests described above, and by plotting available motor torque curves at various degrees of slip and superimposing these curves over the required curves.

(5) Details regarding how to access the calculations for determining loads using the Ohio-type linkage (hydraulic operation) are provided in Appendix C. Details for accessing the calculations for determining loads using the Panama Canal-type linkage (electric motor operation) for the same design conditions are also provided in Appendix C.

6–6. Computation of pintle torque for direct-connected linkages

The kinematics for this type of machine should be developed to provide the shortest practicable piston stroke. This will require the gate pin connection to be located out from the pintle 25% to 35% of the gate length with 33% currently being recommended. The center line of the cylinder gimbal bracket should be located to give the best effective operating arm about the pintle at each position throughout the entire stroke of the piston.

a. Using this linkage and a uniform traveling piston, gate angular velocity will be greatest at the extreme closed or open position of the gate. Uniform travel of the piston is, therefore, undesirable, and it will be necessary to slow the speed of the piston near the closed and open positions using a variable-volume pump in the oil circuit. By slowing the travel near the open or closed position of the gate, angular travel rates will be comparable with the Panama Canal linkage. Slowing the speed will also reduce the anchorage forces at end of travel.

b. Figure 6–16 shows comparison curves for angular velocity of gates plotted against percent closed for Panama Canal linkage and for Claiborne Lock direct-connected linkage with and without variable speed control.

c. Time of operation should be selected for the proposed lock that will give angular gate velocities approximately equal to the velocities shown on the curve for Panama Canal. Gate pintle torque then should be taken from the prototype curves (see Appendix C) and by means of Froude's Law of Similarity to the submergence and time requirements of the proposed lock using the same exponents as for the Panama Canal linkage. Load computations for a direct-connected machine are summarized below.

d. The proper exponents can be seen in equations 6–5 and 6–6. The equations represent the pintle torque scale factor for opening and closing as

$$P_1 \text{opening} = CP\left(\frac{L_1}{L}\right)^4 \left(\frac{S_1}{S_2}\right)^{1.7} \left(\frac{T_2}{T_1}\right)^{1.3} \quad (6\text{–}5)$$

$$P_1 \text{closing} = CP\left(\frac{L_1}{L}\right)^4 \left(\frac{S_1}{S_2}\right)^{1.5} \left(\frac{T_2}{T_1}\right)^{1.1} \quad (6\text{–}6)$$

where

L_1 = proposed lock gate length
L = Claiborne model lock gate length
S_1 = proposed lock submergence
S_2 = corrected Claiborne submergence
T_2 = corrected Claiborne opening time
T_1 = proposed lock opening time

P_1 and P are as described in equation 6–1. However, P is the pintle torque from the Claiborne Lock. The bottom clearance factor C is similar as discussed above for mechanical linkages and described further below for direct connected linkages.

e. To calculate the torque on the pintle for direct connected cylinder linkages, it is necessary to scale the torque values from the Claiborne lock. (See Appendix C for more information on this calculation.) The necessary information from the Claiborne lock to calculate the factor can be found in Table 6–3. The measured pintle torque values (P) from the Claiborne lock at each gate position are listed in Table 6–4. Each of these values must be multiplied by the torque scale factor to obtain the correct torque at each position for the proposed lock.

Table 6–3
Assorted characteristic values of the Claiborne lock

Nomenclature	Variable	Claiborne Lock Opening	Claiborne Lock Closing
Gate Length	L	48.0 ft	48.0 ft
Submergence Note $S=S_2$	S	23.6 ft	23.6 ft
Time Note $T=T_2$	T	109 seconds	140 seconds
Arc of Travel	K	71.57°	71.57°
Bottom Clearance		2 ft 6 in	2 ft 6 in
WES TR 2-651 Scalar Ratio = 48 ft/3ft	L_R	16	16
WES TR 2-651 Plate 33 Scaled Bottom Clearance	–	1.875 in	1.875 in

f. To calculate the torque on the pintle for direct connected cylinder linkages, it is necessary to use the measured torque values from the Claiborne lock at each gate position listed in Table 6–4.

Table 6–4
Claiborne lock measured pintle torque at specific gate positions

Opening	**Opening**	**Closing**	**Closing**
Percent Open	Torque P (kip-ft)	Percent Open	Torque P (kip-ft)
100 (0)	315	100 (0)	0
97.5 (.25)	270	97.5 (.25)	200
95 (.5)	200	95 (.5)	360
90 (1)	190	90 (1)	350
80 (2)	160	80 (2)	65
70 (3)	175	70 (3)	110
60 (4)	170	60 (4)	70
50 (5)	175	50 (5)	75
40 (6)	185	40 (6)	85
30 (7)	225	30 (7)	100
20 (8)	230	20 (8)	125
10 (9)	115	10 (9)	160
5 (9.5)	360	5 (9.5)	65
2.5 (9.75)	200	2.5 (9.75)	120
0 (10)	0	0 (10)	165

g. If the proposed lock gate has the same scaled bottom clearance (or greater) as the Claiborne Lock (1.875 in), then C equals 1.0. If the proposed lock gate has a scaled bottom clearance less than the Claiborne lock (1.875 in), then C will be greater than 1.0.

h. The Claiborne lock can be scaled using the WES TR 2-651 report and using the scalar ratio L_R of 16 and the scaled bottom clearance of 1.875 in. The Claiborne Lock bottom clearance is plotted in red as a datum in Figure 6–15 and values are shown in Table 6–5.

i. See Figure 6–16 for comparison curves for angular velocity of gates plotted against percent closed for Panama Canal linkage and for Claiborne Lock direct-connected linkage.

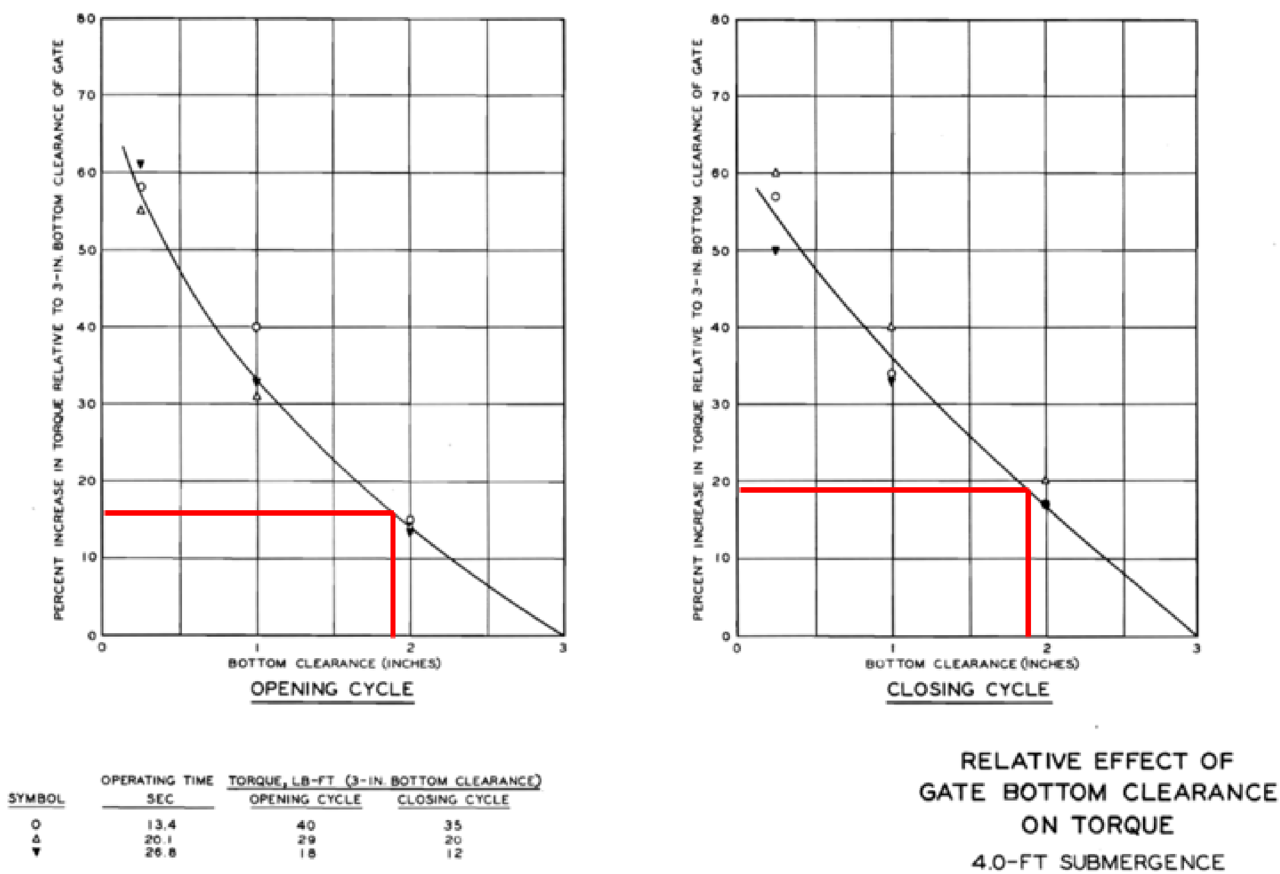


Figure 6–15. Relative effect of gate bottom clearance on torque for direct connected cylinder linkage Claiborne Lock (from WES Technical Report 2-651 Plate 33)

Table 6–5
Claiborne bottom clearance factor as a percentage

	Claiborne Bottom Clearance Factor (BCF_{CL})
Opening	16%
Closing	19%

j. The bottom clearance factor for the proposed lock can be derived in equation 6–7 as follows assuming the scaled bottom clearance is less than 1.875 in:

$$C = \mathrm{BCF}/BCF_{CL} \quad (6\text{–}7)$$

where BCF_{CL} is the scaled percentage Claiborne bottom clearance shown in Table 6-5 and BCF is the scaled percentage proposed lock gate bottom clearance.

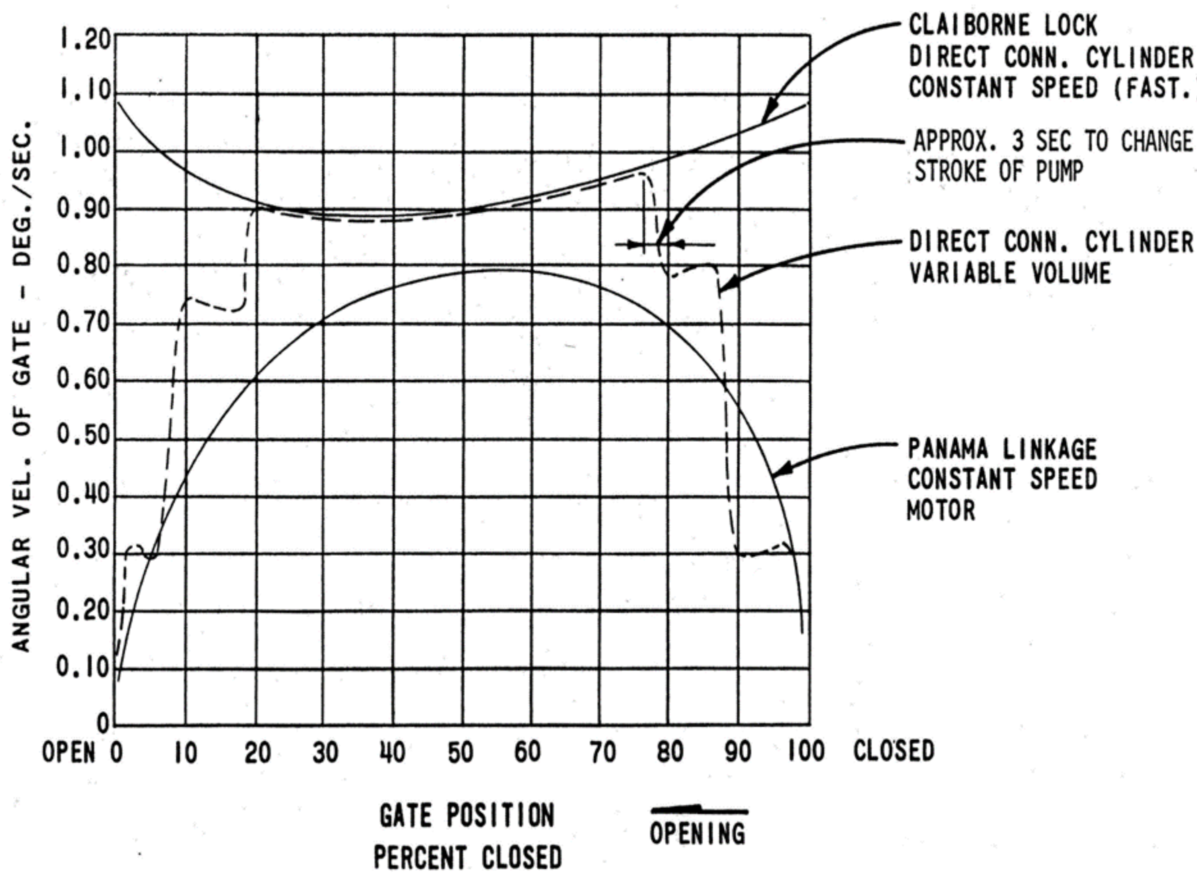


Figure 6–16. Gate velocity comparison curves Panama Linkage and Claiborne Lock

6–7. Miter gate operating machinery control

a. Hydraulically operated machines. A complete description of the basic types of hydraulic systems for locks, along with pertinent hydraulic system design criteria, is presented below and in Chapter 4. Control of these systems has used manual, solenoid-controlled, pilot-operated, and cartridge valves. Limit switches can be incorporated into the hydraulic cylinder or installed external to the hydraulic cylinder.

(1) With manual control, a small control stand is typically located over a recess on one lock wall near the gate machinery and is equipped with control valve operating levers. A schematic piping diagram of a manually controlled central pumping system is shown in Plate 8. This diagram includes the connections for the tainter valves and shows the complete lock operating hydraulic system.

(2) Recent control systems use solenoid-controlled, pilot-operated, four-way and solenoid-controlled cartridge valves to control the flow of oil to cylinders. This makes the system more flexible and enables the inclusion of an electrical interlock between the miter gates and lock fill-and-empty valves so that the lock chamber water level cannot be changed before all gates are closed.

(3) Changing the water level in the lock chamber before the gates are closed creates a swell head on the partially closed gates, which could cause them to slam shut, damaging the gate and/or gate machinery. This type of control is recommended rather than the manual control.

b. Lock control schemes. Chapter 17 discusses the lock control systems.

(1) Gate and valve control consoles are typically in the control building near the upstream gate. To enable the operators to view the downstream gate during opening and mitering, a multi-camera, closed-circuit television system should be provided. A simplified control stand also can be provided near the downstream gate for the operation of the lower miter gates.

(2) The control system should provide two speeds for miter gates and one speed for culvert valves. Electrical interlocks are mandatory and should be used in the control circuit to prevent inadvertent gate operation. The Inland Marine Transportation System (IMTS) Working Group has developed an Interlock Standard (USACE IMTS 2014) that should be referred to in developing proper interlock sequences. Multiple interlock diagrams are provided in this document. Refer to Chapter 17 for interlock diagrams.

(3) Limit switches located at the miter point of the gates and in the gate machinery recesses and the culvert valve recesses are used to prevent the upstream culvert valve from being opened when the downstream gate and/or valves are open and vice versa. A miter gate position limit switch is shown in Figure 6–17.

(a) Interlocks are used to prevent the gates from slamming or the lock chamber water level from changing when gates are mitered improperly. One miter limit switch should be located near the top of the gate. Miter gate limit switches installed on the bottom of the gate have been problematic since they are highly susceptible to being damaged by the large amount of debris near and around the gates. If one of the switches is damaged, it will need to be replaced by a dive team. This is expensive, adds risk to the maintenance program, and could cause a lengthy lock outage.

(b) If the gates fail to seal along the gate sill, it usually will be obvious to the operator because a boil will be seen below the gate. Since the bottom seal resistance of the gate will prevent the lower portion of the gate from closing properly, even though the top is mitered, only the top miter limit switch and the rack-mounted, gate-mitered limit switches must be actuated before the corresponding filling or emptying sequence can be started.

(c) A manual backup system should be provided for gate and valve control if the automatic control system fails. The manual control system should be independent of the automatic control system and bypasses all gate-valve interlocks. See Chapter 17 for specific interlock guidance and diagrams.

Figure 6–17. Miter gate position limit switch

c. Miter gate control equipment.

(1) The electrical control systems use either electromechanical relays or solid-state controllers or PLCs. This is discussed in Chapter 17. Control equipment typically consists of full-voltage magnetic controllers, limit switches, and control switches. Strut limit switches are used to shut off the motor if the strut stresses in either tension or compression are beyond a preset point. This will protect the strut and machinery if an obstruction is encountered.

(2) The limit switches used in previous designs were of the traveling-nut type in NEMA 4 enclosures with heaters. Cam-operated switches are now more widely used and available and can be incorporated into the machinery drive. It is recommended to specify that cam-operated switches should now be specified as metallic, as plastic cams

have been known to melt from the enclosure heater. Limit switches also can be used on the miter gate to provide an additional safety cutoff and prevent overtravel of the miter gates. Electrical valve-gate interlock features are mandatory and should be like that described above.

6–8. Miscellaneous equipment and systems

a. Machinery stops.

(1) To deal with ordinary construction tolerances, a means must be provided to adjust the miter gate machinery linkage at installation. For direct-connected cylinders, it is usually desirable to provide approximately 50 mm (2 in.) of overtravel at each end of the hydraulic cylinder to allow for adjustment. With the linkage connected and the miter and recess positions established for the gate, stops are installed and adjusted to limit the machinery motion to these extreme positions.

(2) For Ohio River-type machines that are operated by hydraulic cylinders, one stop is placed to stop the rack when the gate is mitered; another is placed to stop the sector arm when the gate is recessed. Details of this arrangement are shown in Plate B-7. For mechanical linkages with a sector arm and strut arm, the only adjustment available is in the strut arm and springs. The amount of adjustment in the strut arm springs is typically small or negligible.

b. Lubrication.

(1) A system should be provided to grease each miter gate pintle bushing and gudgeon pin as shown in Figure 6–18. The system may be automatic or manual, depending primarily on lock operator preference.

(a) An automatic system should dispense a measured amount of grease to each location automatically. Equip the system with a built-in programmable controller to allow variations in grease cycles and quantities to be provided. Since the grease systems have to be field-tuned for a particular lock application, the programmable controller should be provided.

(b) Special consideration should be given to the pintle bushing. Its grease arrangement should be designed to permit the installation of an O-ring seal and a grease return line that can be monitored to ensure grease delivery to the pintle bushing. Special consideration should be given to the layout and sizing of the grease lines to ensure proper operation and minimum pressure loss.

(c) Grease lines should be stainless steel pipe of adequate wall thickness for the anticipated pressures. The lines should be located in areas of the gate that afford the greatest degree of protection from damage due to ice and drift. This is typically in the quoin structure of the gate. The pumping unit should be located near the gate to minimize grease line length. Provisions should be made to remove the pumping unit if flooding is likely.

(2) Self-lubricated bushings can provide an alternative to greased bushings for the pintle and gudgeon pin, thus eliminating the need for greasing. The CERL evaluated field performance and conducted laboratory tests of commercially available self-lubricating materials used in lock and dam applications. See Chapter 3 for more detail and for discussion on self-lubricated materials.

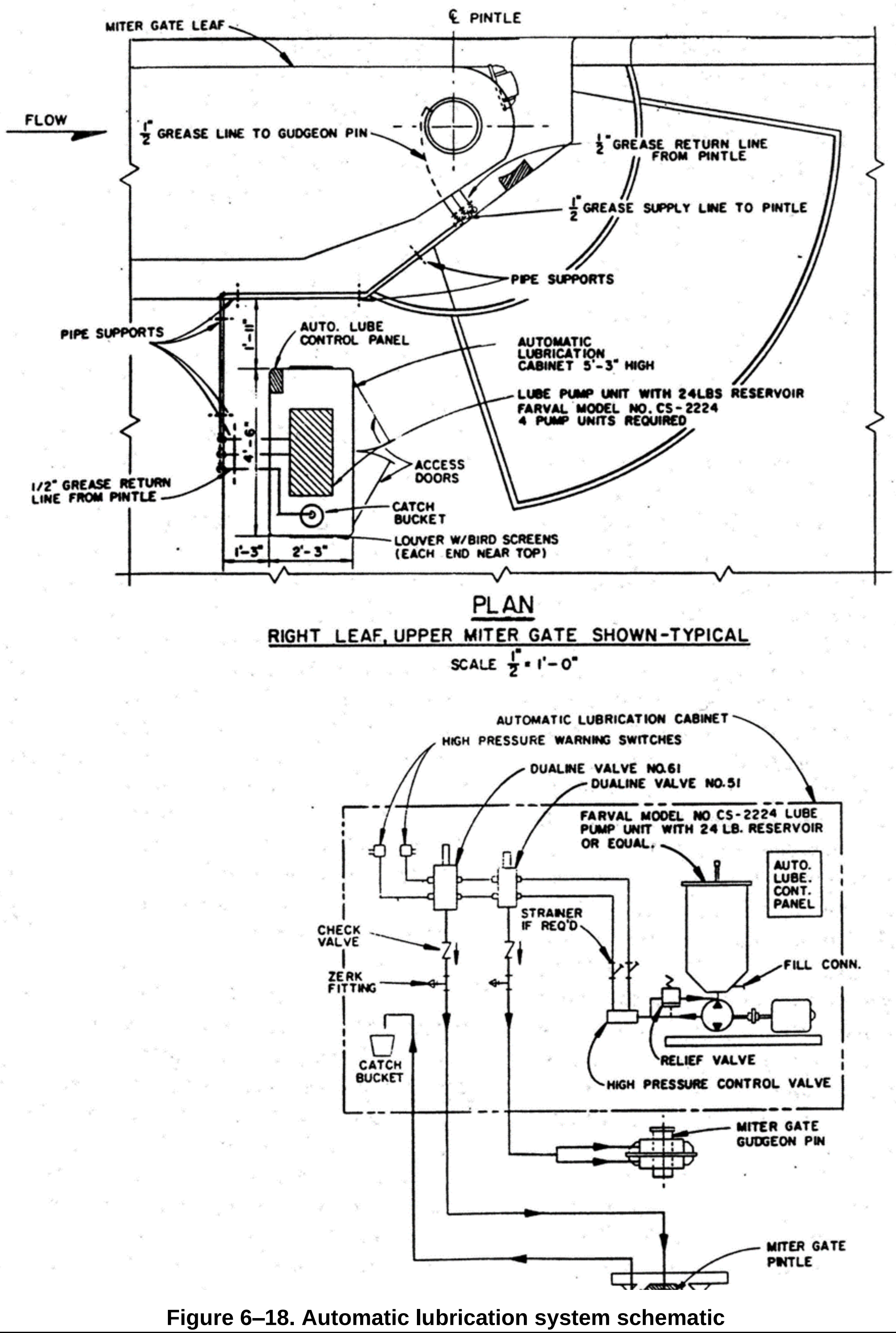


Figure 6–18. Automatic lubrication system schematic

c. Automatic gate latches.

(1) For miter gate drives with direct-connected cylinders, latches should be provided for holding the gates in the recess. The latches should be designed to latch the gate automatically when it comes into the recess. The latches should be released automatically each time a gate-close function is initiated. The system should be provided with latched and unlatched position indication. If latches are not provided, ensure the hydraulic cylinder design has adequate means for load holding to prevent the gate from drifting out of the recess as shown in Figure 6–19.

Figure 6–19. Miter gate latch Soo Locks Poe Lock

(2) Miter gate drives with mechanical linkages typically will not require a gate latch. However, this should still be evaluated for each design for any possible special circumstances such as ice flushing or passing large amounts of flows through the lock chamber. Gate latches should also be evaluated at both the recess and miter positions for any temporal loading.

d. Load-holding feature for direct-connected cylinders.

(1) A load-holding feature should be provided in the hydraulic system to prevent miter gates from drifting apart prior to the lock filling/emptying. Plate 26 shows a system designed to hold the gate leaves together against wind loading or small water surges prior to changing the chamber water level. Miter gates that drift before they are loaded can improperly miter causing overloading on the quoin or miter blocks.

(2) The load-holding feature should be activated by the lock operator depressing a pushbutton on an operator console. This system can be deactivated manually by the operator or is deactivated automatically when the gate, under maintain pressure, is opened or after the valves are opened for a predetermined time to allow an adequate head of water on the gates to keep them mitered. The maintain-pressure system should use the slow valve or the lowest pumping rate available.

(3) Lock 19 on the Upper Mississippi River incorporated this system in 2006. The intent was to keep hydraulic pressure on the cap end of the cylinder to continue to push the gates together while the gates are in miter. It also worked by reapplying the pressure by turning on both miter gate pumps, to push the gates together (add pressure because the gates are already in miter). Repressurization was prevented from automatically occurring when:

(a) Both river-wall tainter valves are operating, and the normal miter gate pump is in use.

(b) Any emergency operation function is enabled, and the available pump is being used to drive a tainter valve, then initiation of re-pressurization waits until all equipment (tainter valve) motion stops.

e. Overfill and overempty control system. The overfill and overempty system should be evaluated on a case-by-case basis and considered mainly on high-lift locks or locks with long, narrow approaches. A control system has been developed to eliminate overfilling and overemptying of the lock chamber. It measures water levels by sensing the back pressure of compressed air constantly bubbling through tubes extending below the surface of the water.

(1) This system compares the level of water in the lock chamber with that of the upper pool when filling and the lower pool when emptying and, at a predetermined time, begins closing the fill or empty valves, respectively. This dissipates the momentum of flowing water in the culverts, thereby eliminating lock overfill or overempty.

(2) The operators at locks who use the gate-mounted limit switches have developed an operating technique that eliminates or greatly reduces overfill or overemptying. As the lock fills or empties, the operator watches the indicating lights controlled by the gate-mounted limit switches. When the lights start going off, the operator opens the appropriate gate.

6–9. Pintle design and assembly

a. Pintle assembly. The pintle and related components support the dead weight of each leaf of the miter gate. Additional discussion on miter gate pintles is in Chapter 2. The unit is made up of four major components: pintle socket and bushing, pintle, pintle shoe, and pintle base. Pintle assemblies used for horizontally framed miter gates are generally two types: fixed and floating. Pintle bearing stress is defined as:

$\sigma = P/A_p$

where P is the resultant load from the miter gate onto the pintle and $A_p = \pi(r_2)$ where r_2 is the radius of the pintle.

b. Pintle socket and bushing.

(1) The pintle socket usually is made of cast steel and is connected to the bottom of the lower girder web with turned Monel™ or stainless steel bolts. The bolts are sized to carry the gate leaf reaction in shear but, as an added safety factor, a thrust plate should be welded to the underside of the bottom girder web, with a milled contact surface between the plate and pintle socket. The minimum plate size should be 31.75 mm (1-1/4 in.) in thickness and 0.3 m (12 in.) wide, with a length as required by the girder web.

(2) The socket encloses the bronze bushing, which fits over the pintle ball. A conventional allowable bearing stress of 10 Mpa (1,450 psi) is desirable but might not always be practical. An automatic greasing system allows a higher bearing stress but bearing pressures should not exceed 17 Mpa (2,500 psi).

(3) Several USACE districts are in the process of changing all miter gates with newer bolted-construction gates. These gates are about 1.5x heavier than existing, so bearing stresses on the pintles are extreme, more than 55 Mpa (8,000 psi). For the case where pintle loads will exceed the more conventional load of 17Mpa (2,500 psi) ensure that materials specified for the pintle ball and pintle bushing have a yield strength of a factor of 5 about the yield strength of the bearing pressure.

(4) In the case of these extreme bearing pressures, it may be desirable to use self-lubricated materials as they have much higher allowable bearing capacity. Self-lubricated pintles pose operational challenges. They do not handle debris well so they must be carefully designed with seals to prevent contact with debris.

c. Pintle.

(1) The pintle is generally made of cast alloy steel with a nickel content of 3% to 5%. The pintle should conform to ASTM A148 GR 80-40 or ASTM A27 GR 70-40. It is usually 0.25 to 0.50 m (10 to 20 in.) in diameter, with the top bearing surface in the shape of a half sphere and a cylindrically shaped bottom shaft. Pintles also have been produced with bearing surfaces of stainless steel deposited in weld passes to a thickness of not fewer than 4.8 mm (0.1875 in.) and machined to the required shape.

(2) Pintles for locations in salt or brackish water should be forged alloy steel with a stainless steel bearing surface. For use in salt or brackish water, pintles should be of forged alloy steel with bearing surfaces of corrosion-resisting steel deposited in weld passes to a thickness of not fewer than 3.2 mm (1/8 in.) and machined to the required shape. The pintle ball and bushing are finished to a 16 micro-inch finish where the two come in contact.

d. Fixed pintle. This type of pintle is recommended for new construction and major gate rehabilitation. The pintle fits into the pintle shoe, which is bolted to the embedded pintle base. The degree of fixity of the pintle depends on the shear capacity of the pintle shoe bolts. The pintle should be designed so that, after the load on the pintle is relieved by jacking, the pintle assembly is easily removable. See Plates 20 and 21 for a typical fixed pintle. The pintle base, made of cast steel, is embedded in concrete, with the shoe fitting into a curved section of the upper segment of the base. The curved section, of the same radius as the pintle shoe, is formed so that, under normal operation, the reaction between the shoe and base is always perpendicular to a line tangent to the curve of both shoe and base at the point of reaction.

e. Floating pintle. This type of pintle is not recommended for new construction or rehabilitations. It is discussed here because various navigation sites have used this design. The pintle is fitted into a cast steel shoe, with a shear key provided to prevent the pintle from turning in the shoe. The shoe is not fastened to the base, thereby allowing the gate leaf to move outward in case debris between the quoin and wall quoin prevents the leaf from seating properly. See Plates 18 and 19 for a typical floating pintle. Damage to the pintle bearing has occurred frequently with this type of pintle because of the relative movement between the pintle shoe and base.

(1) The movement can consist of the shoe sliding on the base during leaf operation from either the mitered or recessed position, until the leaf reaches approximately the mid-position, at which time the shoe slides back against the flange on the base. This type of movement generally is visually detectable and causes serious wear. However, an alternative to the floating circular shoe is to make the shoe three-sided, with one corner having the same radius as the circular shoe and attach a steel keeper bar to the embedded base in front of the shoe.

(2) This would prevent the shoe from rotating. Again, the degree of fixity would depend on the shear capacity of the bolts in the keeper bar. This alternative will meet the requirements of the fixed pintle and provide the capacity to minimize damage in case of emergency.

f. Pintle base. The pintle base is designed so there will be a compressive force under all parts of the base. The value of the compressive force on the concrete will vary from a maximum on one edge to a minimum on the opposite edge. Computations are based on that portion of the pintle above the point under consideration acting as a composite unit. The overturning moment can be found from the horizontal force on the pintle and will be resisted by the reaction on the section being investigated. The eccentricity of the vertical force can be determined by the angle the resultant makes with the horizontal and the distance between the horizontal force on the pintle and reaction on the pintle base.

g. Pintle location.

(1) The center line of the pintle (vertical axis of rotation) is located eccentric (upstream) relative to the center of curvature of the bearing face of the quoin contact

block. This center of curvature is on the thrust line. The center line of the pintle should be located on the point of intersection of the bisector of the angle formed by the mitered and recessed gate leaf work lines and the perpendicular line from the bisector to the quoin contact point, resulting in an offset of approximately 180 mm (7 in.), as in the details shown in Plate 21.

(2) Studies and experience show that eccentricities arrived at by this method will reduce the contact time between the fixed wall quoin and the contact block of the moving gate leaf sufficiently to minimize interference and binding between the bearing blocks. The 180-mm (7-in.) offset will be exact and constant for all gates with the same miter angle and distance from the face of the lock chamber to the recessed work line 0.37 m (1 ft, 2.5 in.), as shown in Plate 22.

h. Pintle bushings. Pintle bushings for lock gates have traditionally been grease-lubricated aluminum bronze. The aluminum bronze alloy typically used is C95400, meeting the requirements of ASTM B148 or ASTM B271. The aluminum bronze bushing is press-fitted into the pintle socket and bushing and secured by bolting to the socket.

(1) The bearing surface should be finished truly hemispherical and the pintle balls fitted to the bushings by scraping or should be lapped until uniform contact is attained over the entire bearing surface. This can be determined by testing with carbon paper or a similar media transfer technique.

(2) The pintle and bushing need to be match-marked. Show finished surfaces on the drawings, according to ASME B46.1. Compliance with surface requirements is typically determined by sense of feel and visual inspection of the work and comparing it to the Roughness Comparison Specimens of ASME B46.1.

(3) Grease-lubricated bronze continues to work well, but environmental issues created by pumping grease to the pintle bushing have started a shift toward considering self-lubricated pintle bushings.

i. Self-lubricated bearings. Additional discussion on self-lubricated pintle bearings is in Chapter 3. The designer must be aware of the limitations of self-lubricated bearing material. The bushings and pintle balls should be designed as a system so they work together. The self-lubricated composite materials also can be designed with much larger bearing pressures than conventional bronze for large gate loads. However, the bearing pressures for miter gate pintles are relatively low and generally well suited for self-lubricated bearings and bushings.

(1) More recent designs have been completed with self-lubricating material installed onto hemispherical or near-spherical pintle sockets with matching stainless steel pintle balls. See Figure 6–20. The self-lubricated material is shaped into pucks or discs recessed and secured to the socket bushing or the pintle ball. Conductivity indicator wear pins should be incorporated into the bearing surfaces to allow the project personnel to test periodically for bearing surface wear and to schedule replacement.

(2) Self-lubricated bearing material has been produced for many years. CERL has conducted a number of research projects to study the performance of self-lubricating materials, first for hydropower application and more recently for navigation lock and dam application. These reports include ERDC/CERL SR-04-8 (Race et al. 2004) and ERDC/CERL TR-99-104 (Jones et al. 1999). See Chapter 3 for more discussion. Appendix D provides some examples of miter gate pintle failures.

(3) Some materials and arrangements have worked better than others. Any material selected should be tested by an independent laboratory. The ERDC/CERL report SR-04-8 addresses this. The composite is typically fitted in a bronze housing through interference fit and fasteners. The pintle is typically manufactured of cast steel with bearing surfaces of stainless steel deposited in weld passes to a thickness of not fewer than 4.8 mm (0.1875 in.) and machined to the required shape.

(4) Selecting the correct type of self-lubricated bushing and specifying the proper design criteria (composite thickness, surface finish, interference fit, or clearance fit) for each application is critical to ensure a successful installation. ERDC/CERL SR-04-8 (Race et al. 2004) identifies USACE lock and dam projects that have used self-lubricated pintle bushings. Designers should contact the districts identified in this report to get an update on the information provided in the report.

(5) Some significant failures of these self-lubricated pintles have occurred. Inadequate seals around the base of the pintle ball allowed debris to infiltrate into the pintle ball socket. The debris then worked its way in between the pucks and pintle shoe, causing a total failure of the self-lubricated material. Careful design and consideration must go into the self-lubricated pintles to ensure sediment is blocked from entering the bearing.

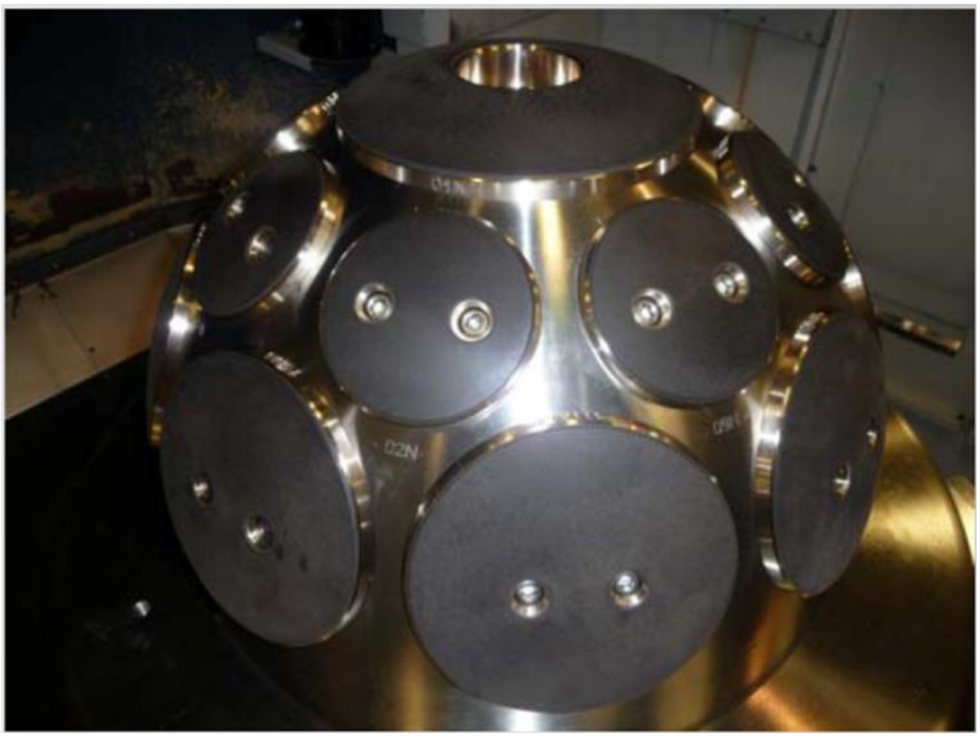


Figure 6–20. Pintle ball with self-lubricating wear pads

j. Structural monitoring and analysis in real time gate technology. Structural health monitoring (SHM) or(S)tructural (M)onitoring and (A)nalysis in (R)eal (T)ime of Lock Gates, or SMART gate technology, has grown in use across USACE. Several projects, including Bonneville, The Dalles, Lock 27 on the Mississippi, Greenup, Meldahl, and Racine are using equipment that allows real-time damage detection. Structural health monitoring equipment and components have been primarily adopted on miter gates, but their application is possible on any type of moveable gate.

(1) There is no standard conventional equipment or design to follow for implementation of SMART gate technology. A strong source of technical information regarding the different types of sensors, gauges, and accelerometers is available in EM 1110-2-1908. The design of a structural health monitoring system will require technical review from the INDC MCX.

(2) ERDC has extensive research and development of SMART gate monitoring technology, but they are not considered an MCX, and do not typically provide design or review guidance. ERDC may be available to provide indicative designs or provide sample equipment catalog equipment on request.

(3) Design of a SMART gate system requires team members with significant knowledge of electrical systems and should include members with significant knowledge of current market components and emerging technologies.

Chapter 7
Sector Gate Operating Machinery

7–1. General description

Sector gates are used on both storm protection (hurricane protection) and lock gates. See Figure 7–1 below for the surge barrier gate on the Inner Harbor Navigation Canal (IHNC) in New Orleans. Their primary advantage, as explained below, is they can operate with differential head on either side of the gate. The topic of this chapter is horizontally swinging, vertically hinged sector gates. Gates rotating about a horizontal axis used for flood protection, such as those used at the Thames Barrier in the United Kingdom, are also described as sector gates, but USACE has very limited direct experience with this type of gate. As such, these types of gates are not covered in this manual.

a. The sector gate consists of two gate leaves, each made of a curved skin plate, with a framed structure linking the skin plate back to a point of rotation located at the skin plate's center of curvature. When open, the gate leaves are within recesses at either side of the navigation channel. Operating machinery is employed to rotate the gate leaves across the channel, meeting at a vertical seal at the center, thus affecting a closure. Gate structure is generally made of a combination of horizontal frames and vertical trusses. Construction material is typically of wide flange steel beams or pipes; however, a recent study has indicated composite material construction could provide a lower life cycle cost in some applications.

b. Hydrostatic forces on the skin plate act in a radial direction and, as such, are orthogonal to the line of action for the operating machinery, which acts tangentially to rotate the gates leaves. The design of a sector gate ensures that the hydrostatic forces across the skin plate do not directly counteract the operating machinery; however, they still do contribute to the frictional load at the point of rotation. The sector gate, thereby, is better suited for operation in the presence of differential heads than the miter gate.

c. A general discussion and design criteria for three types of sector gate operating equipment for lock application are presented. They include wire rope and drum, rack and pinion, and direct-acting hydraulic cylinder. Detailed sector gate structural description and design information is presented in EM 1110-2-2107. Details regarding the sector gate machinery design calculations are provided in Appendix C.

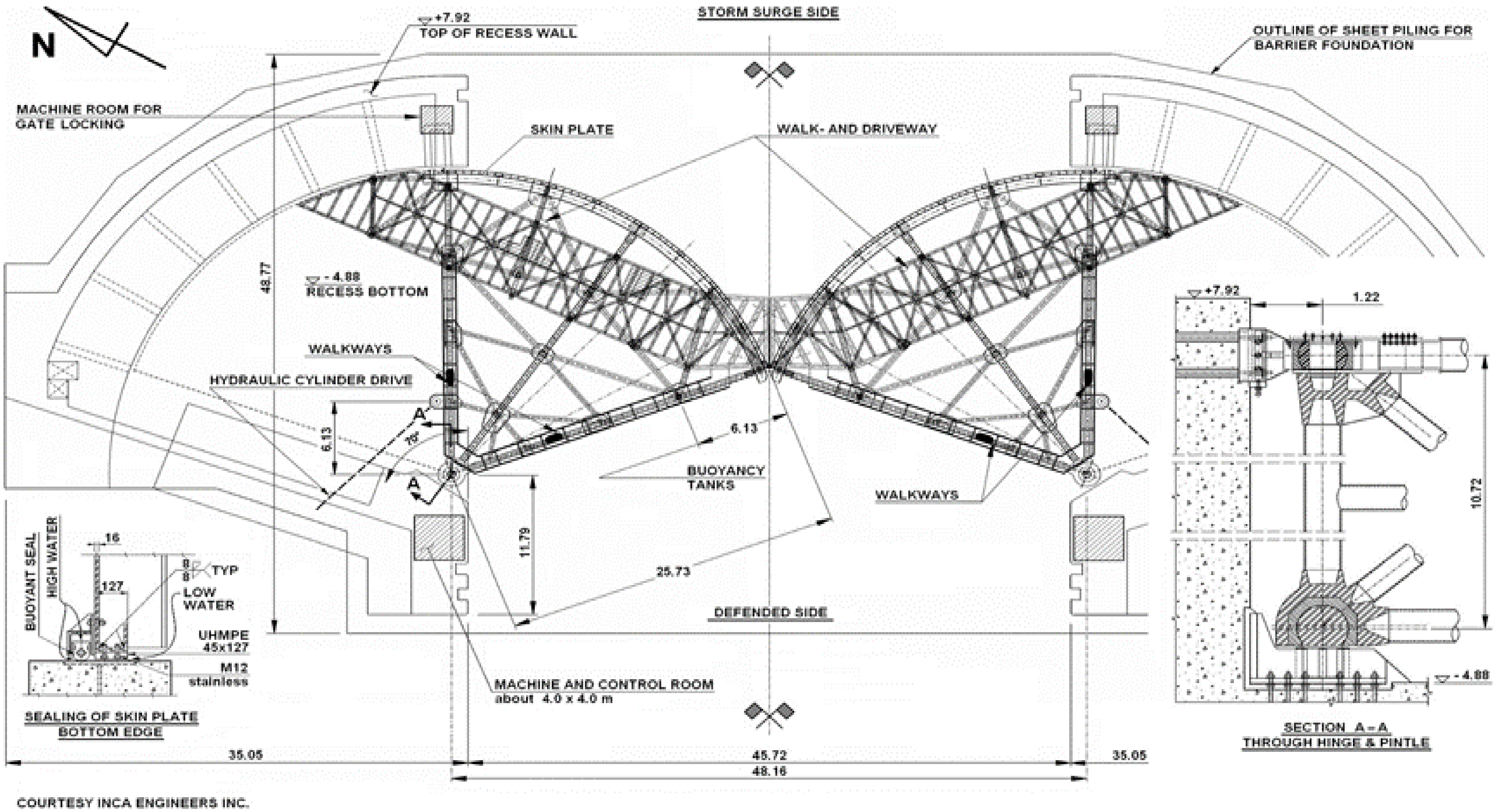


Figure 7–1. New Orleans Inner Harbor Navigation Canal surge barrier sector gate

7–2. Operating system descriptions and selection criteria

a. Design. Sector gates traditionally have been driven either by a wire rope-and-drum mechanism, shown on Plate 34 in Appendix B, or by rack and pinion, shown on Plate 35. A third design uses a direct-acting hydraulic cylinder, as shown on Plate 36. The direct-acting hydraulic cylinder has been around for several years but is not in widespread use. The track along the gate face where the rack would be placed or where a wire rope typically would lay generally requires some interruption in the vertical seals for passage of the rope, providing a leakage point near the top of the gate.

b. Wire rope and drum. The wire rope-and-drum mechanism was designed to be an inexpensive method of operating infrequently used gates, such as floodgates. Wire rope systems, or similar winch or capstan systems, also may be employed as a backup system. A disadvantage is that the wire ropes tend to lose tension with use, requiring periodic re-tensioning and replacement. Also, because the wire rope drum position does not accurately correlate to the gate position, limit switches must be located on the gate or in the gate recess, potentially exposing them to damage.

c. Rack and pinion. The rack-and-pinion mechanism is used mainly on lock gates or gates that have a high frequency of use and floodgates of any substantial size (Figure 7–2). The rack-and-pinion system is the most common type selected today. This type of system allows simple operation and little maintenance on the major load-bearing mechanical components. Once the rack-and-pinion mechanism is aligned, there is no need for continual adjustments. In addition, the gate drive pinion gear accurately correlates to gate position, thereby permitting the use of limit switches that can be located to operate directly from the machinery.

(1) The rack-and-pinion gears should have a diametrical pitch of 1 or more to minimize the effects of changes in gear clearance resulting from the relative radial movement of the gate rack-and-pinion gears. Additionally, to facilitate initial alignment and future adjustments, it is recommended that adjustment in the radial direction (with respect to the gate leaf) be built into the pinion mounting, and both radial and vertical adjustment, such as slotted bolt holes and shim stacks, be built into the rack mounting.

(2) Wear in the gate’s hinge and pintle eventually results in a tightening of the gear mesh. However, by this time, it is usually wise to either replace or rotate the gate bushings. Thermal expansion and contraction will also impact gear mesh. Gears should be set such that at maximum expected thermal expansion they will not cause binding. Rack-and-pinion mesh should be set per equation 7–1 below.

$$\Delta = L * \alpha * (Tmax - T) \tag{7–1}$$

where:

Δ	=	the pitch line separating distance between the rack and pinion gear
L	=	the distance between the centerline or axis of rotation, for the rack and the pinion
α	=	the coefficient of thermal expansion for the material of construction for the main structure of the sector gate
$Tmax$	=	the maximum temperature the gate is expected to reach. 60 °C (140 °F) has previously been used as a conservative value for dark, painted gates in direct sunlight
T	=	the temperature at the time of installation/setting of the pitch line separation

Figure 7–2. Hydraulically operated pinion gear and rack

d. Direct-acting hydraulic cylinder. Direct-acting cylinders (Figure 7–3) are often used on gates with the hydrodynamic feature generally referred to as “ears,” which complicates implementation of wire rope or rack-and-pinion systems. However, use is not limited to gates with ears. The simplicity of the system may prove advantageous over other systems, particularly on smaller gates or where forces are small, such that the cylinders do not become prohibitively large. Mechanical linear actuators, discussed in paragraph 4–4, could be used in a similar arrangement to hydraulic cylinders in this application.

(1) To reduce the cylinder’s stroke length, the cylinder’s rod end is attached to the gate’s top frame near the hinge and at an operating radius that is approximately 1/5 that of either the rack-and-pinion or cable-and-drum mechanisms. The short operating radius and non-tangential component of the cylinder force impose higher forces on the

gate and machinery than the previous two designs. Other disadvantages may include the size of the hydraulic cylinder, which generally is larger than any individual components of other gates.

(2) The advantages of the direct-operating cylinder are as follows: The operating system includes fewer machinery components. The cylinder is self-aligning with the gate. Limit switches can be built directly into the cylinder where they are not easily damaged. All machinery is located on the protected side and does not require an interruption to the vertical seal.

Figure 7–3. Hydraulic cylinder-driven sector gate, New Orleans Inner Harbor Navigation Canal

e. Power transmission. Mechanical and hydraulic are the two types of transmissions that provide power to the three gate-operating mechanisms described above.

(1) The hydraulic transmission usually consists of an electric motor-driven hydraulic pump, control valves, and either a direct-acting hydraulic cylinder or a hydraulic motor. Hydraulics provide flexibility in control and physical layout. They are particularly suitable for gates where routine operation can be ensured. Hydraulic drive systems design should include cross-over relief or a counterbalance valve to prevent an external driving load from over-pressuring the hydraulic motor or cylinder. Valves should be selected carefully to ensure smooth operation without surging or pulsing of the gate.

(2) The mechanical transmission usually consists of an electric motor, motor brake, and multiple shaft speed reducer. Mechanical transmissions are dependable and require little maintenance and are more tolerant of long periods of intermittent use,

which makes them suitable for floodgates. However, where danger of flooding of the machinery recesses are of concern, hydraulic systems tend to be more resilient, provided HPU and control systems are protected. Achieving equivalent gear reduction with a mechanical system tends to be more expensive than by hydraulic systems.

7–3. Design considerations and criteria

Operating loads necessary for consideration in machinery design include the following: loads induced by hydraulic head conditions during operation (water elevations and differentials across the gate); frictional loads induced by gate weight; and other frictional loads such as friction between the bottom seal and embedded seal plate. Wind load may also be considered when non-negligible. Additional loading should be considered in installations where silt buildup is anticipated. See Appendix C.

a. Hydraulic loading on sector gates is produced from direct heads and reverse heads. A direct head (or normal head) is a head differential across the gate with the highest water elevation on the convex side of the skin plate. For a reverse head differential, the highest water surface is on the concave side of the skin plate. Under direct heads, sector gate tests have shown that the loads created by flowing water tended to close the gate but were considerably less than those observed under reverse heads. Reverse head loads on the gate by the flowing water tended to close the gate.

b. Loads increased with gate openings up to 5 to 7 ft, then showed a tendency for a slow decrease at greater openings. Model data for gate openings of about 6 ft can be used to predict peak torque for various lower pools and reverse heads. Model and prototype tests demonstrated that the major loads on the gate are caused by structural members in the immediate vicinity of the skin plate at the miter noses of the gate leaves and by the side seal bracket that blocks side flow at the recess edge of the skin plate. Timber fenders, which are offset from the skin plate, have a negligible effect on forces.

c. Operating forces from direct heads considered in calculations include the following: Direct head forces are resolved to the total hinge and pintle reactions, which determine the friction from the pintle and hinge during operation. Direct head imparts hydraulic forces on the seal bracket. Direct head increases the contact force at the bottom seal, increasing seal friction.

d. Operating forces from reverse heads are loading affecting hinge and pintle friction, hydraulic forces on the seal brackets, hydraulic forces on the vertical steel members near the nose of the gate, and friction from reverse head seals. Depending on the construction of the bottom seal, additional bottom seal friction might not be created during reverse heads, or seal friction might be relieved by a reverse head.

e. Unpredictable forces such as those caused by silt, debris, wear, wind, and construction inaccuracies should be accounted for by applying a 1.5 application factor to the calculated loads. Ice loading should be calculated separately, then added to all other calculated loads.

7–4. Determination of machinery loads

When determining operating loads for a sector gate, WES TR H-70-2 and Appendix A (USACE 1971a) should be used as a guide. Details regarding the sample calculations for determining closing loads with a reverse head are provided in Appendix C. However, if a gate design varying considerably from the type shown in the report is used, model studies to determine the loads should be performed.

a. Hydraulic loads.

(1) Difficulty was experienced in the design of the first sector gates when operating under reverse heads. Prototype tests showed that hydrodynamic forces on the vertical steel member near the nose of the gate created much greater loads than anticipated during design. As a result, extensive tests were made to obtain operating hydraulic forces on sector gates and to account for the hydrodynamic forces. These tests made by WES are published in the following reports, which are noted in Appendix A:

(a) WES TR H-70-2 (USACE 1970).

(b) WES Miscellaneous Paper H-71-4 (USACE 1971b).

(c) WES Technical Memorandum (TM) 2-309 (USACE 1951). The appendix covers gate operating forces and modifications to reduce operating forces.

(d) Coastal and Hydraulics Laboratory (CHL) TR-03-3.

(2) The tests by WES resulted in the design of an improved gate with operating forces approximately 40% of those experienced in the original designs. The third and fourth reports are for tests conducted on models of modified sector gates referred to as ear sector gates.

(3) In plan view, an ear sector gate resembles a traditional sector gate with the addition of two protruding radial members at each end of the gate called ears. Ear sector gates are designed to pass water through the center of the lock and through the gate recesses as the gates open. This enables the lock chamber to fill and empty at a faster rate and with less turbulence, because not all the water is entering or leaving the lock chamber through the center opening as is done with non-eared gates.

(4) This feature is of greater importance with increase in lock lift. The design also prevents siltation in the gate recesses. Algiers Lock, located on the Intracoastal Waterway and the Mississippi River at New Orleans, has ear sector gates designed for a differential head of 5.6 m (18.5 ft), about 3.6 m (12 ft) higher than would be practicable with non-eared gates.

b. Computing loads. After maximum operating conditions on the sector gates have been determined, the gate operating loads should be computed both for normal flow and reverse flow conditions. Loads due to reverse head conditions usually will establish the size of machine to be used; however, loads due to normal heads should be checked.

(1) Water load on the gate will be created by the projected width of miter beam, skin plate rib, and seal bracket. Figure (a), Plate 44, of WES TR H-70-2, Appendix A (USACE 1971a), gives the peak closing pintle torque for the improved type of gate. These torque curves are reproduced for this manual (see Appendix C for more details). This torque is based on a gate having a total projected width of miter beam, skin plate rib, and seal bracket of 30.375 in. (17.875 in. + 8 in. + 4.5 in. = 30.375 in.). The torque should be corrected, according to Froude's law of similarity, to the lengths used on the proposed gate based on the scalar ratio.

(2) For gates varying considerably from the type shown in the report, initial load estimates prior to completion of a model study can be calculated assuming a linear profile between pool-to-pool water elevations across the channel-side face of the total projected width of the miter beam, skin plate rib, and seal bracket and the reverse head water elevation on the recess side of the same components.

(3) As such, the estimated closing force would be half the differential reverse head acting on the projected width of those components over the average submerged height of the miter beam. Hinge friction and pintle friction torque should be added to the above water load to determine the total machinery load and a 1.5 safety factor applied for machinery sizing. Reference should be made to Technical Paper H-71-4, paragraph 14 (USACE 1971b), along with establishing reasonable values of hinge and pintle friction. Details regarding the typical calculations for determining loads on the improved type of sector gate are provided in Appendix C.

c. Hinge and pintle friction. Hinge and pintle frictional torque is the torque generated at the bearing surfaces between the stationary part of the bearing and the movable part. The bearing load is the load resulting from the gate weight, hydrostatic loads, and reaction loads generated by the operating machinery. Based on using self-aligning hinge and pintle, a bearing frictional factor of 0.25 for steel on bronze should be used. If either a cylindrical hinge or pintle is used, the designer should anticipate much higher frictional loads resulting from possible construction misalignment. WES has found that cylindrical hinge and pintle friction for Calcasieu Saltwater Barrier sector gates were 4.5 times the calculated value.

d. Bottom seal friction. Bottom seal friction is caused by the differential hydrostatic head across the seal and force of pre-compressing the seal 6.4 mm (0.25 in.). A coefficient of friction of 1.0 should be used, even for Teflon-coated rubber seals. Initially, the seals on a sector gate are set with approximately 0 to 0.8 mm (0 to 1/32 in.) of clearance. The 6.4 mm (0.25 in.) pre-compression accounts for gate sag, hinge and pintle wear, and variations in gate temperature between submerged members and non-submerged members.

e. Contingencies. After the gate loads are calculated, an application factor of 1.5 should be applied to the combined friction and hydraulic loads. The application factor accounts for transient and unpredictable forces such as those resulting from silt, debris, hinge and pintle wear, and construction inaccuracies.

f. Machinery components. General criteria applicable to machine components are in Chapter 2.

7–5. Operating procedures and controls

Sector gates usually are controlled from a small control house adjacent to each pair of gate leaves. For electric motor drive, the control equipment consists of the combination of full-voltage magnetic controllers, limit switches, control pushbuttons, and switches arranged to produce the desired operating sequence. For fluid motor drive, the speed of the gate is varied by controlling the flow of oil to the fluid motor either by throttling or by using a variable-stroke piston pump. With this system, control valves can be controlled either manually or electrically.

a. Low-head locks. Low-head locks are locks that have a lift of 1.5 m (5 ft) or fewer. To fill and empty a low-head sector gate lock chamber, the operator opens the filling or emptying sector gates from 0.3 to 0.9 m (1 to 3 ft). The gates then are held in this position until the differential water level across the gates is within 150 mm (0.5 ft). At this time, the gates are opened fully. See Figure 7–4 sector gate from T.J. O'Brien Lock. A single operating speed of between 20° to 35° of gate rotation per minute with cushioned gate start and stop has been found satisfactory. With a hydraulic transmission, cushioned gate start and stop can be incorporated into the hydraulic system using ramp-proportional valves or other flow control devices. Machinery brakes also should have cushioned movement.

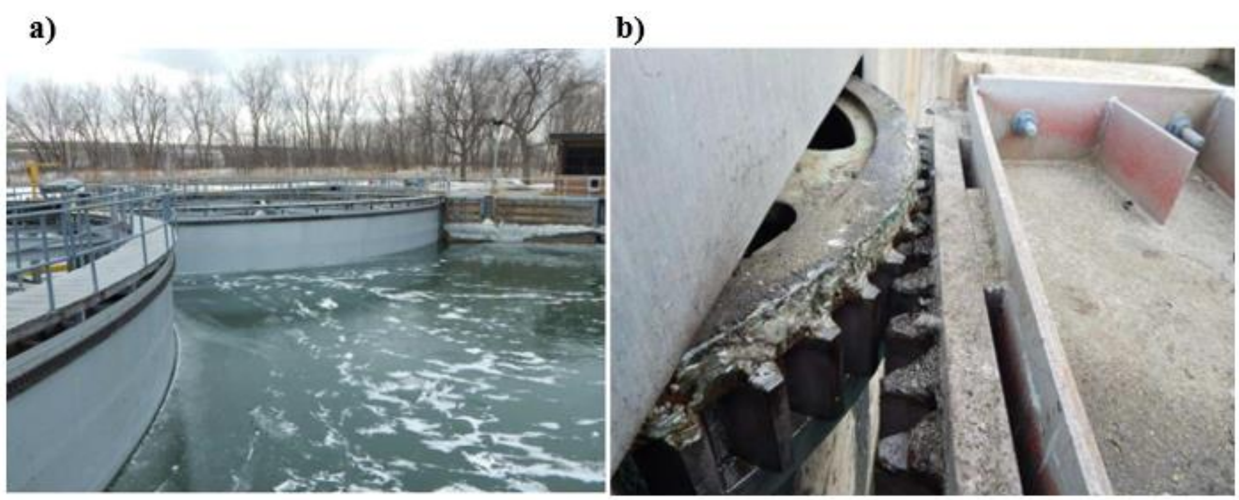


Figure 7–4. T.J. O'Brien Lock, Illinois Waterway

b. Flood control gates. Single speed operation of between 5° to 7° of gate rotation per minute has been found satisfactory. At this low speed of operation, cushion gate start and stop are not required. The sector gate drive at the New Orleans West Closure complex is shown in Figure 7–5. The West Closure complex includes a 225-foot sector gate.

c. Medium to high lift gates. Medium to high lift locks are locks with lifts of more than 1.5 m (5 ft). For medium to high lift locks, where the gates are used to fill and empty the chamber, a two-speed operating system is required with a slow initial opening speed. The slower speed enables the lock operator to accurately set the gate opening to prevent excess chamber turbulence. The slow speed should be field adjustable with a range of from 1.5° to 5° of gate rotation per minute. A higher speed of 20° to 35° of gate rotation per minute can be used once the differential head across the gate is within 150 mm (0.5 ft). Starts, stops, and changes in gate speed should be cushioned.

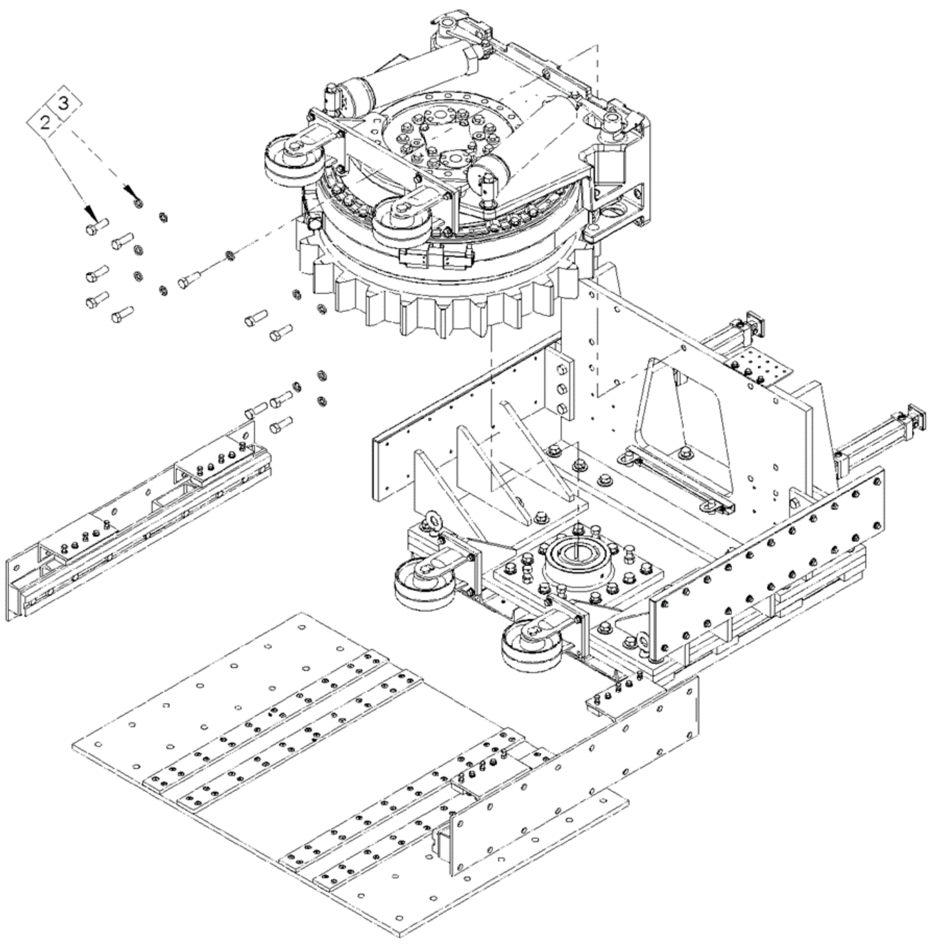


Figure 7–5. West Closure complex sector gate drive

7–6. Special design considerations

a. General. The gate operating machinery is crucial to the operation of a lock or floodgate structure. Reasonable means should be made to incorporate into the design a high degree of reliability and serviceability.

b. Auxiliary drives. For most hydraulically driven gates, an auxiliary drive has proven valuable. The auxiliary drive should be basic and provide an operating speed that is half to a quarter of that of the primary drive. The auxiliary drive should consist of a pump and motor connected permanently to the gate's hydraulic system.

(1) A portable drive system for a hydraulic drive is shown in Figure 7–6 can also be used. Other hydraulic system components such as valves, solenoids and hoses should be accessible and easily replaceable. A dual pump and motor arrangement where both pumps operate in parallel for primary operation, with each pump providing half capacity redundancy should the other fail, is an acceptable means of providing an auxiliary drive.

(2) Mechanically operated gates normally do not require an auxiliary drive. However, flood control gates with mechanical drives should have auxiliary power sources such as an auxiliary generator, hand crank, or air motor with air storage. When incorporating a hand crank mechanism, consider the required time to operate such a system and possibly alleviate it by providing operability with a portable actuator.

(3) The incorporation of pad eyes or bollards into the gate structure for closure by alternate means (portable winch, tow boat, etc.) might be prudent for some applications. A backup winch system using wire rope is shown in Figure 7–7. This can be used to close the sector gate in the event of a hydraulic system failure.

Figure 7–6. Auxiliary power unit for Bayou Dupre Gate, New Orleans

Figure 7–7. Backup winch system

c. Hydraulic system contamination. Hydraulic-driven sector gate drives (on storm barriers) are vulnerable to water contamination since they can be exposed to hurricane-force winds and driving rain. This is something the designer has to mitigate. Water in the hydraulic system is one of the primary reasons for hydraulic component failures. Water usually infiltrates the system due to the moisture in the air that is exchanged in the reservoir through the breathers. To eliminate this source of contamination, the hydraulic reservoir should be in a dehumidified room and/or be equipped with a bladder that prevents direct exchange with outside air. Chapter 3 provides additional discussion on this issue.

d. Material selection. When practicable, machinery components subject to damage should be constructed from field-welded materials. This is especially important for items that have a long lead time to acquire or require substantial effort to replace, such as gear racks, drive pinions, and machinery bases.

e. Generator backup. All sector gates used for storm (hurricane) protection must be provided with generator backup power (Figure 7–8). An automatic transfer switch (ATS) that will transfer utility power to generator power should be provided when consistent with operational protocols and considerations specific to the installation in question. Generators should be installed in a protected building. Generators should be sized for the full operational capability of the gate, including simultaneous operation of any lighting and other ancillary systems.

Figure 7–8. Bayou Dupre, New Orleans, backup generator

7–7. Pintle and hinge design

a. Sector gate operation is highly dependent on a functioning bearing system at the gate hinge and pintle. It is critical the hinge and pintle bearings be designed, constructed, and maintained correctly.

(1) The hinge and pintle are the reaction points against the pool-to-pool head load when the gate is closed; they also provide support to accommodate the lateral load from the cantilevered weight of the gate. In addition, the pintle receives the vertical dead load of the gate.

(2) The hinge transfers the horizontal load into the concrete wall. A high degree of reliability throughout the service life should be incorporated into their designs. Spherical bearings typically are used to prevent binding in the case of minor misalignment. Additional discussion on pintle bushings and self-lubricated bearings follows and is also in Chapters 2 and 3.

b. Traditionally, grease-lubricated bronze bushings running against stainless steel bearing surfaces have been used for sector gate hinge and pintle bearing systems. The bearing relies on a layer of grease to provide lubrication and, as such, bearing pressures must be at a low enough level to maintain adequate film thickness. Recommended maximum static bearing pressure should be no more than 2,500 psi, with loading during operation not to exceed 5,000 psi. Design of a grease-lubricated bearing system should include the proper running clearance, surface finishes and bearing material properties, the grease lubrication system, and the arrangement of any seals used.

c. Clearance on large greased hinge and pintle bearings should be medium running fits, class RC5 to RC6. Surface finishes should be specified as 0.4 microns (16 micro-inches) or better. Refer to Chapter 2 for appropriate material selection for bronze bearing components. Surface hardness of the stainless steel bearing surface should be minimum 40 Rockwell C. Bushings and balls may be matched fit and lapped to one another prior to installation to ensure fit and finish. In addition to mechanical material properties, selection of a bushing material also should include considerations of its position on the galvanic scale relative to the pintle ball material to avoid galvanic corrosion.

d. The basic grease lubrication system includes manual grease fittings located in an accessible location, with grease lines of stainless steel tubing run to ports on through the bronze bushing.

(1) The bushing should be fixed within the housing, such that a grease pathway is maintained, and proper fit is ensured by eliminating the possibility of wear induced by bushing rotation within the housing. The bearing surface of the bronze bushing should incorporate grease grooves to adequately distribute the grease across the entire bearing surface.

(2) The pattern of grease grooves and number of grease ports should be designed according to the size and range of rotation specific to the bearing. In locating grease ports, priority should be given to introducing grease to the loaded side of the bearings. Automatic grease dispensers might be appropriate in gates with frequent operation.

(3) Recirculation systems incorporating grease return lines and/or environmentally benign grease might be necessary when grease systems are used in environmentally sensitive locations. The preferred alternative in such cases is to use a greaseless bearing system. Grease lines are typically field fit but should be run so that they are protected by the gate structure as much as possible.

e. Seals generally are recommended on greased systems. Seals might be required to keep dirt and debris out, to keep the grease contained, or both, and should be designed according to their intent. When grease return lines are used, double-acting seals should be used. Note that if return lines are not supplied, the seal should provide some pathway for old grease to exit the bearing as new grease is pumped in. In this case, single-acting seals should be used, oriented according to their purpose of excluding contamination, but allowing grease to exit.

f. Self-lubricating or greaseless bearing systems have been used for various sector gate applications, including hinge and pintle bearings. These are used extensively in the New Orleans District and have generally worked well.

(1) Greaseless systems eliminate the need for grease lines, which are vulnerable to breakage below waterline, and prevent the introduction of grease into the marine

environment while providing a very low-friction bearing system. Using seals to exclude sediment is recommended when using these types of bearing systems on sector gate pintles.

(2) The West Closure complex sector gate uses self-lubricated bearings for both the hinge and pintle. This includes a 38-in. diameter hinge ball (Figure 7–9) and 36-in. diameter pintle ball. Projected bearing pressure is limited to 2,500 psi. Bushings machined to receive bearing inserts surfaced with self-lubricating material.

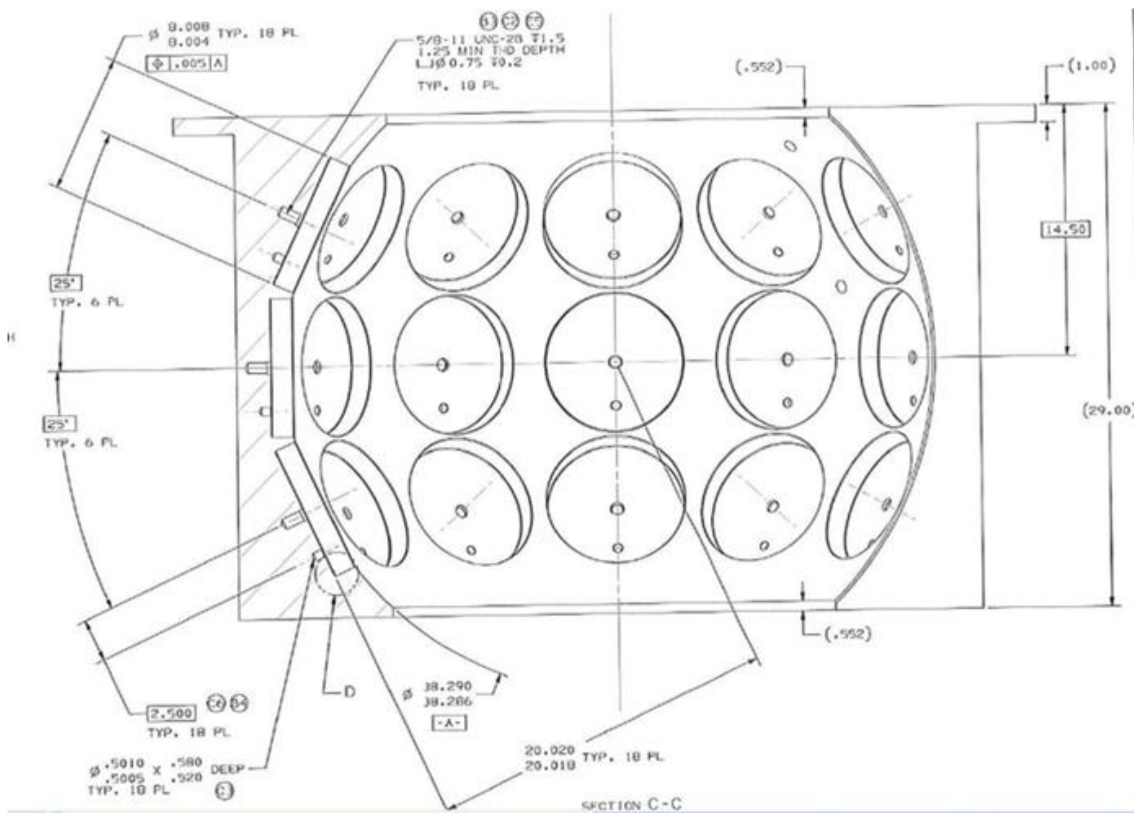


Figure 7–9. Hinge bushing West Closure Complex

g. Hinge and pintle assemblies are comprised of large components manufactured to tight tolerances. Incorrect fits and finishes might lead to binding or vibration, causing excessive component wear and increasing the required operating force. The pintle housing at the West Closure complex in New Orleans is shown in Figure 7–10.

(1) To avoid such issues, quality control should be addressed in the design specifications, and an expectation for a reasonable amount of quality assurance effort should be anticipated to ensure radial tolerances, spherical tolerances, and surface smoothness.

(2) For bearing systems using the assembly of multiple components, such as a self-lubricating puck-type system, tolerance stack-up could be an issue. Recommended is a robust quality assurance procedure using coordinate measuring machines, and/or

final machining of the liner material with the inserts in place. For greased bronze on steel, machinist dye or similar technique may be used to check for surface contact.

Figure 7–10. West Closure pintle housing

Chapter 8
Filling, Emptying, and Water Control Valves and Machinery

8–1. General description

On a river or canal, a lock separates an upper pool or reach from a lower pool or reach, and the differences in elevations of these pools are called the lift of a lock. The lower pool is also sometimes called the tailwater elevation of a lock.

a. During the filling of the lock chamber, the water volume (a product of the length of the chamber inside the gates, the width of the chamber, and the water level difference between the upper and lower pool) enters the lock chamber. This is done by gravity from the upper pool into the lock chamber until the water level in the lock is equal to (or level with) that of the upper pool. Emptying involves the transfer, also by gravity, of the water in the lock chamber to the downstream pool or reach. Filling and emptying valves and the associated machinery are integral to the filling and emptying of the lock chamber.

b. There are several types of filling and emptying systems possible with several different types of associated machinery. The different types of filling and emptying systems are related by the method by which water is brought into or exits the lock chamber. Filling begins with valves opening either in the upper lock crown or in the upper culvert. As the lock fills, the chamber water surface rises. For locks with sector gates, often the sector gates themselves are used to fill and empty the lock chamber. See Chapter 7. This is the case for example at the Chicago Locks (Figure 8–1) where the sector gates are opened and closed to fill the lock chamber. The advantage is there are no culverts or culvert valves. The opening speed of the sector gates, however, need to be controlled properly to eliminate excessive turbulence in the lock chamber.

Figure 8–1. Chicago Lock

c. The rate of rise is an important characteristic because the faster the rate of rise, the more difficult it is to provide a level water surface free from turbulence that may be unsafe to small craft in the chamber. The discharge into the lock is the product of the rate of rise and the plan view area of the chamber. The peak discharge is directly related to the lift and the type of filling system; and can sometimes be controlled with the lock valves.

d. The most common type of filling and emptying system used in USACE locks is a longitudinal culvert in the lock wall extending between the upper and lower pools. Each culvert has a streamlined intake at the upstream end and a diffusion discharge at the downstream end. Figure 8–2 shows a typical sidewall port filling system. EM 1110-2-1604 describes in depth all the different types of filling and emptying systems used for locks.

(1) Culvert flow is distributed in and out of the lock chamber by wall ports or secondary culverts in the floor of the chamber. Each culvert has two valves: one for filling and one for emptying the chamber.

(2) The filling valve allows the upstream pool to fill the chamber while the emptying valve remains closed. The emptying valve allows the chamber to drain to the downstream pool while the filling valve remains closed. Guidance on hydraulic design criteria including forces due to hydraulic loading can be found in EM 1110-2-1610.

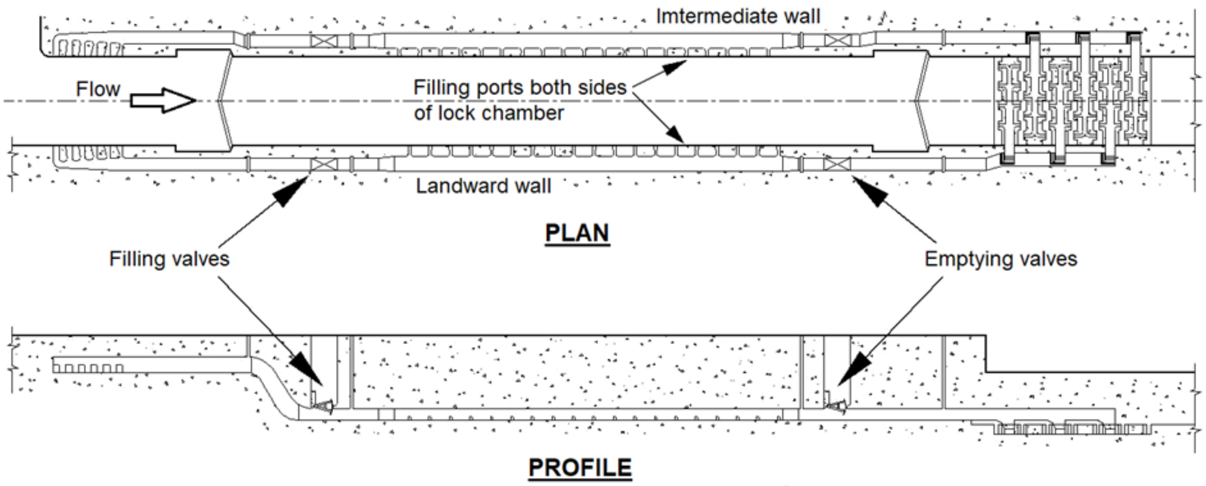


Figure 8–2. Sketch of a typical lock filling and emptying system using lateral side ports at Lock 1, Mississippi River

e. Vertical lift valves, conventional tainter valves, and reverse tainter valves are the three valve designs that are commonly chosen to control culvert flow and discussed in more depth below. Most modern locks use reverse tainter valves while older low-lift locks often use conventional tainter valves with the skin plate orientated to the flow direction. Other valve types sometimes used in culverts include Stoney valves, fixed-wheel valves, vertical slide valves, and rotary valves. The main distinguishing feature of a tainter valve is its curved section skin plate, where gate loads are transferred to a single-axis trunnion bearing system.

f. Culvert valves usually have a vertical access opening located on the top of the lock wall through which the valve is installed, serviced, and removed. This access opening extends from the top of the lock wall down to the installed culvert valve below. The access opening facilitates maintenance, construction, installation, and removal with a crane.

(1) Service access openings are important as they are often the most cited reason that vertical valves are used instead of tainter valves. The relatively small access opening required for vertical slide valves allows some design advantages.

(2) Tainter valve access requirements are larger than corresponding vertical valve access openings simply because tainter valves take up more space in the longitudinal direction. Bulkhead slots are typically provided on both sides of the valve to facilitate dewatering and maintenance. This allows dewatering of the valve well and maintenance of the valve without dewatering the entire lock.

g. Mechanical drive systems for culvert valves need the ability to operate the valve under differential head and flow conditions. Sometimes it is desirable under emergency conditions such as a power outage to have the valve close under its own weight even under head and flow conditions in the culvert. Tainter valves will generally have an advantage over vertical lift valves in this regard.

(1) It is often assumed that vertical slide valves do not close under flow, however, fixed-wheel valves and Stoney valves may be able to close under flowing conditions because of their roller trains. This depends on several factors, including the weight of the gate, the coefficient of friction, and the amount of water head on the gate.

(2) Tainter valves generally have more mass than a vertical gate, and a major advantage of tainter valves over vertical-type valves is the location of the mass relative to the bearing interface. In other words, the tainter valve has a large moment arm in relation to its trunnion bearing.

(3) If the culvert valve cannot be closed by gravity, the culvert valve machinery must be designed to ensure that adequate hoist machinery power is available under all conditions to both open and close the valve.

8–2. Lock filling and emptying time

The lock filling time and emptying time is usually a significant factor in the total transit time and affects lock capacity. The designer should be aware of how the filling and emptying valves affect this. A low-cost and simplified filling system can be used for a very low-lift lock of 3 m (10 ft) or less because it is likely that the hawser stresses and vessel forces in the lock chamber will be satisfactory within a short filling time. On the other hand, for a lock with a lift of 15 m (50 ft) or more, a more complex and sophisticated and, hence, expensive filling and emptying design is often necessary to achieve a satisfactory filling time while avoiding unacceptable hawser stresses and vessel forces.

Table 8–1
Range of design lifts at U.S. Corps of Engineers locks (from EM 1110-2-1604)

Range of Maximum Design Lift	Project Classification	Percent of USACE Locks
Less than 3 m	Very Low Lift	25
3 m to 10 m	Low Lift	60
10 m to 30 m	High Lift	15
Greater than 30 m	Very High Lift	Less than 1%

a. The factors affecting lock filling and emptying system design and performance become more important as differential head (lift) increases. Most of the documented problems such as vibration related to culvert valve designs have been for high-lift locks. USACE hydraulic lifts range from 3.2 ft (1 m) for Moore Haven Lock on the Okeechobee Waterway to 108 ft (33 m) at the John Day Lock on the Columbia River.

b. In general, filling times vary according to the lift, the size of lock, and the filling system used. Filling times vary from 5 minutes or less for small locks and low lifts to 15 minutes or more for large locks and high lifts. The low-lift locks on the Upper Mississippi

River have filling times from 8 to 10 minutes. Table 8–2 lists a sampling of locks and their associated lifts and filling and emptying times.

Table 8–2
Indicative hydraulic lifts and filling and emptying times for various locks

Lock	Waterway	Lift (m)	Filling and Emptying Time (minutes)
American Waterways			
Upper St. Anthony Falls	Mississippi River	14.9	8 minutes fill or empty
Lock 1	Mississippi River	11.55	10 minutes fill or empty
Lock 5	Mississippi River	2.7	5 minutes fill or empty
Lock 12	Mississippi River	2.7	10 minutes fill or empty
Lock 15	Mississippi River	4.8	7 minutes fill or empty
Mel Price	Mississippi River	7.3	10 minutes fill or empty
T.J. O’Brien	Calumet River	1.5	5 minutes fill or empty
Lockport	Illinois Waterway	12.8	22.5 minutes fill or empty
LaGrange	Illinois Waterway	1.3	10 minutes fill or empty
Emsworth Lock	Ohio River	5.4	8 minutes fill or empty
Marmet Lock	Kanawha River	7.3	8 minutes fill or empty
Markland Lock	Ohio River	10.6	6 to 9 minutes fill or empty
John Day Lock	Columbia River	32.6	39 minutes fill and 15 minutes empty
Bonneville Lock	Columbia River	21.35	9 to 13 minutes fill or empty
Ice Harbor Lock	Snake River	32	11 minutes fill and 14 minutes empty
Bankhead Lock	Black Warrior River	21	25 minutes fill or empty
Montgomery Lock	Tennessee-Tombigbee Waterway	9.1	4 minutes fill or empty

8–3. Machinery design criteria

The general design criteria for machinery components are in Chapter 2. Culvert valve machinery must be designed to raise the valve under flowing water conditions at the full maximum head differential. If the valve cannot be closed by gravity, the machinery must be able to close the valve under all head and operating conditions.

a. Operating speeds. Hydraulic design engineers should provide the gate operating speeds, including any pauses, to be used at the various head conditions planned for the specific lock location. Operating speeds are based on specific flow conditions designed to fill or empty the lock chamber without producing unsafe hawser stresses, air entrainment, or other operating conditions dangerous to the tows or their personnel.

b. Culvert valve closure by gravity. Many culvert valves in USACE are designed to be closed by gravity, including nearly all the valves on the Mississippi River.

(1) If wire-rope connected, the valve should provide sufficient weight to close, even under flowing water conditions, because the wire ropes are incapable of forcing the valve to close. The designer must ensure this during the design.

(2) The structural engineer should be aware that the operating machinery is not designed to force the valve down. Since the valve must lower due to its own weight, it is important that the structural designer compensate for any uplift hydraulic loads. EM 1110-2-1610 and ERDC TR-11-4 (Stockstill et al. 2011) both provide extensive discussion of these uplift tendencies with respect to valve design and head conditions.

c. Valve machinery design. Closing under flowing water conditions might be required where ice or debris flushing operations are typical, especially at locks with upstream lift gates. It is customary to design all valve machinery to be identical for economy of fabrication. The culvert valve machinery must be designed to ensure that adequate hoist machinery power is available under all conditions to close the valve.

d. Culvert valve hoist loads. The hoist design should account for the following loads:

(1) The gate connection load due to flowing water under the valve, typically referred to as downpull force. Loads should be calculated for the range of operation.

(2) The buoyant (submerged) weight of the valve.

(3) The weight of the operating equipment linkages or wire rope assemblies.

(4) The side seal friction.

(5) The trunnion bushing friction under maximum normal flowing water load.

(6) Bushing friction at other points in the drive.

(7) The head differentials across the top seal of the valve. Evaluation of these loads is a mandatory minimum requirement for machinery design.

e. Valve operating speeds. Typical operating speeds for culvert valves should permit opening in approximately 1 to 3 minutes. Operating times as long as 15 minutes have been used at the John Day Lock because of the significant head.

(1) Discharge conditions such as scour, low water, or temporary moorings also could result in the need for slower valve operating speeds. Sequencing of valve opening or closing positions might be necessary to control lock chamber overfilling or overemptying.

(2) Dual speed operation can be accomplished with a two-speed electric motor. This type of system is used on the Upper Mississippi River culvert tainter valves.

(3) For multi-speed operation, an electric motor controlled by a VFD is more practical. Modern technology has resulted in the DC drive and the VFD, which provide

widely variable speed and torque at a competitive cost. These devices can provide almost infinitely variable speed with constant horsepower. This system allows ice flushing at low rpm and high torque, while normal, balanced head operation can occur at high rpm and low torque. For more detailed information, see Chapter 16.

f. *Hydraulic system design*. Hydraulic system design criteria is provided in Chapter 4. The discussion below is specific to filling and emptying valve machinery. The hydraulic control circuit for culvert valve machinery should include:

(1) *Directional control valve*. A solenoid-controlled, pilot-operated, four-way, directional control valve. The directional valve should be designed with a blocked center or tandem center spool providing positive pump output to the cylinder in both directions of operation. Culvert valves should not be allowed to lower through the hydraulic control circuit only by their own weight. Such operation could lead to undesirable shock and vibration within the control circuit.

(2) *Cylinder control and directional control valve*. There is no benefit to designing a single-acting hydraulic cylinder system that does not have a four-way directional control valve to direct positive pump delivery to the cap-end side of the hydraulic cylinder. Systems that are designed to allow the weight of the culvert valve to lower the valve do not take advantage of the speed and force controlling features of a power-down control system.

(3) *Adjustable pressure relief valve*. An adjustable pressure relief valve for opening operations. The pressure relief valves are provided to protect the controls and cylinders from excessive pressure, which could lead to damage of the strut, bellcrank, or associated bearings and pins.

(4) *Counterbalance valve*. A remote pilot-operated counterbalance valve. The counterbalance valve is the typical method to prevent an overrunning load while providing a positive locking of the cylinder, at any valve position, until hydraulic pump pressure is applied to the cylinder for actual planned movement.

(5) *Instrumentation*. The installation of pressure transducers and pressure gauges at strategic locations such as at HPU within the hydraulic circuit provide useful information in the adaption of the hydraulic system to actual lock operating conditions.

(6) *Pressure relief valves*. Pressure relief valves should be designed for the maximum pressure range that will not cause damage to the system. The smallest commercially available range that will meet system requirements should be used because this will yield the maximum setting sensitivity. A pressure relief valve should be provided to prevent excessive pressure on closing the tainter valve against the sill plate in the culvert. A pressure relief valve should be provided to prevent excessive pressure on opening the tainter valve to the full open position.

(7) *Pilot-operated counterbalance valve*. A remote pilot-operated counterbalance valve is required to hold the tainter valve open at any position where it is stopped until

positive pump pressure is applied to move the tainter valve. See Chapter 4 for more discussion.

g. Controls. Appropriate control devices are detailed in Chapter 17. Overfill and overempty controls should be included if found to be needed through hydraulic model studies or testing of the actual lock. To limit the overfilling or emptying of the lock, this control scheme varies the valve opening.

h. Slack cable safety devices. Slack cable safety devices are an essential safety feature for wire rope-operated culvert valve machinery. The culvert valve could seize against the valve chamber walls, above the culvert floor, or on debris or zebra mussels. The slack cable safety device will shut down the motor before too much cable is unspooled. This will prevent problems with guiding the wire rope back onto the drum properly.

i. Positional encoders. Positional encoders or sensors connected to the machinery or integral to the hydraulic cylinders are essential to the operation of the culvert valve machinery and lock electrical control system. Encoders or sensors are used to provide the elevation position of the bottom of the culvert valve, which can control the filling, emptying, and miter gate operation interlocks. Encoders or sensors can be used to indicate speed, motion, or actual angular position of various machinery components, which can be translated to culvert valve motion. For more information, see Chapter 17.

j. Resolvers. The design should also consider including positional single-turn or multiple-turn resolvers, which have been successfully used at one navigation lock (Lock No. 2 Lockport) and one navigation dam (Lock and Dam No. 5 Marseilles) on the Illinois Waterway. Resolvers are suitable for the lock and dam environment when provided with NEMA 4X outdoor enclosures.

k. Limit switches. Limit switch locations must be coordinated with the structural designer to prevent overtravel in the valve opening or closing position, or to signal fully open or closed. These switches and their electrical appurtenances should be submersible.

l. Lubrication system. Where grease-lubricated bearings or permanently lubricated bearings with grease supplementary provisions are provided for bellcranks, struts, or other connections, the supply lines should be mounted inside the structural tubes. Flexible hose connections might be required to connect piping across pivoting joints. All exposed piping and hose should be equipped with rigid structural steel guards designed to provide maximum protection against waterborne debris and ice.

8–4. Culvert tainter valve

The most common type of filling and emptying valve is the tainter valve. The tainter valve is constructed in a manner like the tainter gates typically used as spillway gates, but oriented either in the standard or reverse configuration. Additional information on culvert valves is available in EM 1110-2-1610, ERDC TR-11-4 (Stockstill et al. 2011), CHL TR-03-3, WES TM 2-309 (USACE 1951), and WES TR-2-537 (USACE 1961).

a. Tainter valve. Many of the navigation locks on the upper Mississippi River have conventional tainter gate-type valves. The valve is oriented with the trunnions downstream of the skin plate, causing the convex surface of the skin plate to face the flow and seal along the upstream end of the valve well.

b. Reverse tainter valve. Many of the navigation locks on the Ohio River, as well as some of the newer ones on the Columbia, Snake, Mississippi, Red, and Arkansas rivers, have reverse tainter gate-type valves. The valve is oriented with the trunnions upstream of the skin plate, causing the convex surface of the skin plate to face downstream and seal along the downstream end of the valve well.

(1) The reverse tainter valve offers an advantage over the conventional tainter valve in that its orientation prevents the introduction of air into the culverts in higher submergence applications. Figure 8–3 shows a reverse tainter valve, stored on the lock wall.

Figure 8–3. Reverse tainter valve

(2) By reversing the valve, that is, placing the trunnions upstream of the skin plate with the convex surface of the skin plate facing downstream and sealing against the downstream end of the valve well, air is prevented from entering the culvert at the valve recess (Figure 8–4). As the head increases on a conventional tainter valve, the hydraulic grade line immediately downstream of the valve drops below the top of the culvert and thus can allow large volumes of air to be drawn into the culvert system. The reverse valve arrangement puts the strut arms of the valve in tension and converts the valve well into a surge chamber. This can relieve water hammer stresses on the valve that might occur during a sudden closing due to structural or mechanical failure.

c. Machinery. The machinery arrangements discussed below may be considered for either tainter or reverse tainter valves. The major limitation of wire rope-operated valves is they are not suitable for use where uplift forces exceed downward forces. The term tainter valve used below refers to both conventional tainter valves and reverse tainter valves.

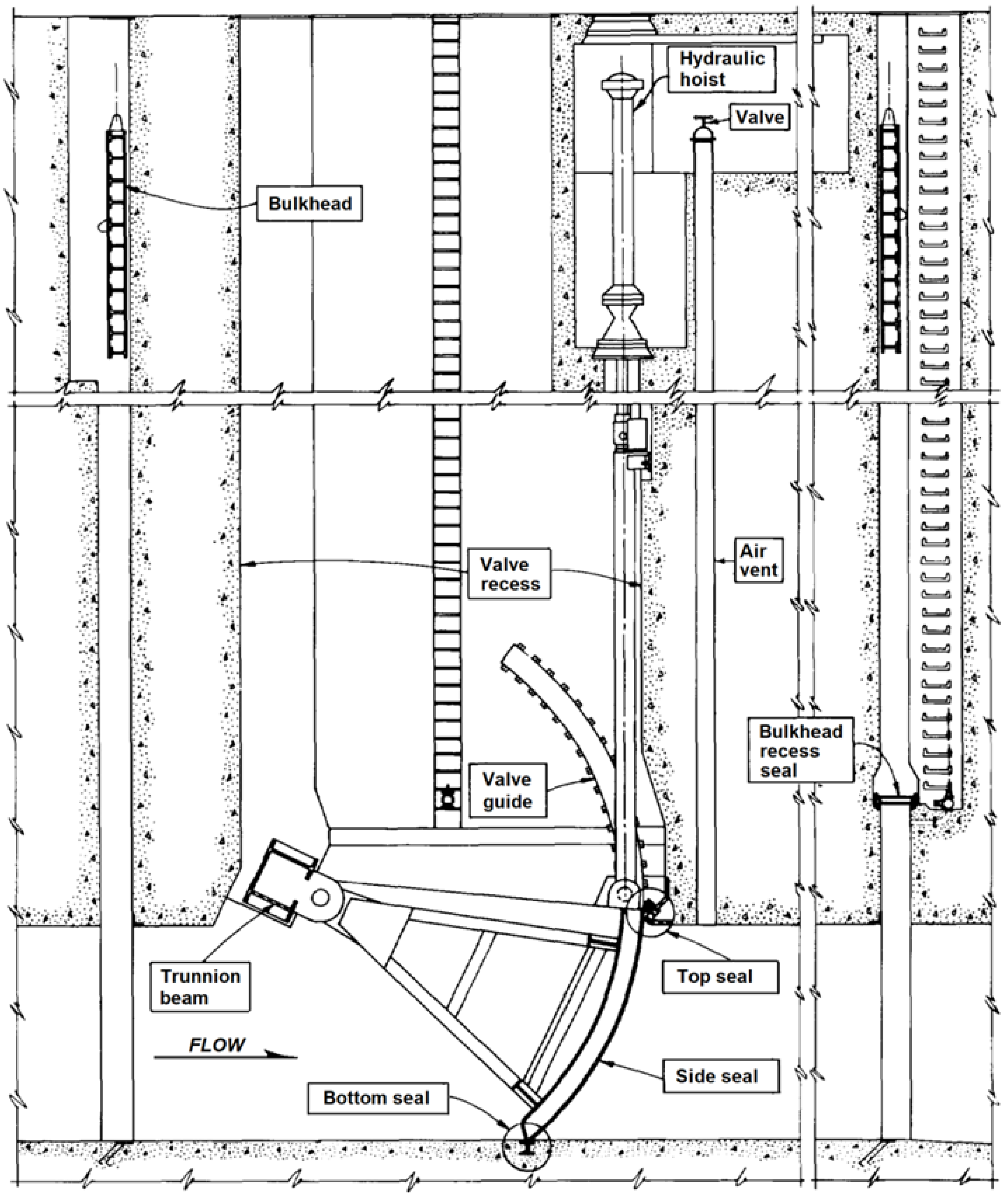


Figure 8–4. Elevation view of typical reverse tainter valve and hoist

8–5. Electric motor-driven tainter valve hoist

This hoist uses two stainless steel round wire ropes, one at each end of the tainter valve (Figure 8–5). The wire rope is connected to the convex side of the tainter valve at the lower main girder near the side strut location. The valve should provide sufficient weight to close even under flowing water conditions, because the cable system is incapable of forcing the valve to close.

Figure 8–5. Lock 4, Mississippi River culvert tainter valve showing wire rope connections

a. The cables are connected to two grooved drum assemblies that are flanked by spherical roller-bearing pillow blocks. The drum assemblies are connected to a quadruple reduction parallel shaft reducer by geared flexible couplings. The parallel shaft reducer has dual extended input shafts to connect to the electric drive motor and hoist holding brake.

b. A rotary limit switch assembly is connected to the brake shaft extension. The holding brake is typically a solenoid-operated shoe brake. The electric drive motor may be a custom two-speed constant torque motor or a VFD motor system (for multi-speed operational requirements).

c. Hard-wired overtravel limit switches also are used to supplement the rotary limit switch assembly. A slack cable limit switch assembly is provided to prevent unspooling of the cable when the gate is not moving. Figure 8–6 shows a typical design.

Figure 8–6. Electric motor-driven tainter valve hoist

8–6. Hydraulic-operated bellcrank type hoist

The typical hoist for the reverse tainter valve on large capacity locks consists of: (1) a trunnion-mounted hydraulic cylinder, (2) a bellcrank, (3) a gate operating strut, (4) a support base, and (5) bearings.

a. The hydraulic cylinder has a center trunnion mounted on pillow block bearings. The cylinder rod is attached to one corner of a truss-type bellcrank made of steel pipe. The bellcrank has one corner about which it pivots, connected to a pair of pillow blocks. The other corners are connected to the hydraulic cylinder and the gate strut.

b. The gate strut is a steel pipe assembly that contains clevis and eye end connections and a spring assembly. The gate strut connects the bellcrank to the tainter valve. All pivot connections are equipped with bushings and pins. Lubrication piping is routed to all bushings and pillow blocks. Lubrication piping can be routed inside struts and bellcrank tubes to reduce exposure to damage. Plate 49 in Appendix B shows a typical design.

8–7. Trunnion-mounted hydraulic cylinder

Trunnion-mounted hydraulic cylinders, used for bellcrank-type tainter valve machinery, experience a kinematic motion that places large side loads on the upper half of the rod end seals. This usually leads to premature seal wear and chatter marks on the cylinder rod. Special attention is necessary for the proper design of seals and rod material. One solution for this problem is mounting the cylinder in a cardanic ring to eliminate side loading.

a. Considerations. The bellcrank must be specified with proper dimensional tolerances to ensure that it rotates in an accurate vertical plane. The assembly should undergo mandatory testing after fabrication to ensure that all shaft pin holes are parallel, and all arms are straight within maximum standard tolerances. There should be mandatory survey requirements through its range of motion after installation. Past installations with poor quality control have caused accelerated wear of bushings, clevises, and eyes, leading to premature failure of machinery. Another important consideration is the protection of the shaft pin/bushing lubrication lines against damage by debris or ice. Lubrication piping can be placed inside the bellcrank tube arms, except at the pivot joints. Other forms of guards may be fabricated to protect the hoses used at pivot joints.

b. Gate-operating strut. The gate-operating strut generally contains a spring assembly to assist in positive closure against the culvert sill. Several types of springs, including ring springs and Belleville washer-type springs, have been used. Coil springs appear to give superior performance because of their relative independence of lubrication. Since there is no easy way to verify grease effectiveness without actual disassembly of the spring, performance can be measured only by failure. Several recent failures have been observed with the shattering of ring springs and Belleville springs in normal service. Detailed inspections show the components have not received sufficient lubricant on the essential rubbing surfaces.

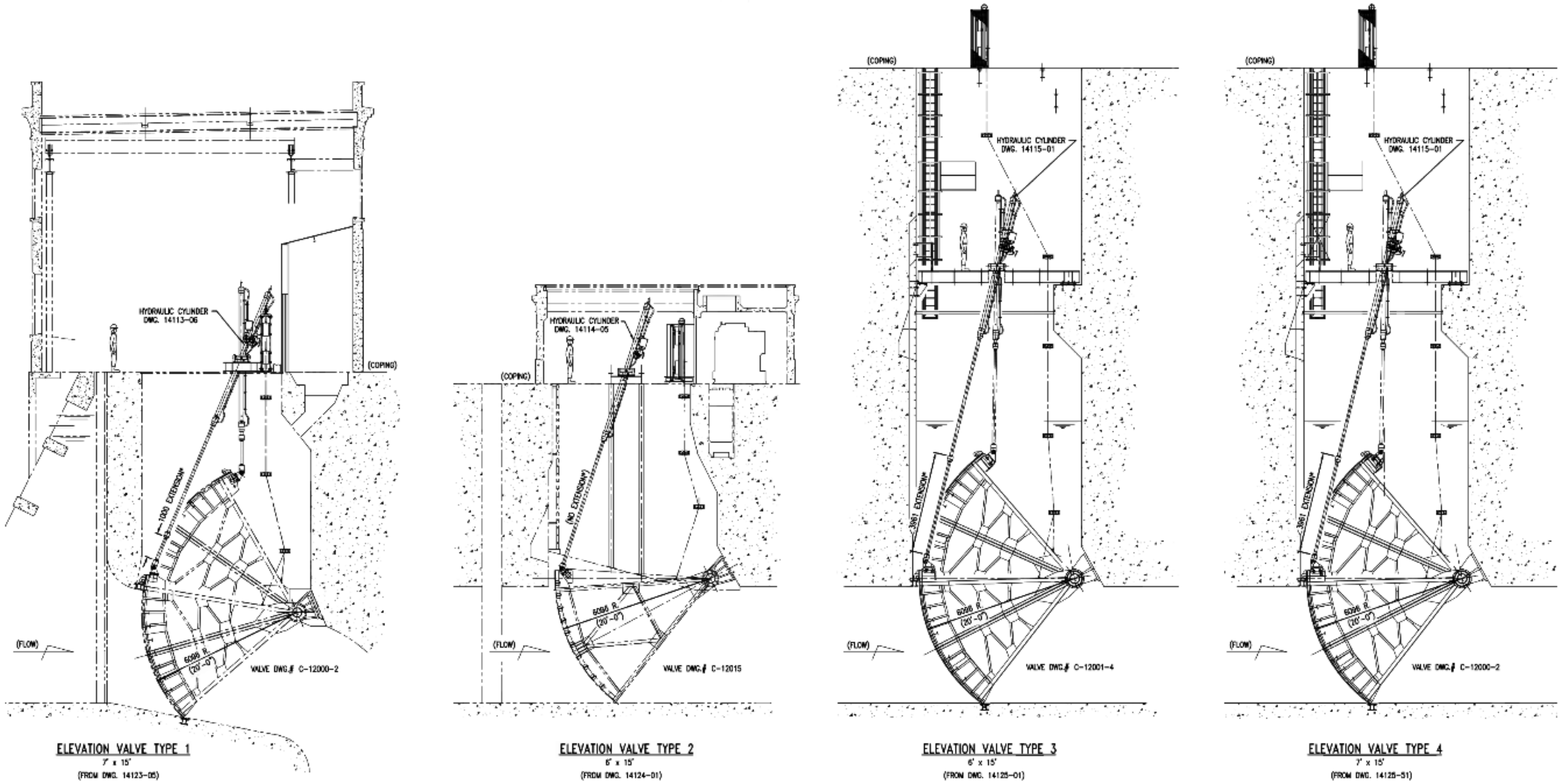
c. Support base. The tainter valve machinery support base is designed to properly align the trunnion-mounted hydraulic cylinder and the bellcrank pivot trunnion bearings. This is essential to ensuring the cylinder, bellcrank, and strut operate in an accurate vertical plane. It is mandatory that the support base be inspected after fabrication to establish the relative positions of the machinery mounts to ensure the accurate vertical plane. The support base must be installed level to allow a properly constructed bellcrank and trunnion support assembly to move in an accurate vertical plane.

8–8. Hydraulic-operated/wire rope-connected

This hoist type is considered a variation on the electric motor-driven tainter valve hoist because wire ropes are used to connect the valve to the prime mover. In this case, multiple wire ropes are attached to the rod end of a horizontally mounted hydraulic cylinder, routed over a grooved drum, then connected to the valve. Plate 38 shows a typical design.

a. Alternative design. Some locks use a vertically mounted hydraulic cylinder with a sealed bonnet around the cylinder rod end to exclude water from the valve well. The vertical cylinder does not pivot but extends straight downward. The cylinder rod drives a pivoting gate-operating strut that is connected to the gate. The connection between the cylinder and the strut is guided along the wall of the recess. Plate 41 shows a typical design.

b. Direct-acting cylinder design. A direct-acting cylinder design, which pivots about a cap end trunnion with the rod connected directly to the tainter valve, has been used successfully. This system is submerged during operation. Some evidence of water leakage mixing with the hydraulic fluid does indicate sealing problems. This system might be applicable to locations where frequent inspection and maintenance of the cylinders are feasible. Extreme measures are required to protect and maintain seals and piping/hose from debris or ice. The design drawings from the Saint Lawrence Seaway (SLS) for their valves are shown in Figure 8–7.



By courtesy of St. Lawrence Seaway Management Corporation (SLSMC)

NOTES: Drawing numbers in this image refer to original design drawings
All dimensions are in U.S. customary units

Figure 8–7. Direct connected valves at Welland Canal

8–9. Vertical-lift culvert valves

Vertical lift culvert valves offer a viable alternative where the site constraints make it an economical choice, or the culvert size is small. Advantages include that vertical valves require a shorter length of lock wall compared to tainter valves and the distribution of the hydrostatic load is spread over a greater area. Disadvantages include the need for gate slots.

a. Also, vertical lift valves often require the use of wheels or rollers when sliding friction becomes prohibitive. These requirements contribute to the typically higher cost when compared to tainter valves. The wheels or rollers also are susceptible to fouling due to their exposure to silt and debris-laden water. More information on structural design of vertical lift valves can be found in EM 1110-2-2107.

b. One significant advantage of a vertical lift valve is that it does not require the large recess that is necessary with either a conventional or reverse tainter valve. The vertical lift valve can also be used for throttling and modulating flow in a culvert system if designed correctly (in particular the bottom lip of the valve). This allows variation of the filling and emptying times of the lock chamber. If used for throttling, a model test should be done.

c. Vertical lift valves can be grouped by the way in which they are guided during operation. Vertical lift valves can be either a sliding type or rolling type. Sliding valves typically utilize ultra-high molecular weight polyethylene (UHMWPE) slides. Stoney gate valves are one type of a rolling valve. Caterpillar or tractor gates are another type. For culvert valve applications, the bonnet feature prevents air entrainment during high-head valve opening. This means the pressurized culvert is sealed from the atmosphere with a watertight bulkhead. Any operating mechanism for the vertical lift valve, including the drive cylinder or actuating shaft, is required to go through the watertight bulkhead.

d. Vertical lift culvert valves are well suited for the use of electric rising stem valve actuators, directly connected, vertically mounted hydraulic cylinders, or electric motor/gear reduction/wire rope drum driven. The vertical valves at Chittenden Lock are operated with hydraulic cylinders (see Figure 8–8). If hydraulic cylinder actuators are used, a method for preventing the introduction of transverse loads to the cylinder rod should be employed to avoid premature wearing of the rod seals and rod bearing. This method could include the trunnion mounting of the hydraulic cylinder in a cardanic ring.

e. A slide gate is a vertically sliding valve, typically with metal-to-metal contact for end support with UHMWPE slides (Figure 8–8). These surfaces also serve as the gate seal. Due to this, the bearing surfaces must be machined to tighter tolerances than wheeled or tractor type gates. See EM 1110-2-2107. General design criteria for culvert valves found in this manual and hydraulic criterion found in EM 1110-2-1610 may be used with slide gate design guidance available from manufacturers.

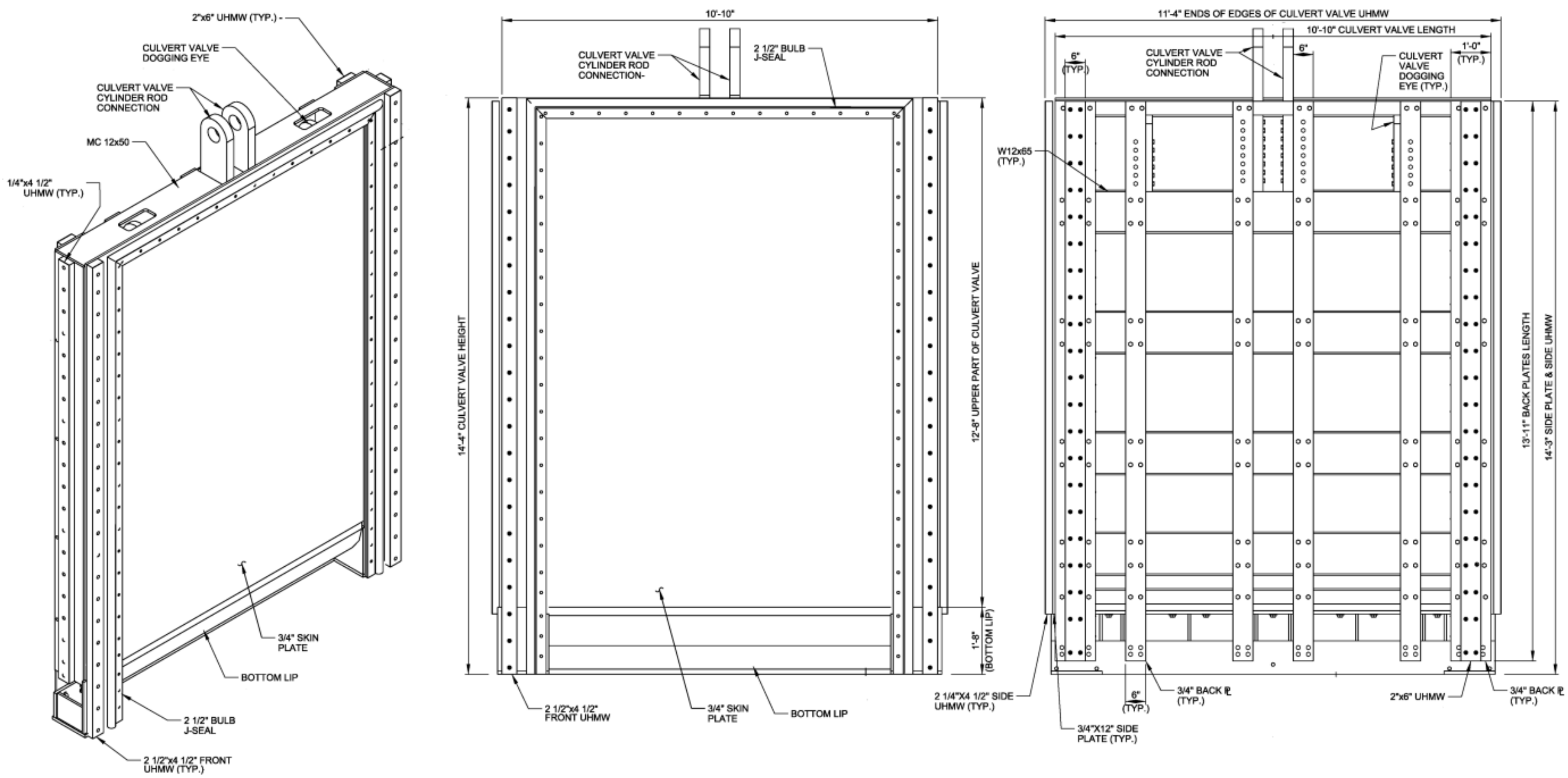


Figure 8–8. New vertical slide valves for Chittenden Lock

f. Stoney gate valves are vertically operated valves in which the rolling load is transmitted from the face of the valve to the track through roller trains on either side of the gate. Plate B-45 shows a general plan and elevation of a Stoney gate valve.

(1) The advantage of the Stoney gate design is that the rollers and axles theoretically are subject to nominal rolling friction. In some applications, Stoney valves use a wire rope drive system. The roller trains are typically suspended from 2:1 reeving, with one end of the wire rope connected to the valve and the other end anchored so the roller trains move at half the speed of the gate. Figure 8–9 below shows the Marmet Lock Stoney valve with liner being assembled and tested in the fabrication shop.

Figure 8–9. Marmet Lock Stoney valve

(2) Stoney valves for lock culverts have been used for over 100 years, including for all the original Panama Canal locks. They were also used at Chittenden Lock in Washington State during the original lock construction in 1916. The design of the Chittenden Lock essentially copied the Panama Canal design. Note that both the Chittenden Lock and the original Panama Locks both recently removed the Stoney valves and switched to slide valves. These were replaced with vertical lift valves primarily due to maintenance issues with the rollers. There are still several locks in the United States that use Stoney valves, however, including Marmet Lock.

(3) Stoney valves are a vertical lift valve with rollers on the front seating face of the gate. The rollers are often attached to the concrete support structure rather than to the valve body. The rollers on the front face transfer hydraulic loading into the concrete support structure and transmit the rolling load from the face of the gate to the track through roller trains on either side of the gate.

(4) Rollers are sometimes also placed on both sides of the valve to control and support any lateral movement. This is the case for a Stoney valve in a lock culvert such as the original 1916 Chittenden Lock design shown below. As noted, a primary advantage of the Stoney valve design is that the rollers are subject to nominal rolling friction. However, in the case of Chittenden Lock, the rollers often became fouled with barnacles (Figure 8–10).

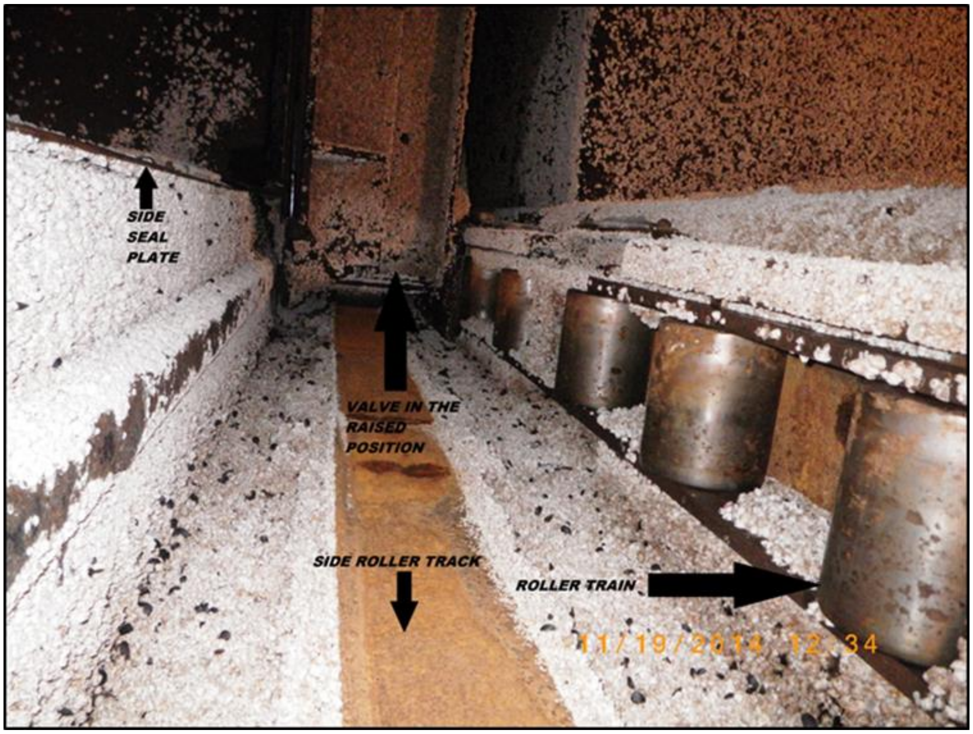


Figure 8–10. Chittenden Lock Stoney valve before replacement

(5) A design limitation of fixed-wheel valves is the high point contact forces between the wheel and track if the valve misaligns or vibrates. Several USACE locks on the Illinois Waterway (Dresden, Brandon Road, Lockport) use older fixed-wheel valves. The Marmet Lock, with a normal lift of 24 ft. (7.3 m) has four new vertical Stoney valves to control flow in the in-chamber longitudinal culvert system.

(6) The rehabilitated Marmet Lock with these valves first became operational in 2008. Other Kanawha River projects that use Stoney valves include London and the Old Winfield Locks. The valves at the new Marmet Lock are being monitored to assess their performance over time.

(7) At Chittenden Lock in Seattle, there were 6 Stoney valves installed for filling and emptying the lock chamber. The valves were approximately 14 ft 6 in. high and 11 ft 2 in. wide. These valves were composed of vertical I-beams connected by cross beams. The roller trains had various maintenance issues over the years, and thus the decision was made to replace the valves with a sliding system and wear pads using UHMWPE.

(8) The traditional and oldest means of operating Stoney valves is a jack screw or Acme screw assembly and crosshead. This was used at both the Panama Locks and Chittenden Lock (Figure 8–11). Through bronze half-nut bushings, the rotation of the Acme screws either raises or lowers the crosshead assembly. The crosshead assembly is connected to the top of the Stoney valve stem. The pulleys and chains connected to the crosshead operate the roller trains at half the speed of the crosshead/valves. An electrical motor and right-angle gear set are typically used to drive the cross head and screw assembly. At Chittenden Lock, a 50-hp motor was used.

Figure 8–11. Chittenden Lock Stoney valve drive

g. Tractor gates, fixed-wheel valve, and caterpillar gates are names describing the same general valve type. The fixed-wheel valve is a flat rectangular skin plate valve with rigidly attached hydraulic load-bearing rollers or wheels. The wheels reduce opening and closing friction forces compared to a sliding contact slide valve. Most valves of this type use two linearly arranged sets of rollers, one set along each vertical side of the valve skin plate. The main wheels are oriented to transmit hydraulic loads. To further reduce friction, most fixed-wheel designs use additional wheels or sliders in other directions.

(1) Caterpillar or tractor valves can be thought of as a design extension of the Stoney valve. The Stoney valve roller train assembly is mounted on a rigid linear frame. The caterpillar valve roller train resembles a continuous crawler crane tread, with a long length of rollers assembled into a flexible loop. The two caterpillar valve roller train loops wrap around the valve circumference (front, bottom, back, and top) of the valve on an oval path. The tread roller loops are allowed to roll freely around the valve body as the

valve cycles up and down in its tracks. Caterpillar gates used as vertical lift gates are shown in Chapter 9, Figure 9–15.

(2) With very few exceptions, all fixed-wheel valves operate vertically up and down in tracks. Fixed-wheel valve designs are varied. There is rolling contact between the rollers and the tracks. The wheels themselves are often mounted on sealed antifriction cartridge bearings or cylindrical plain sliding contact bearings and sometimes self-lubricated bearings. A major challenge is keeping any bearings lubricated. Antifriction bearings are the lowest friction alternative but are more complex.

8–10. Butterfly valves

The closing mechanism of a butterfly valve is a circular or rectangular disc that rotates either parallel to the flow in the open position or perpendicular in the closed position. Passing through the horizontal or vertical axis of the disc is a rod or trunnion on which the disk turns. The trunnion then is connected to an actuator.

a. Butterfly valves offer the advantage in that their structure and operating mechanism is contained mostly within the area of the flow path. This arrangement lends itself to a filling and emptying system contained in the floor of the lock with submerged valve and actuator requiring no top of lock wall area. See Plate 43 for an example.

b. Actuators may be rotary or linear with a linkage bar. Manufacturer's torque curves should be consulted to determine torque requirements at varying heads and valve angles.

8–11. Hawser forces

The optimal selection of lock culvert valves and machinery can also help reduce forces on vessels during filling and emptying. The reports ERDC/CERL TR-03-8 (Hite 2003), EM 1110-2-1604, and the PIANC WG 106 Report all discuss vessel forces during filling and emptying and hydraulic modeling done to determine these forces. The water surface above a filling system intake must be free of any large air entraining vortex and must not create currents that are hazardous to moored vessels.

a. Acceptable and safe performance of a USACE filling and emptying system is to limit hawser forces for commercial tows no higher than 5 tons, with acceptable valve operations and filling and emptying times for the design lift condition. This limiting maximum hawser force guidance is provided in EM 1110-2-1604.

b. Many locks also are used for recreational boats and vessels and these vessels are often not tied off in the lock chamber. Large hydraulic forces from the filling and emptying system in the lock chamber can endanger the operators of these vessels.

c. Disturbances caused by the flow of water during filling and emptying the lock chamber should not endanger any craft that may be in the lock chamber or in its approaches. Localized turbulence can be generated by jets of water that the filling and emptying systems introduce into the lock chamber or lower approach. An oscillatory, longitudinal surge can also occur in the lock chamber during operation of the filling or emptying system.

(1) This disturbance is more serious since the possibilities of damaging both the vessels in the chamber and lock structures such as gates are greater. To avoid damage to vessels and structures, it may be necessary to reduce the filling or emptying rate below the design capacity.

(2) Since surging tends to cause a vessel to drift from one end of the lock chamber to the other, the commercial vessels must be restrained by hawsers (lines) to keep it from striking the gates or damaging other parts of the structure. The stress in the hawsers is essentially a function of the gross tonnage of the ship or tow and the slope of the water surface in the lock.

d. During filling, water entering a lock produces surges that will cause movements to vessels tied to bollards by hawsers. The hawser stresses that occur when emptying are generally lower since the dynamic energy of the water is not dissipated in the lock. In some locks, because of the inertia of the water in the culverts, it takes time for the oscillation of the water level in the lock chamber to subside after the filling level is first reached.

e. At the beginning of filling, the water volume in the lock is at a minimum as is the depth over the lock floor. The flow energy is dissipated in the lock chamber and the danger of rough water surface is at its greatest. However, in emptying, the volume of water in the lock is at a maximum at the beginning of the operation and the energy of the flow is not dissipated within the lock chamber.

8–12. Recommended system

For most modern locks, the reverse tainter valve has been the preferred choice. This is due to improved hydraulic characteristics, ease of fabrication, and lower installation and maintenance costs. For new locks or rehabilitation of existing locks, model studies should be conducted to determine the best valve selection and configuration that will complement the hydraulic characteristics of the filling and emptying system. See EM 1110-2-1610 and ERDC TR-11-4 (Stockstill et al. 2011) for further discussion.

Chapter 9
Vertical Lift Gate Operating Machinery

9–1. General description and application

There are many different types of vertical gates and hoisting arrangements used for both navigation and FRM projects. Vertical lift gates are used on both navigation locks and navigation dams. They are used for culvert valve applications as discussed in Chapter 8. Refer to EM 1110-2-2107 for vertical lift gate description and structural design information. The gate types consist of single or multiple leaves that can be either raised from submerged positions or lowered from overhead positions (Figure 9–1 and Figure 9–2). Vertical lift gates are used and designed for both static and dynamic hydraulic conditions.

a. The dynamic-type designs are generally more robust in structure and hoisting requirements. This is necessary because the gates must be capable of regulating or shutting off flow during normal operation, under hydrostatic head or emergency situations. The static hydraulic head gates are raised and lowered under no-head conditions such as for use in lock chamber gates. The hydraulic head then is placed on the gate by raising or lowering the lock chamber with the filling/emptying system. They are not designed to operate in flowing water conditions. Vertical emergency gates discussed below are designed to operate under hydrostatic head and flowing water conditions.

b. Hoisting arrangements and operating machinery for the vertical lift gates are as varied as the designs for the gates. The more common types of mechanical systems for mechanically raising and lowering vertical gates include wire rope, hydraulic cylinder, mechanical screw, gantry crane, engineered roller chain, and round link chain. This chapter will describe the types of vertical lift gates and provides the designer with general design criteria for the development of vertical lift gate operating systems.

c. Larger vertical lift gates are operated from each end of the gate. The requirements for two-sided lifting are provided in Chapter 11. This includes equal loading on each side of the gate and offset loading conditions. The two-sided lifting requirements for vertical gates should follow the same design criteria. Chapter 11 also provides requirements for single-point lifting, including for overload conditions. Vertical lift gate criteria should also follow these requirements. Vertical lift gates wider than 10 ft should have a two-sided lifting arrangement.

d. Vertical lift gates can be built to different sizes and aspect ratios. They have been used successfully in high head applications and their simple construction also makes them cost effective for low head applications. Vertical lift gates and their machinery are generally the most compact in the upstream-to-downstream direction. In water-regulating structures, the system can often be designed to lift the gates completely out of the water to a maintenance level without any additional equipment.

e. Friction has the largest operational effect on vertical lift gates than any other gate type. The large transverse hydrostatic forces supported by vertical lift gates can create large friction forces for which the hoist machinery must be designed. The location of the gate's lifting points gives almost no mechanical advantage with respect to friction. Features to reduce friction, such as rollers, are usually necessary to reduce hoisting loads. Roller maintenance is critical to ensure operation of a vertical lift gate. Smaller vertical gates sometimes also use sliding surfaces to reduce friction, especially in culvert valve applications.

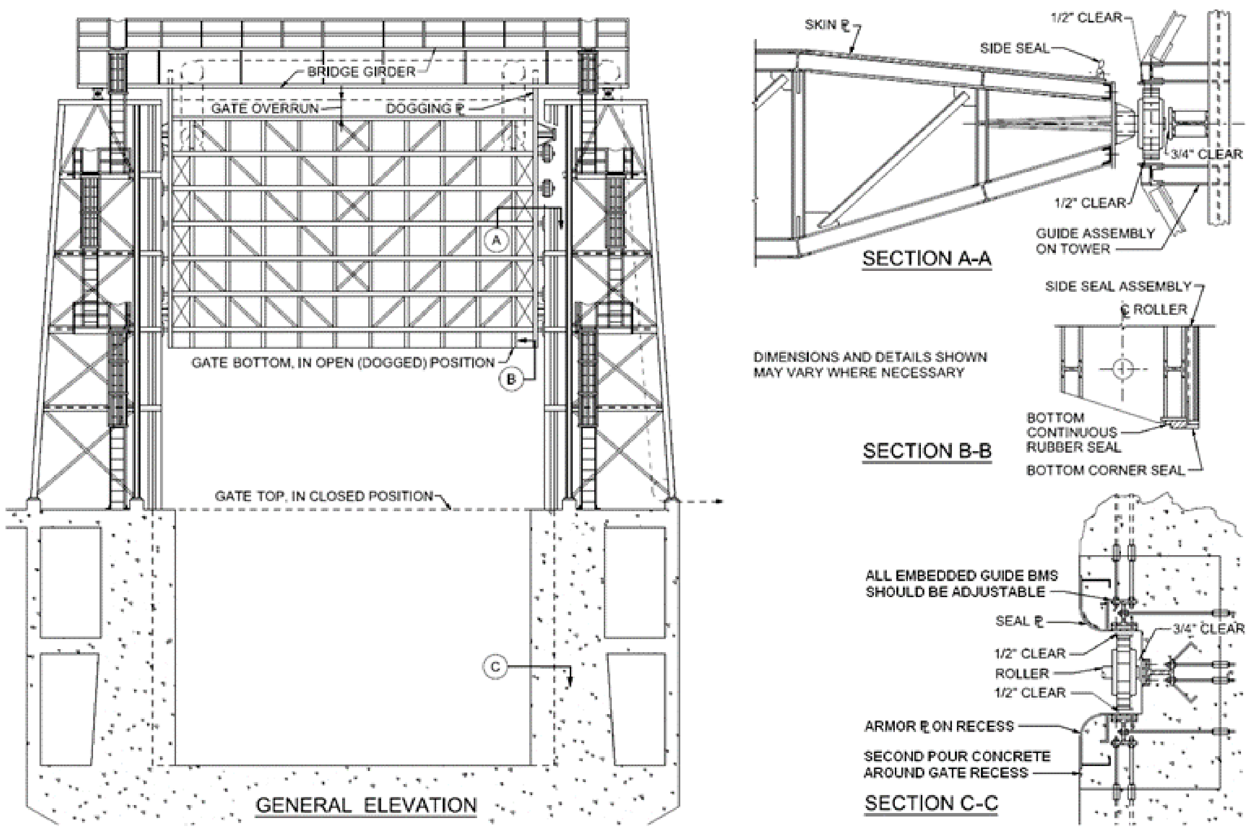


Figure 9–1. Arrangement of a single-section vertical lift gate

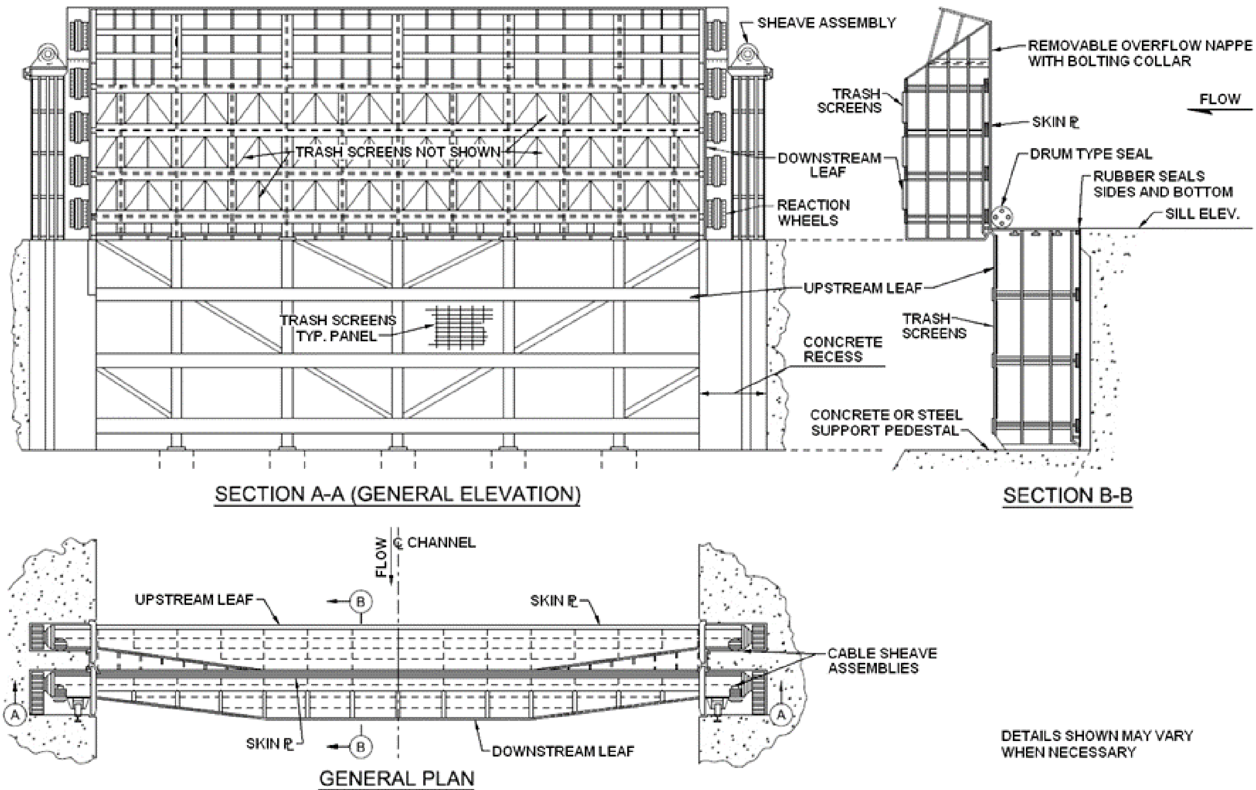


Figure 9–2. Arrangement of a double-section vertical lift gate

f. Counterweights are used mainly in overhead-type gates to offset the dead load of the gate to minimize the hoisting effort. An example of the lock gates at John Day is discussed below. The weight of the vertical lift gate determines the mass of the counterweight required. It should be designed to compensate for adjustment of its mass to calibrate it with the weight of the gate once the system is in place. It is normal to have the gate and counterweight slightly unbalanced to allow the gate to close without power. Another method for reducing the lifting effort is with a multi-reeve system through a series of drums and sheaves. The number of sheaves and arrangement are selected to give the desired mechanical advantage for reduction in the size of wire rope and machinery components.

9–2. Vertical gates for navigation locks

a. Overhead gates. These types of gates use a tower with overhead cables, sheaves, and bull wheels to support the gate during its operation, and use counterweights to assist and reduce the hoisting loads. See Plates 50 and 51. This is the type of machinery used at the John Day Lock, which has the highest hydraulic lift in USACE. See Figure 9–3 and Figure 9–4. The tower height is governed by the lift required to pass barge traffic. This type of gate is used when it is not practical or feasible to use other gate types. Plate 46 in Appendix B provides details.

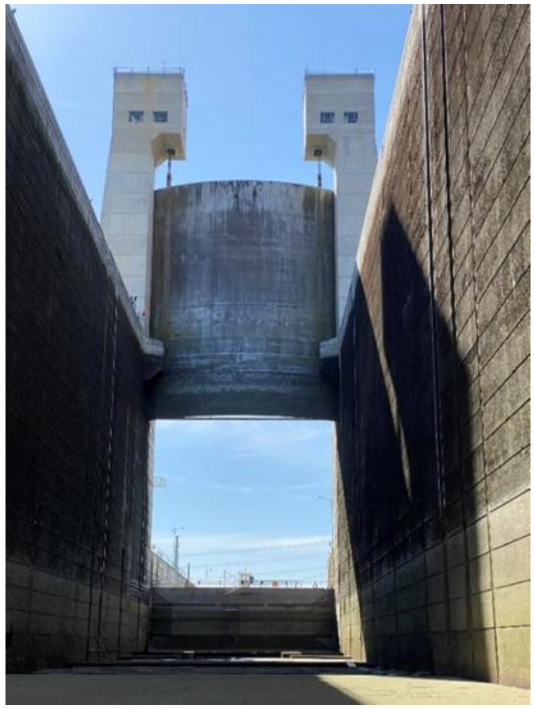


Figure 9–3. Vertical downstream overhead gate John Day Lock

(1) There are vertical gates on both the upstream and downstream side of the John Day Lock. The downstream gate at Ice Harbor Lock also utilizes an overhead gate like John Day but the upstream gate is a tainter gate. The John Day upstream navigation lock gate was originally put into service in 1963.

(2) The John Day upstream gate is a truss-type vertical lift gate approximately 90 ft wide x 27 ft high x 14 ft deep with an upstream skin plate. The gate weighs approximately 208,000 lbs. (180,000 lbs. submerged) and is suspended on each side by four 1-½-in. diameter wire ropes. On each side of the gate, the four wire ropes pass over a 10-ft diameter friction drum and are connected to a counterweight weighing approximately 90,000 lbs. Each friction drum incorporates a ring gear, which is driven by a pinion gear mounted on the output shaft of a parallel shaft speed reducer. The speed reducer is driven by a 20-hp electric motor.

(3) The downstream gate design (Figure 9–3) at John Day is like the upstream gate only much larger. The downstream gate is 87 ft wide x 113 ft tall and weighs approximately 2,000,000 lbs. It is lifted with a total of (32) 2.25-in. wire ropes that are operated by 17.66-ft diameter friction sheaves. The wire ropes connect the gate to counterweights in each tower.

(4) Each friction sheave (Figure 9–4) has a ring gear machinery fitted onto an extended rim on the sheave. The ring gear is driven by a pinion simply supported between pillow blocks with a reduction ratio of 13:1. A 180:1-ratio parallel shaft reducer drives the pinion shaft and is, in turn, driven by a motor. There is a disc-brake wheel coupling acting as machinery brake between the motor and parallel shaft reducer input,

and the motor brake is a Stearns brake on the motor auxiliary shaft. The machinery is powered by a 75-hp, 1,200-rpm motor.

Figure 9–4. John Day downstream vertical gate friction sheave hoisting system

(5) The designer also should reference the CENWP-EC-DS Memorandum for Record Letter Report for the John Day Navigational Lock, April 2008 (USACE, Portland District 2008). The independent technical review provides a discussion of vertical lift gate repairs at John Day and valuable information about the background and consequences of four incidents occurring with the upstream vertical lift gate at the facility from 1975 through 2008.

b. Submersible gates. A submersible vertical lift gate can be used at a navigation lock. See Plate 45. The gate's submersible leaf rests below the upstream sill to allow navigation to pass. Submersible gates generally are not feasible under such conditions as high-head applications. Also, they may not be feasible when the available area to place the gate into the lock monolith is limited. Submersible gates can be single leaf or multiple leaves. The double-leaf arrangement is most common. A multiple-leaf arrangement at Mel Price Lock is shown in Figure 9–5.

(1) The Mel Price vertical gate leaves and operating machinery are being replaced at the writing of this manual. This is due to several operational issues with the existing design. The upstream side of the Mel Price Lock uses a 3-part vertical lift gate, which is

lifted with wire rope. This includes an upstream leaf, a middle leaf, and a downstream leaf.

(2) The downstream leaf is designed with a nappe section for submergence under flowing water. Each lift gate leaf is approximately 118 ft wide x 13 ft high x 10 ft deep. Each leaf is designed to overlap by approximately 9 in. The approximate weight of the upstream leaf is 274,000 pounds. The approximate weight of the middle leaf is 280,000 pounds. Each gate leaf is lifted with a wire rope drum on each side, with 12 parts of wire rope cable. Counterweights are used to reduce the operating load (Figure 9–6).

(3) All of the hoisting cables, including the counterweight cables, were designed as 1-1/2-in. diameter, type 302 stainless steel, 6x30, style G, flattened strand wire rope with an independent wire rope core (IWRC). The cable design, as well as the 45 to 1 ratio of drum diameter to rope diameter design, were intended to provide extreme reliability and minimum maintenance.

Figure 9–5. Multiple-leaf vertical lift gate, Mel Price Lock

Figure 9–6. Mel Price Lock vertical gate wire rope lifting system

9–3. Emergency gates

An emergency and service lift gate arrangement are composed of a downstream leaf used for normal lock operation and an upstream leaf used infrequently as a movable sill or as an operating leaf in an emergency.

a. The emergency leaf is used for lock closure in the event of an accident or damage to the gate that otherwise would result in loss of the navigation pool. See Figure 9–7 and Figure 9–8. The submersible type of gate is also useful when it is necessary to skim ice and drift from the lock approaches or open the lock gates to pass flood flows. See Plate 44 for emergency gate operating procedures.

b. As noted, emergency-type gates generally consist of two leaves, one upstream and one just downstream of the other. The emergency gate leaf gate is equipped with wheels and is designed to be raised in flowing water. The normally operated service leaf is designed to be raised only in a balanced pool or when the swell head is 1 ft or less. When this type of gate is used as an operating lock gate, it normally would be operated under balanced head conditions and not through flowing water.

c. As noted, the emergency gate is designed for use when a catastrophic failure of a lock miter gate occurs. When operating the gates, the gate leaves must be raised in steps and in sequence to match gate lifting capabilities. See Plate 44. Gate-lifting speed for both leaves should be limited to 1 ft/min to 5 ft/min, adjusted to suit the speed of the nearest standard speed motor. Figure 9–9 shows a single-leaf service gate (lowered) with a single-leaf emergency gate (raised).

d. An example of a single-drive unit arrangement to raise emergency gates consists of a double-grooved rope drum driven by two stages of open spur gearing, a herringbone or helical gear reducer, and an electric-drive motor with a spring-set, magnet-release holding brake. The rope drum has several layers of rope. One rope from the double drum attaches to one end of the gate through a multipart reeving. The other from the drum crosses the lock through a tunnel in the gate sill and passes through a multipart reeving that is attached to the other end of the gate. See Plates 52 and 53.

e. In this single-drive unit example, the two drums wind both ends of a continuous cable that lifts the gate through a series of sheaves, the number of which are selected to give the mechanical advantage desired. Two of the sheaves mounted on the gate work to equalize the line pull, in the event one drum winds slightly more cable than the other. Each drum is precision grooved so that each winds the same amount of cable on each layer. Where the fleet angles of the cable approaching the drum exceed 1.5°, a fleet angle compensator must be provided.

Figure 9–7. Emergency gate used for lock closure

Figure 9–8. Flow over emergency gate

Figure 9–9. Single-leaf emergency gate

9–4. Dam gates

Vertical lift gates are used on dams, including Bonneville Dam on the Columbia River. The vertical gate at Bonneville Dam is shown in Figure 9–10. These vertical lift gates use rollers and an overhead lifting system with wire rope. For dam gate applications, gate speeds should be much slower than for a navigation gate. Generally, 1 ft/minute to 2 ft/minute maximum operating speed is sufficient.

a. The vertical lift spillway crest gate is sometimes preferred over tainter gates because the spillway crest requires a shorter length of spillway pier and provides a more economical pier design. These gates usually are raised by using a mobile gantry crane or fixed hoists (Figure 9–11) for each gate located on the spillway deck or operating platform.

b. Sometimes dogging devices are provided to engage projections spaced at intervals on the gate to hold the gate at a desired elevation. In some cases, it might be advantageous to mount the dogs in the gate and provide a dogging ladder in the gate slot. However, the earlier arrangement is more common and preferred. Different types of spillway crest gates include the single-section and multiple-section gates.

c. The single-section gate consists of one section that provides a variable discharge between the bottom of the gate and the sill. Single-section gates operate like the multiple-section gates but are dogged off in the service slots.

d. A multiple-section gate (Figure 9–2) consists of two or more sections in the same slot with variable discharge between the sections or between the bottom section and the sill. Multiple-section gates may be equipped with a latching mechanism to allow use as a single-section gate. As the required discharge increases beyond the capacity of the largest opening between sections, top sections are removed from the service slots and dogged above the pool level in emergency slots.

e. The latching mechanisms should be designed carefully so they do not stick or corrode. Latching mechanisms have proven to be a maintenance problem for some projects.

Figure 9–10. Vertical lift gate at Bonneville Dam

Figure 9–11. Bonneville Dam wire rope and sheaves for vertical gate

9–5. Vertical gates for water-regulating and hurricane protection structures

a. Storm and hurricane vertical gates are among the largest hydraulic steel structures in the world. The storm or hurricane gate is typically a single-leaf, vertical lift gate that is used in a flood protection structure or coastal lock. When they are used as hurricane gates, they are kept in the normally raised position to permit navigation traffic to pass underneath and are lowered to protect a city or a harbor from hurricanes and tidal storm surges. This is the gate used on the New Orleans IHNC. See Figure 9–12 and Figure 9–13.

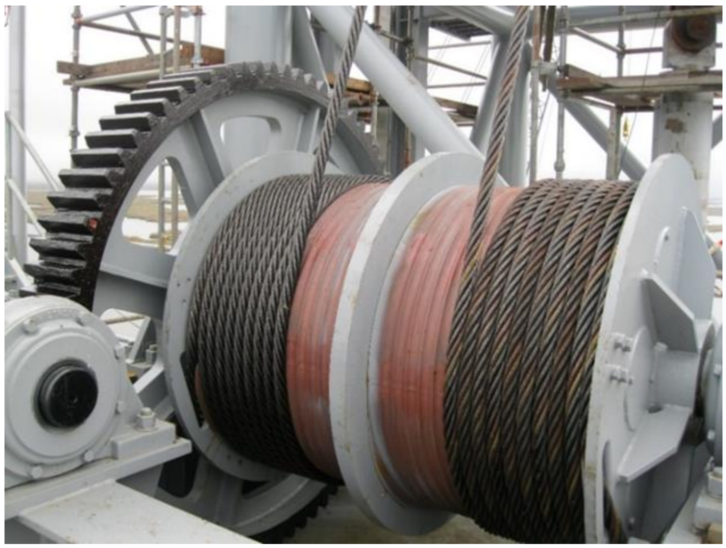


Figure 9–12. Inner Harbor Navigation Canal storm surge barrier gate machinery

Figure 9–13. Inner Harbor Navigation Canal storm surge barrier gate leaf and tower

b. Operating machinery for this style of gate must be designed for the anticipated storm conditions. The designer should anticipate the machinery could remain idle for long periods without use or regular exercising operation. Reliability and simplicity are important considerations. Manual methods to lower these types of gates by gravity operation should be considered in the design. Hoisting machinery for this type of gate is normally like that of overhead dam gates and lock gates. A direct-connected hydraulic vertical storm gate is shown in Figure 9–14 for the Eastern Scheldt Storm Surge Barrier, the Netherlands.

c. One project that made extensive use of vertical storm gates was the construction of the Eastern Scheldt Storm Surge Barrier in the Dutch province of Zeeland. This was constructed by the Rijkswaterstaat. In total, 63 gates of various heights and a uniform span of 41.3 m were needed to protect the province from flooding by seawater. The last gate was installed in 1986.

d. Criteria for the design of storm and hurricane gate machinery are the same as those for the emergency gate machinery, except the gate must be capable of being raised or lowered against a differential head and against a force created by wind on the exposed section of the gate. Criteria for two-sided lifting is provided in Chapter 11.

e. The lifting speed should be of a speed sufficient to permit opening the gate in approximately 10 minutes. Wind load on the exposed section of the gate should be 20 psf for machinery design, unless warranted by locally higher speeds or storm conditions.

Figure 9–14. Direct-connected hydraulic vertical storm gates, Eastern Scheldt Storm Surge Barrier, the Netherlands (R.A. Daniel and Rijkswaterstaat)

f. The lifting machinery used for raising the New Orleans IHNC gate consists of a dual-drum, cable hoist mounted adjacent to one of the lifting towers (Figure 9–12). The two drums are driven by a pinion gear between them. A triple-reduction, enclosed gear unit drives the pinion. The gear unit is driven by a two-speed electric motor with a double-ended shaft. A magnetic electric brake is provided between the motor and reducer. The motor shaft extension permits the connection of a hydraulic emergency lowering mechanism. The low speed of the motor is used when starting and stopping the gate.

g. The gate is normally lowered by means of the electric motor. However, in the event of a power failure, the gate can be lowered by means of gravity with lowering speed limited by the hydraulic mechanism.

h. The emergency hydraulic lowering mechanism consists of a radial piston-type hydraulic pump connected to the electric motor shaft extension, a flow-control valve, oil cooler, check valve, and necessary piping, all connected and mounted on an oil storage reservoir. When lowering without electric power, the weight of the gate, acting through cables and reduction gearing, turns the hydraulic pump. Oil from the pump is circulated through a flow control valve, creating a conversion of hydraulic power to heat. Excess heat in the oil is removed by a tubular-type oil cooler. Further discussion on this emergency lowering system is provided below.

9–6. Outlet gates and regulating gates

Lift gates often are used for normal regulating and emergency closure of water intake systems or outlet works. Regulating gates normally operate in the open position. They are not used for throttling flows, but rather to stop flow under operating conditions. They rest on dogging devices during normal operation. In emergencies, they are lowered into the closure slot to stop the flow of water. Due to their age, condition, and criticality, many ROs across USACE are currently scheduled for rehabilitation. Appendix E provides a link to the full RO report that should be followed for standardizing RO design across all USACE districts.

a. Emergency gates are required for sudden closure of the turbine intakes to prevent subsequent damage to the turbines or powerhouse. The hoisting system uses either hydraulic cylinder(s) or wire ropes. The type of hoisting system will be based on economics and governing criteria for closure times under emergency conditions. The hoisting system for wire ropes may be deck mounted or placed in recesses above the high pool elevation. Cylinders for the hydraulic system are mounted below the deck in the intake gate slot.

b. Since emergency gates must be capable of operating under full head and flowing water, tractor-type gates are commonly used to reduce friction. See EM 1110-2-2107 for more on structural design parameters of this style and end supports. See Figure 9–15 and Plate 56 for examples of a tractor-style gate (sometimes called caterpillar gate) and wheeled-track roller-style gate.

c. There are two types of tractor-style gates that are commonly used. A standard tractor gate uses vertical seals on the downstream side of the gate. These vertical seals can make it difficult for the gate to close under its own weight due to the presence of friction in the seals. Broome gates, a tractor gate variant, use an angled seal assembly to prevent any friction between sealing surfaces during gate movement. The seals require precise surveying of the embedded frame seals so that the gate can properly seal on closure. The seal arrangement requires that an adjustable bottom seal is provided to allow the gate to properly align with the embedded frame seal. Spring-adjusted bottom seals often seize a few years into service. Adjustable bottom seals using large diameter screws have proven to be long lasting.

Figure 9–15. Tractor-style gate

d. Tractor-style gates have multiple options for sealing systems. In cases where a system must be rehabilitated, a designer must first determine if the both the gate seal and embedded frame seal can be designed or if only the gate seal can be designed. Gates can include designs that use metallic and elastomeric seal systems. Metal seals are difficult to align due to the tight tolerances of seal surfaces. Designers must pay special attention to material selection to ensure the seals have a low coefficient of friction and have resistance to galling during operation. When evaluating elastomeric seal systems, center-bulb rubber seals have shown to be an effective option that gives more flexibility in fabrication with looser tolerance requirements.

e. Whitney Point Dam in New York (Baltimore District) uses vertical-type regulating gates. See Figure 9–16. The RO system at Whitney Point is still the original design and construction. The equipment was originally installed in the early 1940s and no major modifications or improvements have been performed since the initial installation. At the writing of this manual, a rehabilitation is planned for both the gates and machinery.

(1) The Whitney Point operating house contains the hoisting machinery, crane, and other equipment used for operation of three 5-ft x 10-ft Broome-type vertical lift gates, called service gates, and one 5-ft x 10-ft Broome-type vertical lift gate, called an emergency gate. The emergency gate can be maneuvered by the operating house crane into any of the three emergency gate slots. The emergency gate slots are located

directly upstream of the service gate slots. Each vertical lift gate is manipulated by an electric motor driven drum hoist system with carbon steel wire rope.

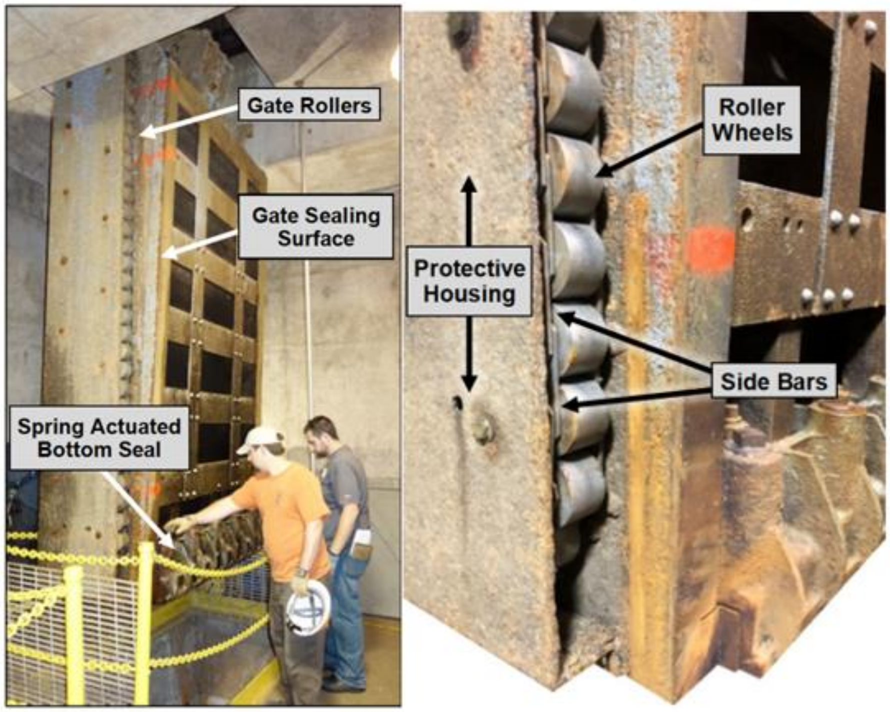


Figure 9–16. Whitney Point regulating gates

(2) There are three service gates and one emergency gate, with each gate having an identical hoist system. The existing mechanical drive system consists of a 5-hp, 900-rpm, three-phase General Electric motor running at 220 volts, which drives the right-angle reducer.

(3) A hand lever to switch to manual operation is located on the shaft connecting the motor to the reducer. The lever moves a beveled gear, which engages with a hand crank for operation of the gate. A holding brake from General Electric is in line between the motor and gear reducer. It contains a drum mounted to the shaft and is spring-applied, 220v AC, electric solenoid-released.

(4) A Foote Brothers Gear & Machine Corporation speed reducer is used with 118.1:1 reduction with dual output shafts. The RO gates incorporate two separate roller chain assemblies, each consisting of 66 4-in.-diameter x 2-1/2-in.-wide stainless steel rollers with stainless steel side plates and bronze pins. See Figure 9–17. A protective steel housing surrounds the rollers and protects them from debris passing through the RO.

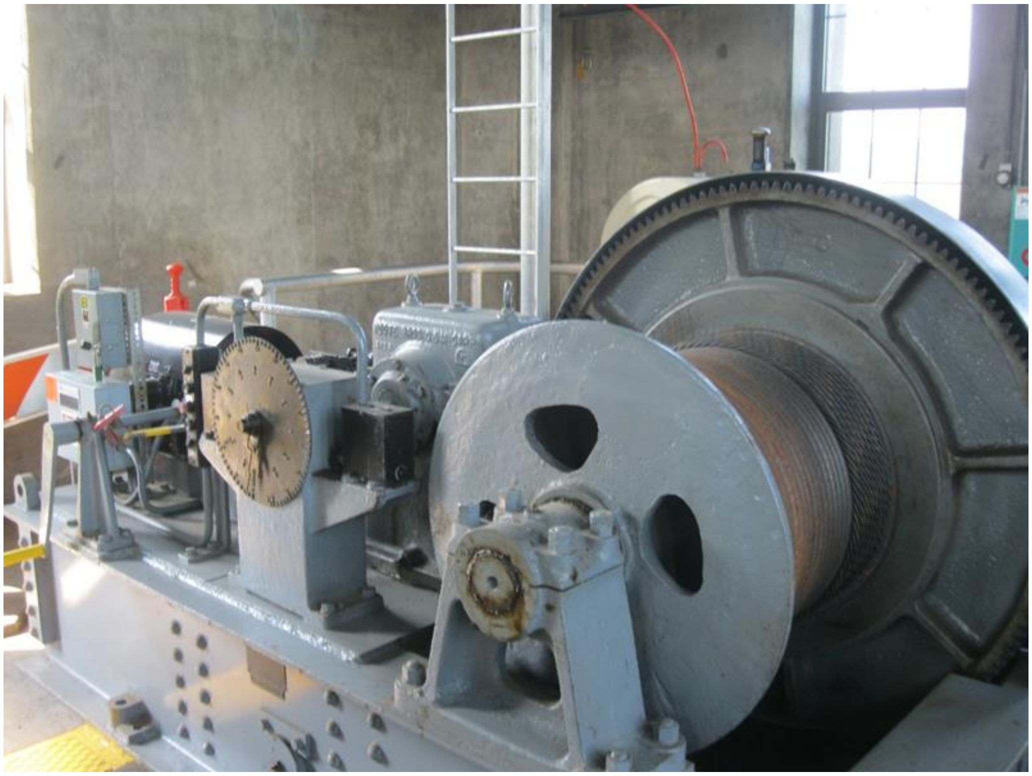


Figure 9–17. Whitney Point gate machinery

f. Emergency closure gates for outlet works are often like those used in powerhouses and often are used for service gates and flow control. Tractor gates for fully submerged outlet works are usually more advantageous for use due to the reduced friction under full head and flow. However, wheeled vertical gates often are used where loading allows. The hoisting system might require the use of a gantry crane or its own hoisting system, either wire rope or hydraulic cylinder driven.

g. Tractor gates or caterpillar gates use roller chains made of rollers, pins, linkage bars, and a roller retainer. Older roller chains often used stainless rollers and bronze pins. Many new chains use 17-4 stainless rollers and pins with coated with a self-lubricating bearing material. In gate-drop events, the roller trains are known to fail in the linkage bars near the top return. Roller retainers can be retaining rings or washers with roll pins or rivets.

h. Roller trains need proper tensioning to avoid coming out of track. During rehabilitation or when replacing tractor gates, the embedded running surface for the wheels should be surveyed for condition and alignment. Selection of roller and track material and their respective hardness must be done to select which surface should wear more. This is project-dependent and should be evaluated based on historical use of the gates and historical wear of the roller tracks. The gate manufacturer may need to adjust the relative position of the roller track in relation to the gate seals to ensure a smooth fit between the gate seals and the embedded frame seals.

i. Whether individual wheels and rollers or roller chains are used, it is important that their contact surfaces are all in the same plane so that the reaction loads are evenly distributed. Roller chains are usually set by adjusting the roller tracks. Wheels are sometimes done by carefully locating and drilling the mounting holes, but often they are on eccentric shafts that can be turned to allow for field adjustments. In all cases, careful coordination with the structural designer on establishing working planes is critical.

9–7. Operating equipment for vertical lift gates

The design of operating equipment for vertical lift gates requires close coordination between the structural and mechanical engineers to determine the operating equipment loading and to furnish the possible loads imposed by the machinery on the gate to the structural designer. In gate rehabilitation projects, the mechanical engineer will need to provide the structural engineer with the maximum dead weight the hoist can handle. The general design criteria for tainter gates, found in Chapter 11, also applies to vertical lift gates. This includes two-sided lifting arrangements with equal loading and offset loading. The requirements for single-point lifting are also provided in Chapter 11.

a. The mechanical engineer will need gate dead weight, hydrodynamic loads (both horizontal and vertical), ice load, silt load, sliding or rolling friction load, and side seal friction load to determine the total gate load imposed on the operating equipment. Friction loads are often significant for vertical lift gates. This total gate load should also include any known inertial effects. The total load then is applied to the general machinery layout design to determine the individual component loads for sizing the machinery. Details regarding examples of load calculations are provided in Appendix C. Further discussion and design details are in EM 1110-2-2107.

b. Any vertical gate wider than 10 ft should be lifted from both sides. The designer also needs to consider the aspect ratio of the gate in determining the need for two-sided lifting. AWWA C560 and AWWA C561 provide similar guidance for slide gates. However, the criteria for two-sided lifting are more conservative and required for gates less than 10 ft wide.

c. Common hoist arrangements include wire rope, wire rope over hydraulic, direct-connected hydraulic, and wire rope with bull wheel or friction sheave. The powered machinery for operation of each side of the vertical gate may be independent or commonly connected through a single drive unit and mechanically connected to drive both sides equally.

d. The hoist machine should be located adjacent to the gate and in line with the hoisting sheaves. The hoist components at either side of the lock may be mounted overhead in a small protective building or contained within operating galleries in the lock monoliths. Plates 45 and 47 show typical hoist arrangements for multi-leaf gates.

e. Most vertical gates on locks will require hoists on each side of the gate. For vertical gates, as for radial gates, it is important the hoist units are synchronized. Independent machinery units must have more sophisticated controls and be designed to operate as a master-and-slave unit to control gate skew during operation. Synchronizing hydraulic hoists with each other often have the most complex controls.

f. The designer should anticipate the impact to machinery caused by high-water events and provide designs that afford protection under the most extreme high-water conditions anticipated.

g. Wire rope hoists are used for spillway gates, RO gates, and navigation lock gates. Wire rope hoists are more suitable for gates that have deep submergence requirements, installations that do not allow portions of the hydraulic cylinders above the deck (shallow settings), or when hoisting loads are too large and economics make hydraulic cylinders impractical.

(1) Wire rope hoists consist of drums and a system of sheaves and blocks that are driven through a motor and arrangement of shafts, speed reducers, and spur or helical gears. Motors may be electric or hydraulic driven. It is common to provide two speeds to permit lowering at approximately twice the raising rate. The hoisting equipment normally is located next to the gate or slot, with controls located in the control room, governor control cabinets, or next to the gate, depending on the gate and its intended use.

(2) Bull wheels or friction drums are used in overhead lift gates as a friction drive for hoisting the gate. Both friction drum and bull wheel are terms commonly used. The bull wheel, motor, and gearing system are in a tower high enough to raise the gate to its full and open position. The wire ropes wrap over the top of the bull wheel in grooves with one side of the wire ropes connected to the gate and the other end to a counterweight. The motor and gear system provide the mechanical effort required to hoist the gate. This type of drum system is advantageous when the hoisting loads are large. The gates at John Day Lock are an example.

(3) Counterweights are used mainly in overhead-type gates to offset the dead load of the gate to minimize the hoisting effort. The weight of the vertical lift gate will determine the mass of the counterweight required. It should be designed to compensate for adjustment of its mass to calibrate it with the weight of the gate once the system is in place. It is normal to have the gate/counterweight slightly unbalanced to allow the gate to close without power. Another method for reducing the lifting effort is with a multi-reeve system through a series of drums and sheaves. The number of sheaves and arrangement are selected to give the desired mechanical advantage for reduction in the size of wire rope and machinery components.

(4) Electric motors are the primary drives for wire rope hoist systems. Guidance for design can be obtained from UFGS 35 01 41.00 10 and UFGS 35 20 20.

(5) Guidance for specifying brakes is provided in UFGS 35 01 41.00 10, and UFGS 35 20 20. See Chapter 2 for brake design guidance.

(6) Open gearing is often necessary in hoisting systems to achieve the required reduction to minimize motor torque and horsepower requirements. Open gearing is

typically of the spur, herringbone, or helical type as required to develop the necessary loading requirements. Design guidance for open spur gears is included in Chapter 2.

(7) The speed reducers must be designed, rated, and manufactured according to applicable AGMA standards noted in Chapter 2 and listed in Appendix A. In all cases where the standards might conflict with one another, the designer must select the more conservative design standard. See Chapter 2 for speed reducer design guidance.

(8) Bearings are necessary for all load-carrying rotational movement and to allow for additional degrees of freedom to prevent binding or unwanted lateral loads. Bearings may be of the roller, self-aligning spherical roller, ball, sleeve, or greaseless type, as necessary. See Chapter 2 for design guidance on bearings.

(9) Shaft couplings for vertical gate systems are recommended to be of the flanged exposed bolt, double engagement, gear type made of forged steel. Couplings of this style may be installed in either the vertical or horizontal orientation, depending on the shaft on which they are mounted. See Chapter 2 for further guidance on the description and selection of shaft couplings that might be applicable for use in vertical lift gate systems.

(10) Torque limiting couplings may be used in designs to prevent motor over-torque in vertical gate-hoisting arrangements. The designer may refer to UFGS 35 01 41.00 10 for specification guidance and Chapter 2 for design guidance on torque-limiting couplings. Other means of torque limiting are provided in Chapter 2.

(11) Wire ropes for vertical lift gates are commonly specified to be 6x37, preformed, lang lay, IWRC, 18-8 chrome nickel, corrosion-resisting steel. A 6x19 wire rope construction in the arrangements of 6x25FW and 6x26WS also are specified for vertical lift gates. In any case, stainless steel wire rope should be used. A 6x19 construction provides increased abrasion resistance compared to the 6x37 construction that has superior flexibility for bending fatigue.

(12) The factors that must be considered when selecting a wire rope include wire rope breaking strength; resistance to bending of vibration fatigue; resistance to abrasion and crushing; reserve strength; and factor of safety for anticipated shock, acceleration/deceleration, corrosion, and environment. A factor of safety of 5 must be applied to wire ropes against the safe working load of the rope under normal loading conditions.

(13) Limit switches should be used to stop the gate drive motor and to engage the holding brakes, prior to the wire rope cables becoming slack. Limit switches to check for excessive slack in the ropes should be considered based on the consequences of a slack rope condition on the machinery.

(14) The designer must use EM 1110-2-3200 for wire rope selection and design of hoist operated systems for vertical lift gates.

h. Roller chain hoist arrangements consist of the lifting chain, drive and idler sprockets, drive machinery, and counterweight. The roller chains are in recesses in the lock wall. Roller chains are flexible about an axis parallel to the lock center line and rigid about an axis perpendicular to the lock center line.

(1) Near the top of each recess, the lifting chain is redirected to the drive sprocket by an idler sprocket. The drive sprocket is in a recess below the top of the lock wall. Beyond the drive sprocket, the lifting chain continues to a second idler sprocket at the top of a counterweight chase. From the second idler sprocket, the lifting chain extends vertically to the counterweight.

(2) The chain connection to the gate leaf is a 3D gimbal. The gimbal allows rotation about the axes both parallel and perpendicular to the lock center line. Rotation of the connection point is allowed to prevent the lifting chain from being bent about its rigid axis when the gate leaf rotates. The connection points on the gate should be located at the end portions to coincide with the approximate center of gravity of the gate.

(3) Like for a wire rope drive, the drive machinery, located in a watertight recess at the top of the lock wall, consists of an electric motor, open gear sets, and reducers. The main advantage of the roller chain drive arrangement is the positive drive connection over the drive sprocket. This arrangement also does not require the larger space of a cable drum. Disadvantages include relative high cost of chains, frequent maintenance for lubrication, corrosion, and critical alignment required between sprockets.

9–8. Hydraulic hoists

Hydraulic hoists normally consist of a single-acting cylinder on a gate, pumps, reservoir, controls, and piping. One or two cylinders may be used per gate. The number of cylinders is determined by the hoisting requirement, width of gate, and economics. Any gate wider than 10 ft should utilize two cylinders. Vertical culvert valves are often lifted with hydraulic cylinders such as the design at Chittenden Lock. Hydraulic hoists are often used for high head regulating outlets. Regulating outlets allow flow through the dam while the reservoir water surface elevation is below the spillway gate ogee. The low-pool tunnel gates at Raystown Dam use two sets of service and emergency closure gates.

a. The arrangement may include the cylinder supported above the gate, with the gate and cylinder rod hanging from the piston supported by the rod end hydraulic pressure, or the cylinder recessed within the gate. Cylinders used for controlling a regulating gate will also have a bonnet cover. Bonnet covers are used to seal the water-side hydrostatic pressure and, in some cases, the oil-side hydraulic pressure. The bonnet cover rod seal design should resist water intrusion, include a method to adjust the seal for wear, and when exposed to hydraulic oil pressure, act to exclude the oil from the water.

b. Some newer rehabilitations are replacing the bonnet cover to allow a manufacturer-supplied hydraulic cylinder replacement. With this arrangement, only the hydrostatic pressure is considered during design. Figure 9–18 shows a bonnet cover at Raystown Dam. These bonnet covers usually use packing seals to prevent leakage through the cylinder rod penetrations.

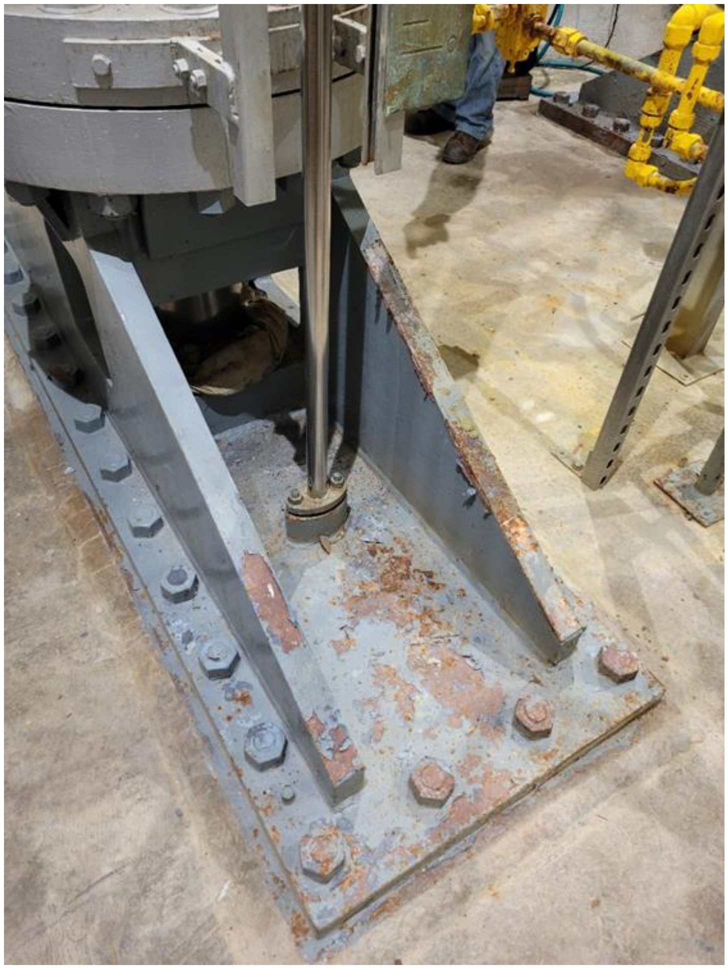


Figure 9–18. Bonnet cover at Raystown Dam

c. When the cylinder is above the gate, both the gate and cylinder bottom may be designed to have removable dogging pins or beams. When the vertical gate is dogged off, the cylinder can be extended to raise the cylinder structure connection to a higher elevation to perform a repeat lift of the gate. This arrangement allows for higher gate-lifting distances and helps to minimize cylinder stroke length. Further guidance for the selection, installation, maintenance, and inspection requirements of hydraulic cylinders and components are in Chapter 4.

d. High head regulating outlet gates require special design considerations for minimizing seal friction. Surveys of the frame seal, bonnet frame, bonnet cover surface, and gate seals are needed to coordinate the dimensions and tolerance of the two sealing surfaces. Machining of the gate seals should be done in the free position to prevent warping of the surface after the tolerance is met. Seal material should be chosen to minimize friction, resist cavitation damage, and resist cold welding.

Embedded frame seals commonly use staked cap screws to secure the seal. Machining these screws flat is important to prevent rocking of the screws when the gate moves. Figure 9–19 shows evidence of uneven wear on the screws, indicating screw movement.

Figure 9–19. Uneven wear on seal screws

e. Hydraulic cylinder construction can vary depending on the required lift force for the gate. Newer designs often use high-pressure, 2,000-psi systems to minimize cylinder diameter. Higher pressure systems seal better and are easier to source from manufacturers. Designers should carefully evaluate the effort associated with cylinder rehabilitation; rebuilding and replacing components in place requires high skill and specialized equipment.

f. Hydraulic system components may begin to leak, special consideration should be given in system layout for collecting leaks. Gates are usually installed in series with one emergency gate and one service gate to allow upstream inspection of the gate and emergency closure. Staff gauges connected to the gate should face toward the operator controls. See Figure 9–20 for an example of two high-pressure cylinders and pipe layout at Raystown Dam.

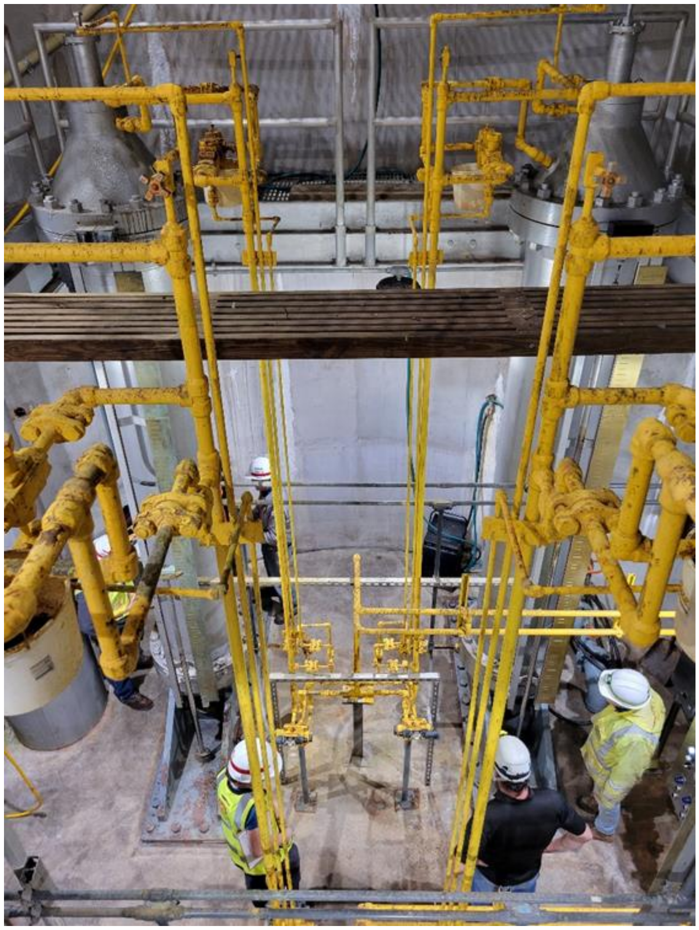


Figure 9–20. Two high-pressure hydraulic cylinders

g. Portland District has developed a regulating outlet standardization report that analyzes the positives and negatives of rehabilitation versus replacement of different system components. This report was written to better standardize the equipment used for operating high head regulating outlets and apply lessons learned from previous rehabilitation projects. A link to the full report is included as Appendix E.

h. Slide gates used for high head regulating outlets are significantly different in design than a standard off the shelf slide gate. They are often larger and require more vertical force to operate. The UFGS for slide gates is tailored for performance requirements of a standard off-the-shelf slide gate. Significant rework and customization of the guide specification is required to match the requirements of a high head regulating slide gate. In almost all cases, a regulating outlet gate will be identified as a hydraulic steel structure. A designer should confirm this requirement and coordinate any additional specification changes.

9–9. Lift gate design components

a. Dogging devices. Dogging devices (dogs) are recommended for vertical lift gate designs. The dogging devices have mechanical components that can be either manually or automatically engaged, depending on the application and frequency of gate operation. The dogging devices provide positive reassurance that gates are in a secured position before other operations are allowed. They also provide a means to remove tension in the load-carrying components of the hoisting machinery. This allows maintenance to be performed while the vertical gates are in the dogged-off positions.

(1) The designer should coordinate with the structural engineers for method and location of gate engagement or support. The type of operating mechanism should also be coordinated with Operations personnel with regards as to how it will be operated and maintained. Also, agreement should be made with the structural engineers on the design loads. Welded fabrications for dogging devices should be coordinated with structural engineers for design and welded, according to American Welding Society (AWS) D1.5.

(2) Dogging mechanisms usually are mounted on grillages in the pier recesses at opposite end posts of the gate. They generally pivot or slide to permit insertion and retraction to provide clearance of the operated gate. Two or more dogging positions at each end of the gate slot might be required. The number and location of the dogs are determined by the operating requirements for discharge regulation and gate storage. The gate sections require dogging seats fabricated with structural or cast steel, welded or bolted on the end posts.

(3) One method of dogging consists of a horizontal pin that moves into pin plates attached to the top of the gate. The pin should be arranged so that it can be operated from the control station of the gate. Instrumentation should be provided to show when the dogging pin is fully engaged or fully released.

(4) Another type of dogging device consists of a cantilevered, mild-steel H-beam that retracts inside the gate at each end between the top and second girder web. The beam is located at the center of gravity of the gate in the upstream/downstream direction and runs through the end post to a reaction point at an interior diaphragm. The dogging beam is extended and retracted by using a bar as a manual lever extending through a hole in the top web and into a row of holes in the top of the dogging beam. The cantilevered end of the beam rests on bearing pads recessed in the piers.

(5) This type of dogging device is preferred for powerhouse gates and bulkheads because they also can be dogged at the intake or draft tube deck level and there are no mechanical devices to be lubricated or maintained.

(6) Where the gate is lifted above the lock wall, the designer should design all components for dogging devices on both the gate and the structure to support two times the calculated full gate load, to allow for impact loading. This should apply to all related pins, bolts, and anchor bolts.

(7) In dogging arrangements where the gate is not lifted above the lock walls, the beams should be designed for shear and moment, using 50% impact for the applied

loading. Stiffener plates should be used on each side of the support beam web under the support brackets of the gate and at the reaction points of the support beam.

b. Lifting beams. Lifting beams are normally provided for outlet gates and maintenance bulkheads. Since these gates usually are stored in a submerged condition, the lifting beam provides a latching and unlatching mechanism to lift the gate from the slot. Design guidance for lifting beams is in EM 1110-2-2107.

c. Guide tracks. Tracks for vertical lift gates usually are incorporated into the guide system, with the track itself consisting of a corrosion-resisting plate. Corrosion-resisting plate, such as stainless steel, is especially important in brackish or saltwater environments. The designer should work with the Mobile District Corrosion and Cathodic Protection Center to ensure correct selection of materials and to ensure there are no galvanic corrosion issues. As an example, Super Duplex stainless steel will act as an cathode to 316 stainless steel in salt water applications. In freshwater applications, the bearing plate or track may be of structural steel with a cladding of corrosion-resisting material on the exposed surface. To minimize the effects of the guide system on the support towers, the system should be connected to steel towers only at panel points of the structure.

(1) The guide system for a vertical lift gate on each end of the gate consists of two bearing or track plates (upstream and downstream) and an end guide plate. The bearing plates are so arranged that the wheels or bearing plates of the gate react against the bearing plates of the guide system. The system is arranged so that the gate can be loaded from either side and the bearing plates will remain effective.

(2) The end bearing plates are like the reaction bearing plates but are placed so that bumpers on the end of the gate will strike the end bearing plate and prevent excessive lateral movement of the gate in relation to the lock or structure slot. The end guide or bearing plate should be of the same material as the bearing or track plates.

(3) Mechanical designers must be aware that some guide systems for hydraulic cylinders and gates have close tolerances between plates to ensure proper alignment of the system. In some applications, the mechanical engineer must provide recommendations for machined plate surface finishes and running clearance fits for the system. The normal clearances for a gate should allow no more than 1 in. of total movement between the gate and bearing plate and no more than 0.5 in. between the gate and end bearing plate.

(4) In systems with guided cylinder movement, much tighter tolerances might be required to ensure no eccentric loading is imposed on the cylinder rod, for protection of the hydraulic cylinder seals. It is recommended to further mitigate the risk of eccentric loading by mounting the cylinders in cardanic rings or other such arrangements that allow rotation of the cylinder as bearing plates and rollers wear. For these cases, allowable wear prior to replacement of bearing plates and rollers should be established during design.

(5) The bearing plate or track must be attached to a suitable support member. The support members are normally standard rolled beams or sole plates with embedment straps. The support member is embedded and anchored in the concrete wall or attached to the tower at tower panel points. Consideration should be given to make the bearing plate or track easily replaceable to compensate for service life wear in the bearing surfaces. The allowable surface variation between non-continuous plates must be specified to ensure the gate or cylinders pass by without catching.

d. Bearings. Critical bearings for the design of a vertical lift gate include both wheel bearings and sliding bearings used to reduce the frictional resistance which must be overcome by hoisting forces. These bearing systems must be selected to minimize operating friction due to the differential pressure created during filling and emptying operations. For smaller vertical lift gates of low differential head, the use of slide bearings made of UHMWPE, polymer, aluminum bronze, or other self-lubricating materials are typically sufficient to reduce the friction reaction at the side seals. Some vertical gates have been fitted with UHMWPE slide pads instead of reaction rollers. These generally require stainless steel sliding surfaces as corrosion pitted steel can be damaging to the slides.

e. Wheel bearings. The selection of wheel bearings required to withstand the large, concentrated forces created by hydrostatic loads on a lock vertical lift gate is also a critical design feature that must be considered. The ability to access and lubricate these bearings must be provided if lubricated bearings are used. This will typically require a permanent access platform or cross gallery that permits access to wheel bearings for lubrication.

f. Maintenance. When a vertical lift gate is used for the downstream lock gate, the gate can be moved entirely out of the water for maintenance. However, some means of accessing the bearings for lubrication must still be provided. This access is typically provided using watertight doors located in the hoisting towers that permit access to the wheel housing locations within each pier. The time required to slowly raise and lubricate each wheel of a large vertical lift gate must be considered. For locks with frequent barge traffic and limited outages, the time required to maintain these lubricated bearings may be unacceptable.

g. Roller wheels. Wheels for the underwater gates are a critical item and should be designed for individual conditions. A gate being raised with a considerable horizontal load caused by flowing water would have considerable deflection at the ends. To avoid point contact of the wheels on the flat plate track caused by gate deflection, the wheels should be constructed with a crowned, hardened tread.

h. Gate deflection. Appendix C provides more detail regarding a method for designing a wheel subject to gate deflection. This method was developed using formulas from Roark and Young (1975). The formulas in the fifth edition also may be used, except the formulas for computing maximum compressive stress are wrong. The formulas give the maximum compressive stresses occurring at the center of the surface of contact, not the maximum shear stresses. The maximum shear stresses occur in the interiors of the compressed parts. The formulas do not provide the maximum tensile stress, which occurs at the boundary of the contact area and is normal thereto.

i. Load distribution. Due to the flexure in the gate, it is difficult to accurately determine the distribution of load on the gate wheels. However, it is considered satisfactory to design the wheel tread for a maximum compressive stress equal range of 2.0 to 2.5 times the yield strength of the material involved. This calculation is based on the maximum wheel load from the gate. A slight misalignment of the track surfaces will prevent a wheel of the gate from bearing on the track for short distances of travel. This can cause an overload on some of the adjacent load-carrying wheels. This condition should be considered when determining maximum wheel load.

j. Spherical bushings. An alternative to the crowned wheel, to compensate for gate deflection at the ends, would be to use flat wheels with self-lubricating, self-aligning spherical bushings. These are available in many bearing and lubricant combinations to suit a variety of applications. Self-lubricating, self-aligning spherical bushings have been used successfully in nuclear offshore, industrial, structural, and dam applications. See EM 1110-2-1424 and Chapter 3 for more discussion on self-lubricating materials.

k. Other loads. Wheel design may need to consider loads not used in the hoisting analysis, such as barge impact. It is common practice to design all wheels to the highest load case; however, special conditions may be encountered that could require more than one roller design.

l. Roller material. Rollers are most commonly solid stainless steel or steel with a stainless steel thread overlay. The stainless overlay allows the bulk of the wheel to be of a less expensive material, but galvanic corrosion at the stainless to steel interface can be a problem as can poor application of the overlay. The solid stainless rollers avoid this issue but can cause galvanic corrosion problems on steel gates and can have higher fabrication costs. As of this writing, no projects have pursued rollers of composite/FRP construction.

m. Spare parts. Any procurement contact should consider the need for spare parts. The designer should make decisions on spare parts in coordination with Operations personnel and any risk-informed decision document for the project. Considerations should include possibility of failure, consequences of failure, lead time, and storage requirements and availability.

9–10. Lift gate design considerations and criteria

Machinery components' general criteria, applicable to all types of operating machinery are presented below.

a. Criteria. The designer must verify that the hoist will raise the gate through its full range of motion. While peak loads are often seen at near full closed, changes in hydraulic dynamics, buoyance, downpull forces, changes in effective drum diameter, changes in reaction support conditions, and other factors can result in the governing case load being at other gate positions.

b. Considerations. This manual does not set forth an overall hoisting capacity factor of safety to be used for all cases; however, the designer should consider leaving spare hoisting capacity based on factors such as accuracy of load calculations, changes in loads due to deterioration of components over time, impacts of construction tolerances, and other factors. Typically, this factor of safety is not less than 10% greater than expected maximum load, but greater factors of safety may be appropriate.

c. Motor torque. The required torque of the vertical lift gate hoist motor should be greater than the maximum expected during the normal full range operation of the gate with the motor selected having a 1.15 service factor. The normal hoist load for the gate leaf will be the loads resulting from the required torque of the motor. The hoist motor should have torque characteristics conforming to UFGS 35 01 41.00 10 and UFGS 35 20 20. In some applications, it might be desirable to consider variable speed (AC or DC) hoist motors with a ramping function adjustable through the drive controllers.

d. Hoist load. The factors of safety from Chapter 2 and Chapter 11 must apply in determining the vertical gate hoist loads in both normal and overload conditions. Criteria for two-sided lifting is provided in Chapter 11. The designer must calculate for both a normal hoist load and a maximum overload condition. The normal hoist load should be considered as equally divided between the two drives of the hoist. The magnitude of the maximum overload condition will depend on the type of hoisting system. For the overload condition, unit stresses must not exceed 75% of the yield stress of the material, and wire rope loads must not exceed 70% of the nominal breaking strength.

(1) For hydraulic cylinder hoists, the system should be designed to support and lower the entire gate from one side. The maximum overload condition would be limited by the hydraulic system relief valve setting. This corresponds to the structural jammed gate condition.

(2) For systems consisting of synchronized but independent electric motor hoists for each side of the gate, the maximum overload condition would be the forces created by the locked rotor torque of each motor applied to each side of the gate. This corresponds to the structural jammed gate condition.

(3) For emergency-type gate machinery, force control switches, load pins, or similar load measuring devices may be used to limit the rope pull under stalled conditions and, thus, reduce the loads on the machinery components. However, the machinery must still be designed to accommodate the design overload conditions noted above.

(4) For systems using hydraulic motors instead of electric, the electric motor cases would apply, but instead of locked rotor torque, use the maximum torque produced by the hydraulic system relief valve setting.

e. Hydraulic fluid brake. A hydraulic lowering brake should be used in the design, to lower vertical tide or hurricane gates when reliable utility power or backup standby power is not available. The vertical tide gates are normally lowered by an electric-drive motor on the hoist, with a diesel electric generator set standing by in the event of power failure. In cases where this is not reliable or available, the gate may be lowered by coupling a hydraulic motor to the shaft extension of the electric-drive motor. This fluid motor is connected in an oil circuit, which permits free flow of the oil in the raising position but restricts flow in the lowering position.

(1) A typical circuit required for this operation is shown in Figure 9–21. The flow control valve used in this circuit should be designed and adjusted in the field to limit the speed of the electric motor to about 140% of its synchronous speed, so as not to damage its windings or rotor. The flow control valve and fluid motor must be sized so that the pressure of the oil leaving the motor must not exceed the normal working pressure rating of the fluid motor. When lowering the gate, approximately 10 minutes might be required. During this time, the braking energy will be transformed into heat in the oil as it passes through the flow control valve.

(2) A shell-and-tube-type heat exchanger must be provided in the circuit to prevent the temperature of the oil in the tank from exceeding 120 °F. A cool, clean potable water or raw water source may be used in the heat exchanger to cool the oil. A thermostatically controlled valve may be used to automatically control the flow of water through the heat exchanger. The water can be exhausted to drain after use and should be capable of being winterized during periods of non-use.

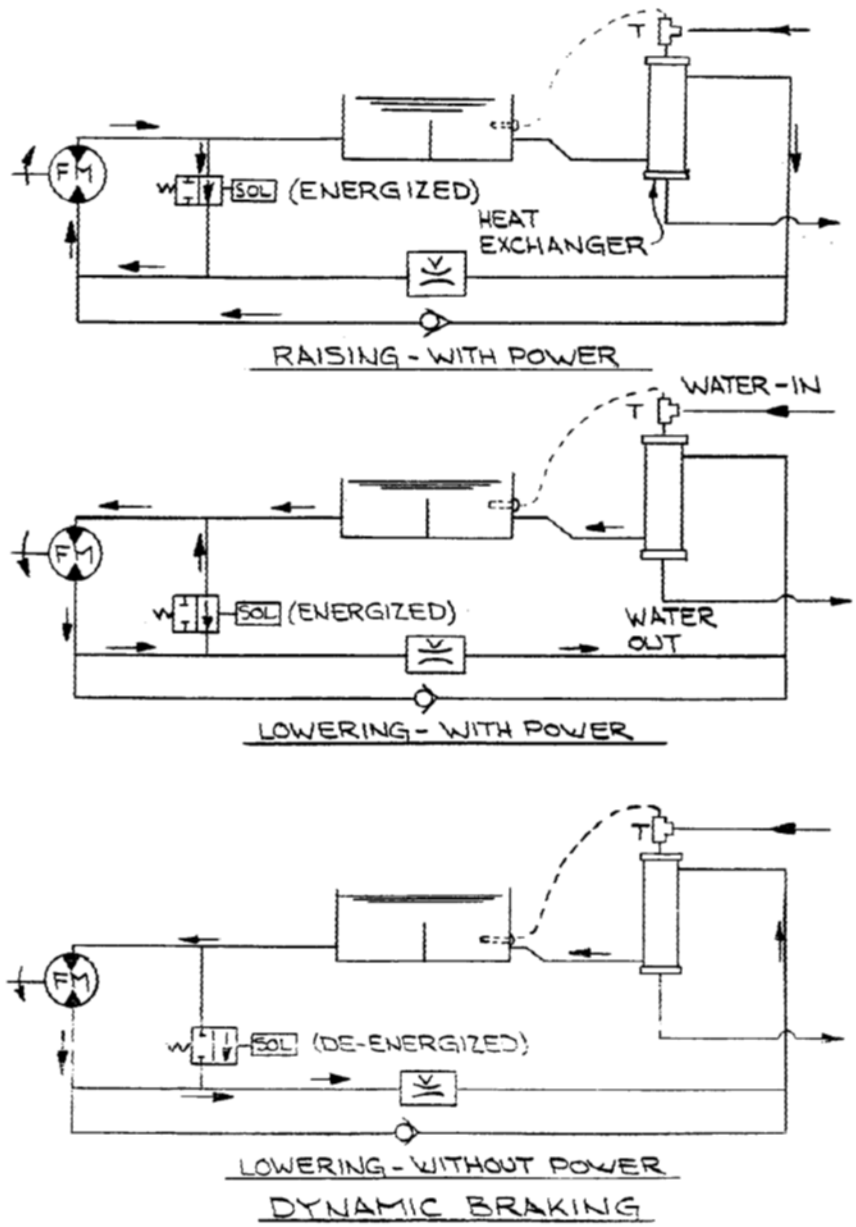


Figure 9–21. Typical circuit requirements for raising and lowering a vertical tide gate

f. Gate hoist loads. Details regarding typical calculations for determining loads for design of emergency gates are provided in Appendix C. The hoist design load for balanced head condition gates, or when the lower pool is 1 ft or less below the upper pool, will be the dead weight of the gate leaf in air, side seal preset force, weight of trash screens, weight of silt load (when raised to maintenance position), or the summation of the balance head loads below, whichever is larger.

(1) Balance head loads are the weight of gate leaf minus weight of water displaced; silt load amount trapped by flanges less weight of water displaced; sliding

friction due to horizontal force caused by 1.0-ft swell head using a coefficient of friction for this condition of 0.40 for steel on steel; downward hydrostatic load due to 1.0-ft swell head; weight of recess protection; and trash screen minus weight of water displaced.

(2) *Silt load*. Additional weight due to accumulated silt should be added to the overall load of the hoisting machinery, if not furnished by the structural engineers. The silt can become trapped above the web of the girders to the height of the downstream flange. Calculate the weight from the possible storage volume on the gate, using a silt density of 125 pounds per cubic foot (pcf).

(3) *Biological growth*. At some sites, mussels and clams grow in significant numbers on the gates and result in increased loads. The designer should investigate if this condition may exist at the project location.

g. Hurricane gates. Loads used for design of vertical tide gates and hurricane gates are like the loads used for vertical emergency gates, except the wind load is a more critical factor. The gate is hoisted high above the structure, permitting barge traffic to pass underneath. This exposes the gate to a considerable wind load, which must be included. To find the hoist capacity, the following two conditions should be considered, with the one creating the greater load being used for design of the hoist.

(1) *Condition I*. Weight of gate leaf in water consisting of the skin plate, framing, sheaves and brackets, wheels, etc., and the weight of silt (125 pcf) trapped by the flanges of the gate girders less the weight of water displaced. Include the rolling friction load calculated to be 5% of the horizontal load on the gate caused by the largest combination of differential head. Finally, incorporate the wind load, calculated at 20 psf, acting normal to the gate’s surface for the exposed portion of the gate.

(2) *Condition II*. Weight of the gate leaf in air consisting of the skin plate, framing, sheaves and brackets, wheels, etc., and the weight of silt (125 pcf) trapped by the flanges of the gate girders. Rolling friction of 5% of the horizontal load on the gate caused by the wind load, at 20 psf, for the exposed surface of the gate.

h. Sliding friction load. Additional load on the hoisting machinery is also caused by sliding friction of the wear surfaces and seals against the stationary mating structure surface. The designer should perform research to decide the best coefficient of friction to use in calculations. This might require independent testing to determine the applied coefficient of friction in applications that are critical. Since frictional loads can be a substantial part of the overall gate load, the coefficient of friction testing to replicate in field conditions will help to make accurate calculations and avoid gross oversizing of the hoisting machinery.

i. Roller friction load. The total friction due to the gate reaction rollers running against steel tracks and the friction of the bearings in the reaction rollers is much lower than sliding friction surfaces and should be taken as 5% of the load normal to the gate leaf. The designer should fully document any values different than this. Where self-aligning, spherical, greaseless-type bearing reaction rollers are used, the designer should consult with the greaseless bearing manufacturer to help determine the reaction roller-bearing friction.

j. *Hydrodynamic load*. A downward hydrodynamic force or downpull force exists for all gates that must be raised through flowing water. This force can be obtained from the curve showing results of studies conducted by WES (see Appendix C). The Bureau of Reclamation also has a published study titled "Hydraulic Downpull Forces on Large Gates" (Murray and Simmons 1966).

9–11. Control system considerations

a. Control stations for vertical lift gates are usually adjacent to the gate, along with the hoist machinery. The control equipment consists of the combination of full-voltage magnetic controllers, limit switches, and control switches arranged to produce the desired operating sequence. Many of the older designs still used today incorporated traveling nut-type limit switches in heavy cast iron NEMA 4-type enclosures. This style is no longer commercially available, and designers are now choosing rotary cam-style limit switches.

b. Vertical lift gates must have position indication for full closed and full open positions and overtravel. With electronic control systems (PLCs), the gate position can be tracked during the full range of motion.

c. In applications with PLC-based systems, the designer may incorporate electronic encoders or an LVDT. The designer must take care to position feedback systems in hoisting systems that are not mechanically coupled to give 100% reliability in gate position. All electronic feedback instruments must have absolute positioning in case power is lost. This is to ensure the gate's position and skew always are known by the control system. The designer should also reference Chapter 11 for additional discussion on position control systems.

d. Slack cable limit switches or pressure switches and skew control should be used on vertical lift gates to prevent them from becoming racked or jammed in the slots. Gate leaf control should be coordinated with the electrical engineers.

e. Wound-rotor sync motors can be used when two separate hoisting units are used to lift the gate to prevent gate skew. Typically, the sync motors are installed on the parallel shaft reducer input shaft, opposite the hoisting motor, one per side. These motors are wired together and in opposite phase as the hoist motors. If one sync motor gets out of phase with the other, a torque will be created by the relative slip that brings the two units back into sync. See Figure 9–22 for typical installation of one side of the hoist at Little Goose Lock.

f. The sync motors perform best when they are of the same rating as the hoist motors. The motors will then be able to keep the units synchronized for any load the hoist could create. The advantages of this system are that no instrumentation or external controller is relied on and line shafts are not needed to connect the units. The disadvantage is that two additional motors must be purchased per gate and space made available for them.

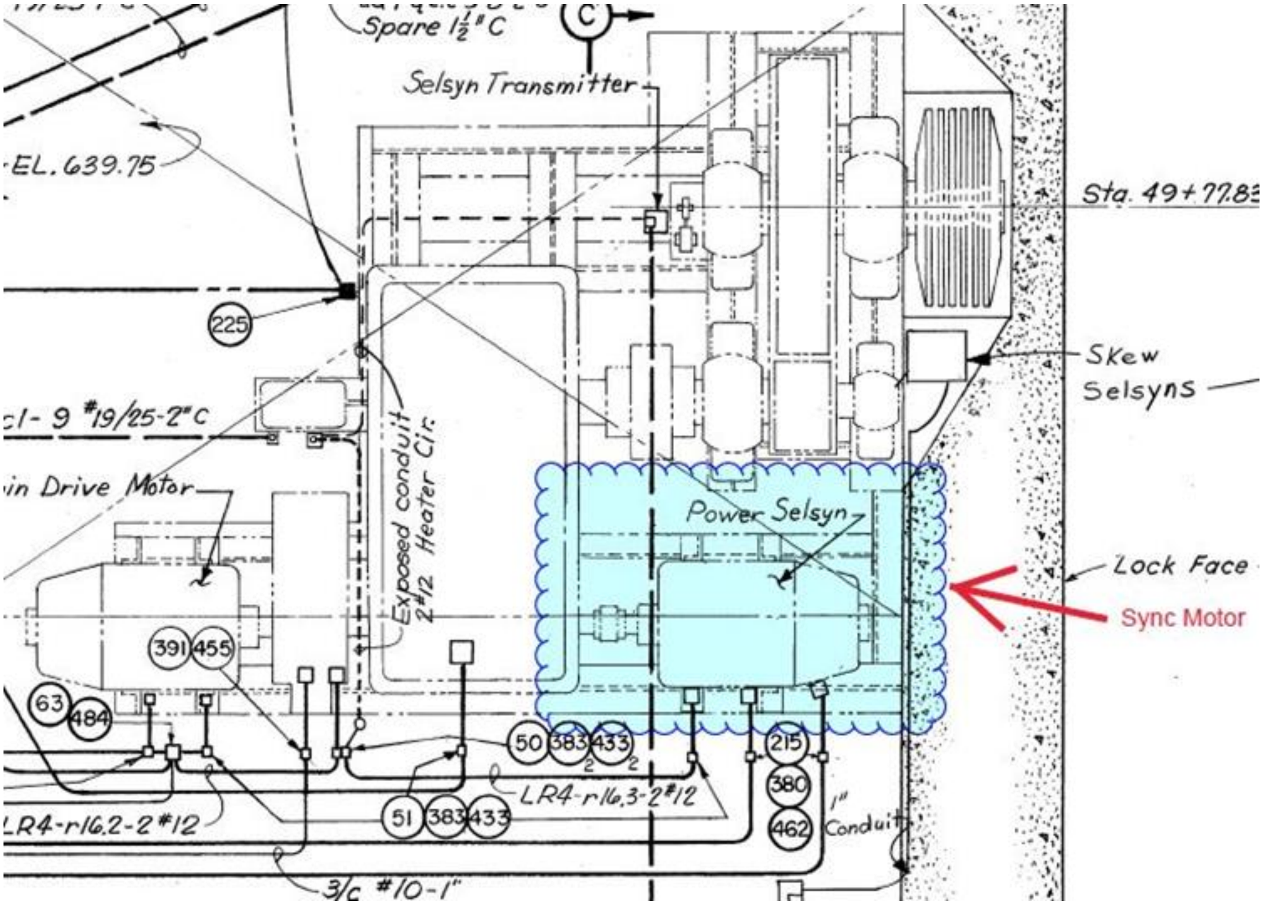


Figure 9–22. Typical sync motor setup (Little Goose Lock and Dam)

9–12. Slide gates and other vertical-type valves

Slide gates are another type of vertical lift gate. The design criteria are provided in AWWA C560 and AWWA C561 for cast iron and stainless steel gates, respectively. EM 1110-2-3105 also provides extensive discussion of slide gates and should be referenced. The designer should also refer to Chapter 2 for additional guidance on buckling criteria. AWWA C542 should be used to help design and select the actuator. UFGS 35 20 16.54 should be used to specify both the slide gate and actuator.

a. The slide gate consists of a self-contained frame or non-self-contained frame and a slide, or disc, as some manufacturers call this. Slide gates are raised and lowered by means of a stem or rod using a manual or electrically operated screw stem hoist, or by a hydraulic or pneumatic cylinder. As such, the buckling load must be calculated. The designer should be aware of how AWWA calculates the buckling load both in the recent 2021 versions of AWWA C560 and AWWA C561 and the previous versions of these standards. The designer must be aware of the criteria used by the slide gate manufacturers and work with them to properly select the stem size. Oversizing the stem will result in a larger gearbox than necessary; however, to correct an undersized stem in the field involves changing many components.

b. The 2021 versions of AWWA C560 and C561 call for designing for buckling relative to the extreme operator load. For manual operation and for sizing stem guides, that is specified as an 80-pound effort. For hydraulic systems, it is the system relief pressure setting and for electric actuators it is the stall (locked rotor) torque. Both AWWA standards then say to use the extreme load multiplied by 1.25 and to use a buckling coefficient C = 2. The designer needs to be aware of the NEMA design rating of the motor and the stall torque of the motor to avoid buckling the stem.

c. The 2014 versions of AWWA C560 and C561 call for designing for buckling relative to the extreme operator load without exceeding one-fifth of the ultimate tensile strength of the stem material. For manual operation and for sizing stem guides, that is specified as a 200-pound effort. The 2014 standard also notes: "The user is cautioned that rated output may be more appropriate depending on the features specified with the actuator." Both AWWA standards then say to use the extreme load multiplied by 2, and to use a buckling coefficient C = 2.

d. Valve actuators also typically have torque limiters that may protect against extreme torque conditions. It is important for the designer to work with the actuator manufacturer to set these properly and to set at the correct torque setting.

e. Determining appropriate input to the manual actuator can be difficult, and often is a judgement call by the designer. The manual wheel/crank is sometimes removed in the field and a portable drive, often an electric drill, is connected to the manual input shaft. This operating condition should be checked if considered a reasonable probability.

f. The designer should note that the buckling equation in EM 1110-2-3105 (2020 version), equation 14.4 is incorrect. It has a numerator of C^2*E instead of C*pi^2*E. equation 14.5 is also incorrect and the corrected version is noted below.

(1) Incorrect equation 14.4 in EM 1110-2-3105:

$$F_{CR} = \frac{C^2 EA}{\left(\frac{L}{r}\right)^2}$$

(2) Correct equation 14.4 in EM 1110-2-3105:

$$F_{CR} = \frac{C\pi^2 EA}{\left(\frac{L}{r}\right)^2}$$

(3) Incorrect equation 14.5 in EM 1110-2-3105:

$$L = r\sqrt{\frac{C \times E \times A}{F_{CR}}}$$

(4) Correct equation 14.5 in EM 1110-2-3105:

$$L = \pi r\sqrt{\frac{C \times E \times A}{F_{CR}}}$$

g. There are other gates and valves that also have vertical slides and operating stems. That includes knife gate valves. It is important the operating stems are supported properly, and stem guides are provided at the proper spacing to avoid buckling the stem. The designer should work with the manufacturer on the specific requirements.

Chapter 10
Buoyant Gates and Rolling Gate Operating Machinery

10–1. General description

a. Introduction. The required gate driving and operating forces can be reduced substantially by letting the gate float or become partially buoyant during closing and opening. Buoyancy reduces the hinge and bearing forces and may reduce machinery operating loads. Buoyancy-based systems are used on a variety of gates, including sector gates, rolling gates, sliding gates, drum gates, and swing-type gates. In USACE, the most common application is sector gates and swing gates. Drum gates and bear trap gates are seldom used anymore, but a discussion of these gate types is provided at the end of this chapter for historical purposes.

b. Control. One significant design consideration is decreased control of the floating gate during opening and closing. However, various gates of this type have been constructed and operate satisfactorily. The main application field of buoyancy-based gates is in storm surge and flood barriers. The primary reasons are long closing and opening times are available and high leakage is acceptable when the gate is closed. However, there are multiple navigation lock gates that employ buoyancy to help reduce operating forces. These are typically either sector gates or rolling gates and sometimes miter gates.

c. Water and air tanks. Buoyancy can be accomplished using water tanks or air tanks. There are advantages and disadvantages of both systems, as discussed below. Water-filled tanks require a pumping system to fill and empty the tanks. Air-filled tanks allow the gate always to be buoyant in either the open or closed position. The tanks, however, can be prone to leakage, at which time buoyancy will be lost.

d. Sector gates. Sector gate design was discussed in depth previously in this manual in Chapter 7. The designer can consider buoyant sector gates to reduce the operating loads. An example of a large buoyancy-based sector gate is the drive system of the world's largest storm surge gate of the Maeslant Barrier in Hoek van Holland, Netherlands (Figure 10–1 and Figure 10–2). The gate spans across a 360-meter opening, a height of 21.5 meters with a skin plate radius of 260 meters. The gate weight is 26,000 tons.

(1) The Maeslant sector gate is a sector type with a ball hinge. It is fully buoyant during opening and closing. In the nearly closed position, the buoyancy tanks fill with water. As this happens, the gate sags, then settles on its bottom sill. The drive itself consists of a locomotive winch system and a drive track on the top edge of the gate. To avoid collision due to long trans-late waves, a vertical gap of up to 1 m (3 ft) must be left open. However, such openings which are unacceptable in lock gates usually do not present a problem for storm surge barriers.

Figure 10–1. Buoyant sector gates of the Maeslant Barrier, Netherlands, in closed position (courtesy of R.A. Daniel, Rijkswaterstaat, and Hollandia)

Figure 10–2. Maeslant Barrier sector gate arm and hinge

(2) The New Orleans IHNC surge barrier project and the corresponding sector gate were part of a design-build contract after Hurricane Katrina. The sector gate is driven directly by hydraulic cylinders as shown in Figure 10–3. The surge barrier sector gate is partially buoyant to reduce the operating loads. The design was changed during construction from a sector gate supported on rollers and tracks to a partially buoyant gate. Some advantages and disadvantages of the buoyant system are noted below.

(3) Advantages include:

(a) No wheels to freeze, no wheel track embedded in the concrete floor.

(b) Less force required to move gate.

(c) Less vulnerable to settlements, tolerances, and hinge wear.

(4) Disadvantages:

(a) Requires air/pumps, buoyancy tanks and controls.

(b) Requires watertight welds and introduces risk of tank leakage.

Figure 10–3. Inner Harbor Navigation Canal Sector gate, partially buoyant

e. Barge gates. Barge gates have been used, with some success, as storm surge barriers across navigable waterways. Barge gates are used extensively in the New Orleans area, including for the IHNC Surge Barrier project. See discussion below for barge gate design considerations.

(1) Barge gates typically are constructed from concrete or steel. The gate consists of a floating structure swung into position across the channel and sunk into place, sealing along the bottom and against receiving structures on either side. The hinge assembly is often a simple mooring point or pin.

(2) Operating machinery, in theory, could consist of any means employed to manipulate barges; however, it is typically some form of rope and capstan or winch and cable/chain system to pull the barge into position. Ancillary equipment includes a valve-and-pump system to scuttle and refloat the barge.

(3) Barge gates can be quickly fabricated to provide economical closures, though the operation tends to be somewhat slow and cumbersome due to the limited control of the gate when buoyant, with imprecise positioning contributing to difficulty in producing complete sealing. As such, they are not considered appropriate for lock closures.

f. Rolling gates. A rolling gate is a rectangular structure stored in a recess along the lock wall. The gate is extended and moves transverse to the lock across the waterway to a recess on the opposite side. These types of gates are used extensively in Europe, especially in seaports and on the new Panama Canal Third Lane locks. Rolling gates are partially buoyant and supported by wagons that ride on a railroad track. Operating machinery may consist of a cable and pulley system, hydraulic cylinder, or rack and pinion or similar wheel-and-track type system. The specific design requirements of rolling gates are further discussed below.

10–2. Barge gate

Swinging-leaf barge gates have been incorporated into hurricane protection projects in the New Orleans area and by non-federal entities in protection rings in various locations around New Orleans. That includes several permanent barge gate structures in Terrebonne Parish and Orleans Parish in Louisiana that have recently been constructed. Figure 10–4 shows the barge gate for the New Orleans IHNC surge barrier being moved into position, under construction, and in its final position.

a. Barge gates generally are chosen as an economical alternative when other traditional gate designs become restrictive due to cost of construction or when schedule requirements become critical. Also, for very large structures, the benefits of positive buoyancy become more attractive; however, the inherent control and operational issues also become more prevalent. Barge gates can be quickly fabricated to provide economical closures and that is their primary advantage.

b. A barge gate is a buoyant hydraulic closure that can be floated into the water-retaining position and then sunk by ballasting. The opening of the gate proceeds in reverse order. First, the ballast is removed to make the gate float, then the gate is moved to the parked position.

c. The ballast used for sinking the barge gate can be the surrounding water. An advantage of water is its ensured presence on the site and the relative ease of filling the gate ballast chambers. Its disadvantage is the increased exposure to corrosion and the necessity to install pumping systems for emptying the ballast chambers.

d. As maneuvering the gate into and out of the closing position, letting it sink, and then refloating it, are time-consuming procedures, barge gates are normally not used in navigation locks. Barge gates have mainly been used as storm surge barriers across navigable waterways. These gates should be considered as temporary structures, however, due to several maintenance issues discussed below.

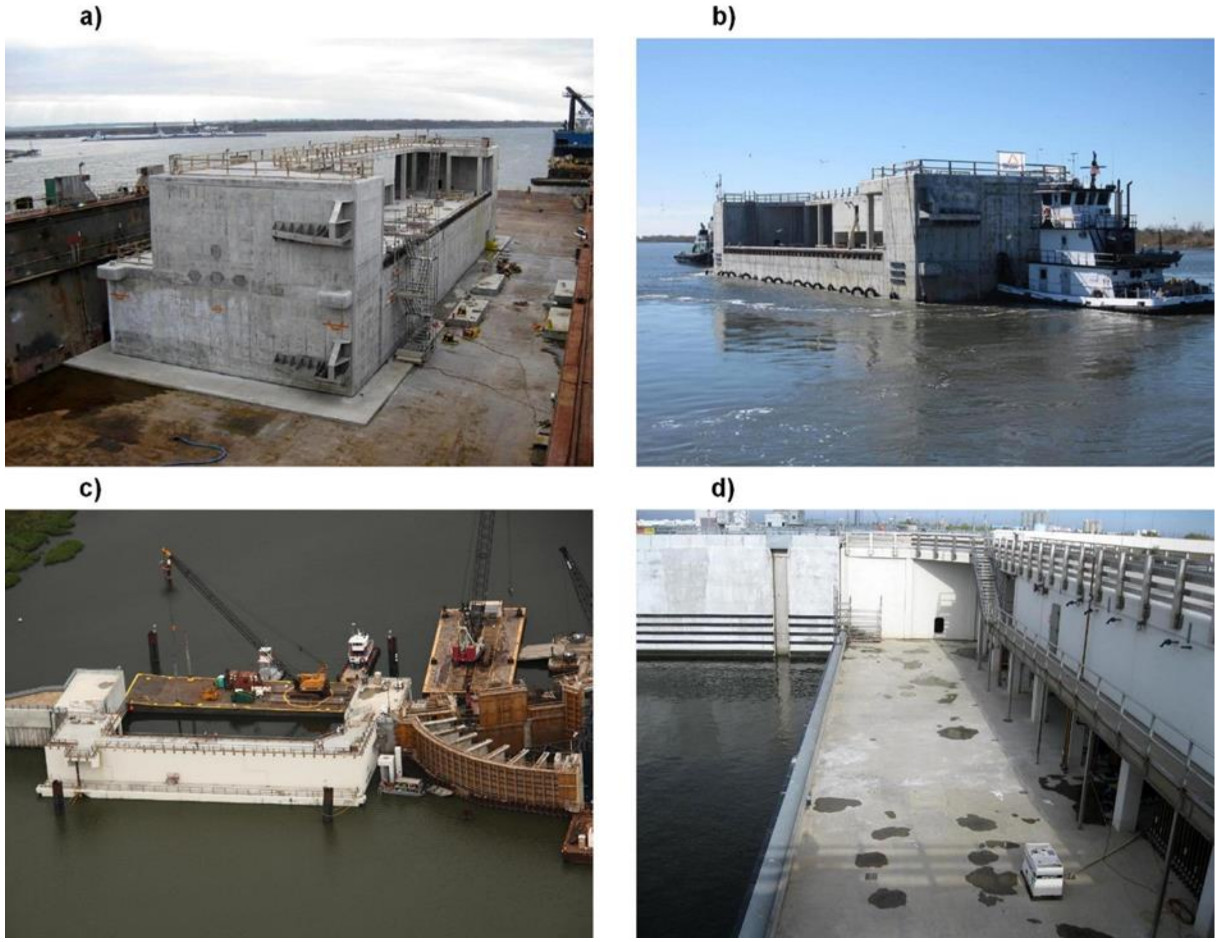


Figure 10–4. New Orleans Inner Harbor Navigation Canal surge barrier barge gate

e. Barge gates can be operated only with equal water head on both sides of the gate. Like a miter gate operating under a differential head, the large surface area exposed to this force would make the gate difficult to control. As such, these gates are practical only when a nominal head difference is expected. Even in this case, the hydrodynamic loading induced by such a head difference is the primary driving force on the sizing of the operating equipment.

f. Barge gates and their receiving structures can be constructed quickly, often in the wet with no cofferdam, reducing costs and facilitating short schedules. An example is the Bubba Dove barge gate near Houma, LA, shown in Figure 10–5. This gate is 250 ft in width and 42 ft in height and was completed in 2013.

(1) The Bubba Dove gate is operated and maintained by the Terrebonne Levee and Conservation District. The testing during Tropical Storm Karen (2013) and Hurricane Patricia (2015) confirmed its effectiveness but also revealed new issues. It

takes approximately six hours to swing the gate into place using a 3-man crew. The process involves pumping 6.8 million liters of water into the structure to sink it. The gate is filled with water in both open and closed position, so it must be pumped out to swing it either direction.

(2) The gate is operated with a winch and cable system. On one occasion, the cable snapped when the gate was already in the closed position. The operating crews then rented a tugboat to reopen the gate. No damage was done to the gate itself. At the time of this writing, the levee district is investigating upgrades to larger winches and pulleys. A standard procedure is now to make sure that under hurricane conditions the tugboats are on standby to operate the gate.

Figure 10–5. Bubba Dove barge gate (courtesy CB&I Construction)

g. The principal operating equipment for barge gates is typically a line pull system from the barge to either its closed or its stored location. Both chain and cable may be used. The chain winch system for the IHNC barge gate is shown in Figure 10–6. For smaller gates that have means of transporting a line across the channel, a cable or rope may be used with a winch or capstan. For larger applications, where the size of the line is prohibitive or it is impractical to run it across the channel, the line may be left permanently along the channel bottom.

h. Typically, chain or corrosion-resistant cabling is preferred in this case. This approach also exposes the cable to damage or snagging by passing vessels. Modern high-strength, lightweight synthetic hawser lines might provide a more manageable alternative to steel cable or heavy chain and allow for onboard storage of the operating line. Capstan systems should employ low-stretch ropes and might need to employ a reversing mechanism to back off the line if it binds.

i. Winch systems should employ a level-wind system or be run to a sheave, preserving the necessary fleet angle for proper cable winding. See Figure 10–6. As chains become corroded and lose cross-sectional area, this will affect the ideal spacing for chain wheel or wildcat systems and could lead to jumping or popping of chain as it nears replacement.

j. The IHNC surge barrier barge gate shown in Figure 10–4 is constructed of concrete. The gate was built for flood protection in the aftermath of Hurricane Katrina that struck New Orleans on August 29, 2005. It was originally designed as a temporary closure that provided a protected navigation passage while the adjacent sector gate was constructed. However, the barge gate was incorporated into the permanent project during the design build contract.

(1) The barge gate provides a passage when the main sector gate closure undergoes major maintenance. As a temporary closure, it meets its requirements. However, if frequently used, the barge gate on the New Orleans surge barrier is an example of the operational issues mentioned above. The operation in general is time consuming, labor intensive, and difficult. It takes 2 to 3 hours to pump out the water and float the gate.

(2) During this time, the operator stands on the deck with the remote control while 3 other people are stationed in various locations watching the pumps, valves, controls, winch, and chain. The gate travel takes about 30 minutes in one direction. At the closure point, the barge needs to be set on its locking pin at the wall end. Hurricane depth sinking takes 10 to 12 hours. The backup operation to move the barge gate is with a tug. The gate itself takes several hours to close and scuttle in the proper position depending on the nuances of the installation.

Figure 10–6. Winch system for Inner Harbor Navigation Canal barge gate

k. Scuttling and pump systems must be versatile enough to maintain proper trim while raising or sinking the gate structure in a controlled manner without inducing instability or upending the barge gate. Typically, this is done by dividing the buoyancy area into multiple independent chambers, with individual control over the filling or emptying monitored by operators or an automated system. See Figure 10–7 below for the pumping and control system on the IHNC barge gate.

Figure 10–7. Pumping system for Inner Harbor Navigation Canal barge gate

l. Refloating of the structure typically is accomplished by pumping out the buoyancy chambers. Sinking is typically achieved by opening scuttle valves and flooding the chambers. Scuttles placed flat to the bottom might induce the accumulation of sediment into the buoyancy chambers. In extreme conditions, pumps might need to be used to avoid excess sedimentation of the barge chambers by taking in surface water.

m. For floodgates, where the water level can be expected to rise on one or both sides of the gate after the gate is closed, scuttling by means of valves alone may not be sufficient. Operational conditions may require flooding the ballast chambers to a greater depth than can be achieved by valves alone, since valves can flood the ballast chambers only to the same depth as the water outside the barge. For this condition, pumps can also be used to fill ballast chambers when surrounding water levels are too low.

n. Barge gates employ a substantial amount of piping, valves, and pumps. It is recommended that the barge be treated as a vessel and American Bureau of Shipping standards be followed for items such as below-deck piping. Adhering to these standards facilitates transport of the structure to marine repair facilities for maintenance.

o. Seals are typically block or bulb rubber, usually on the barge itself, with the sturdier mating surface exposed to channel traffic. The seal arrangement may be completely on the vertical protected side face of the gate or may extend along the bottom of the gate.

p. Benefits of extending the seal on the bottom, and usually toward the flood side, are that the gate weight aids in compressing the seal, and the relative uplift on the gate are based on land-side water levels across the sealed portion of the gate bottom. Vertical face seals typically require a raised face across the channel bottom to seal against, and rely on the buildup of differential head, load-binding, ratcheting-type devices to achieve seal compression. Bottom seals, however, are much more susceptible to debris or siltation impeding the seal, thereby negating their advantages.

q. Hinge design typically consists of some type of mooring point that roughly positions the gate in the proper location as it swings closed. Hinge design must accommodate changes in elevation of the barge gate as it is scuttled and accommodate any tidal variations. The hinge may be as elaborate as a steel collar with internal rubber bumpers around a piling, or as simple as a chain to a pad eye or rope to a bollard.

r. In either case, the hinge system must accommodate the required movement of the gate, as well as enough repeatability in positioning to mate the seals to their respective seal plates, while resisting the loads imposed by currents, operating equipment, and even the inertia of the barge gate itself.

10–3. Rolling gates

Rolling gates have been used in Europe for more than 100 years and were common in the United States in the early 20th century on the Ohio River. See Figure 10–8. Modern gates of this type are typically employed for large lock structures in the range of 33- to 55-meter-wide (110- to 180-ft-wide) closures. Currently, the largest locks in the world are the Berendrecht Lock and Kieldrecht Lock in Antwerp, Belgium, with rolling gates operating in a 68-m-wide (220-ft-wide) lock. A new sea lock is now completed at the entrance of the North Sea Canal at IJmuiden that provides access to the Amsterdam port region. This lock is 70 m wide and 18 m deep and utilizes rolling gates.

a. Based on the history of this design type on structures of similar size, rolling gates were selected for use on the new 55-m-wide (180-ft-wide) Panama Canal Third Lane lock gates. See Figure 10–9. The Panama Locks use double sets of rolling gates at each end for redundancy. The new sea lock at Terneuzen in The Netherlands also utilizes the same design as the Panama Canal Third Lane.

b. Rolling gates are typically designed for operations under minimal differential head conditions in the range of 10 cm (4 in.), which is adequate for lock gate installations. Rolling gates are nearly always designed as buoyant to reduce the operating loads. The use of rollers and buoyancy chambers on these types of gates requires the submergence of some of the mechanical components necessary for operation.

c. Maintenance of these items, except for the cross-channel track, is facilitated by the ease of dewatering the recess bay, granting dry access to the gate structure.

Pumping ballast water out of the structure's buoyancy tanks allows it to be floated and supported before dewatering. Due to the weight of the larger single gate and rolling friction, operating machinery is typically larger for an equivalent miter gate or sector gate.

d. The designer should reference and use the PIANC WG 173 Report, PIANC WG 138 Report, PIANC WG 206 Report, and the textbook "Lock Gates and Other Closures in Hydraulic Projects" (Paulus and Daniel 2018) for details and assistance in the design of rolling gates. The Zandvliet Lock in Belgium and its rolling gate is shown in Figure 10–10.

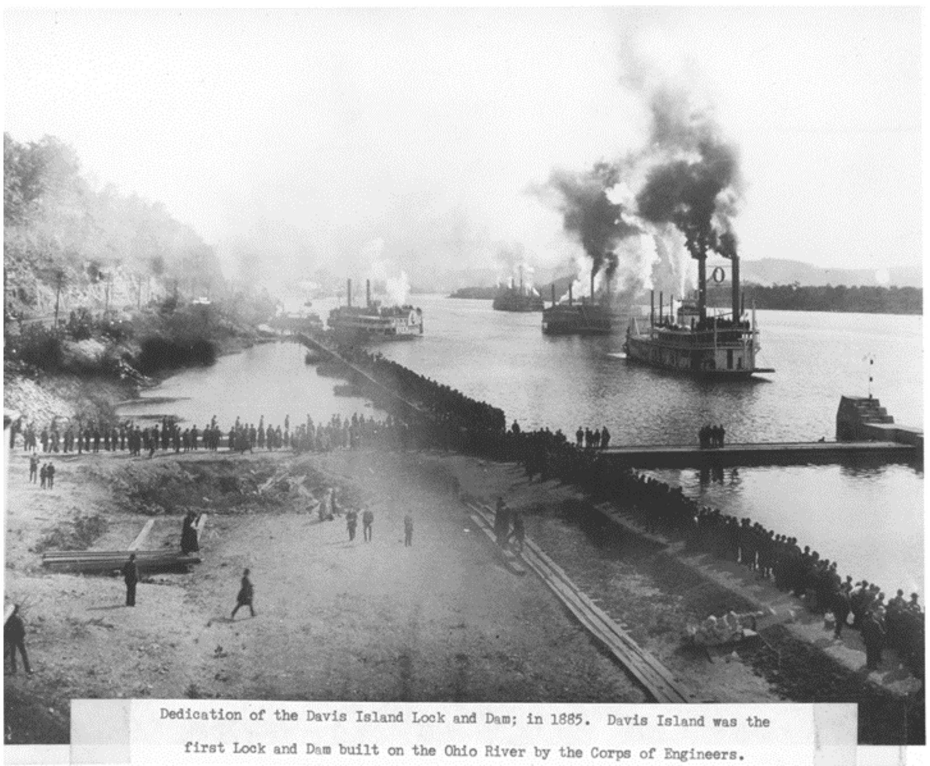


Figure 10–8. Davis Island Lock and Dam, downstream rolling gate near Pittsburgh, Pennsylvania, 1885

e. In addition to required forces that will be applied by the operating machinery, track loading, wear, accommodations for lateral gate movement, and debris management are important in the design. Hydrodynamic loading is typically from small tidal fluctuations or current from leakage through the opposite lock gate, as well as wave- or wake-induced loading. Typically, some lateral movement of the structure is allowed by its support system, permitting it to shift into its sealed position. The support type must accommodate this, and the effects on track loading must be taken into consideration.

f. Rolling gates for lock structures are a single structure as opposed to a miter gate, which generally uses two gate leaves. The structural design of a rolling gate typically uses one or two skin plates, in general designed as orthotropic plates. See the installation of the Panama Canal gates below in Figure 10–9. The gate must be supported during the entire movement. Support in the lock longitudinal direction and transverse or perpendicular direction should be distinguished for the case’s “gate movement” and “closed position.” These conditions should also be distinguished in the gate's direction of movement.

Figure 10–9. New Panama Canal rolling gates before being installed in gate recess

Figure 10–10. Zandvliet Lock, Belgium, rolling gate in closed position

g. A rolling gate can be operated only with minimal or equal head on both sides of the gate. However, the gate can be designed to accommodate large changes in water elevation, such as sea locks with tidal fluctuations. Note that the terms "wagon" and "carriage" for the rolling gate support system are often used interchangeably. Most new locks are equipped with a wheelbarrow system, but, depending on specific requirements and local circumstances, a classical support system can have benefits.

h. Rolling gates using the wheelbarrow design are the largest in world (Table 10–1). In a classical rolling gate, both carriages are placed under the gate. In a wheelbarrow gate, one of them is placed under and one at the top level of the gate on the operating machinery side. See additional discussion in paragraph 10–5. The advantage of this design is that all parts of the upper carriage structure are accessible and not under water.

Table 10–1
Example of sea locks with a wheelbarrow design sorted by chamber width

Lock name	Country	Chamber dimensions (m)			Gate Width (m)	Gate weight (tons)	Construction year
		Length	Width	Depth			
Kieldrecht Lock, Antwerp	Belgium	500	68	27.0	10.9	2,000	2016
Berendrecht Lock, Antwerp	Belgium	500	68	23.0	10.9	1,650	1989
Francois 1 Lock, Le Havre	France	401	67	22.5	10	3,300	1971
Van Damme Lock, Zeebrugge	Belgium	500	57	24.3	10.9	1,840	1985
Zandvliet Lock, Antwerp	Belgium	500	57	23.0	10.9	1,570	1967
Panama Canal Third Set of Locks	Panama	458	55	31.3	8 to 10	2,400 to 4,000 (varies with location)	2016
Charles de Gaulle Lock, Dunkirk	France	365	50	23	10	1,700	1970
Kallo Lock, Antwerp	Belgium	360	50	24.0	10.9	1,470	1979
North Lock Bremerhaven	Germany	372	45	21.2	8.5	2,400	1931
Boudewijn Lock, Antwerp	Belgium	300	45	19.0	8.5	870	1955
Van Cauwelaert Lock, Antwerp	Belgium	270	35	19	7.1	1,170	2011

i. Buoyancy of a rolling gate is also referred to as a ballasting system and provides the following three purposes:

(1) Rolling gates are commonly designed as buoyant to help reducing operating loads and to support the gate load. The gates can be either fully buoyant or partially buoyant during movement to reduce operating loads for the carriages and the track system. Ballast tanks are typically situated across the complete width of the gate. The operation and setting of the gate proceeds by allowing water in the various tanks or removing it by compressed air.

(2) Buoyancy tanks allow the gate to be raised off the carriages by flotation to allow maintenance in recess or transport for maintenance at another location. If maintained in recess, the gate is supported by lowering onto jacks. The gate recess can be dewatered for maintenance by placing a bulkhead in the lock end of the recess and pumping out the water.

(3) Buoyancy is also used to assist in gate installation and removal. On removal, the gate can be transported by floating to a dry dock or a mooring location. See Figure 10–11 for the transport of the new Kieldrecht Lock rolling gates in Antwerp for their first installation on construction.

j. Occasionally, the buoyancy system can also be used to reduce the increased carriage loading due to sea life, silt, and differential buoyancy caused by changing water levels. Some recent projects use automated systems that measure the actual load on the carriages. This allows the gate ballast system to automatically maintain the load on the carriages as low as possible.

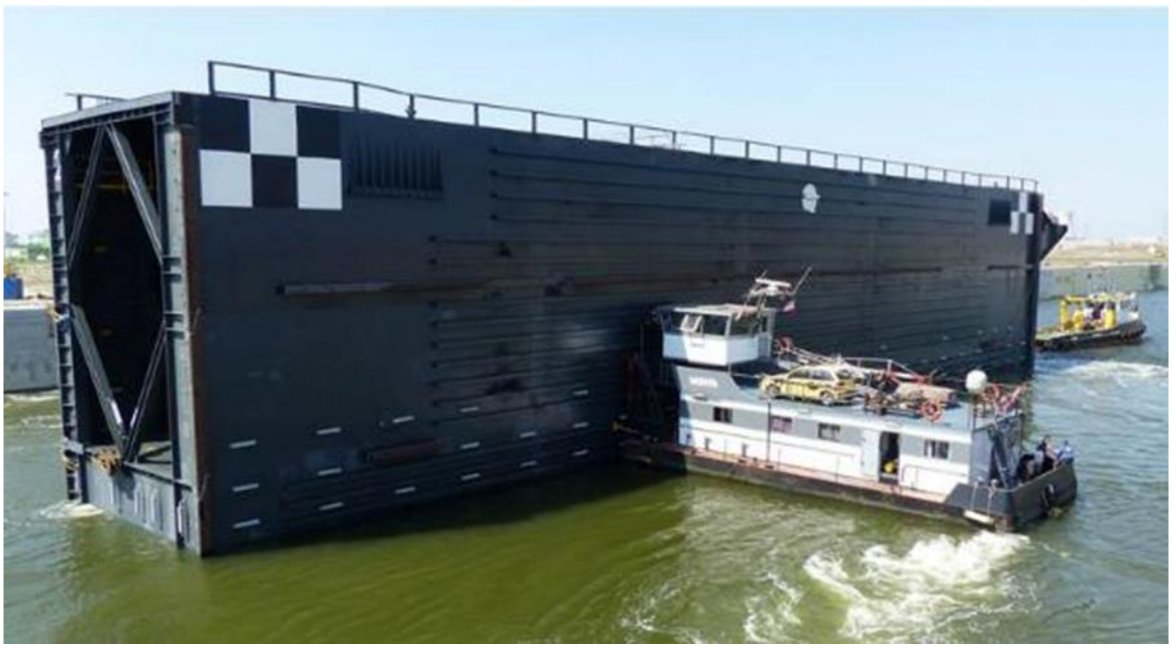


Figure 10–11. New Kieldrecht Lock rolling gate being floated into place (courtesy Vlaamse Overheid)

k. Reducing the operating load can extend the maintenance cycle and significantly reduce the overall maintenance cost of the gate. However, the desire for load reduction by buoyancy can conflict with the stability requirements against the buoyant forces acting upward under extreme operating conditions.

l. On several locations, particularly in Europe, the areas behind sea locks and their gates must be protected against flooding in case of a catastrophic storm surge that might potentially float the gate. To prevent this, the rolling gates can be equipped with a gravity-controlled, self-filling system. Prior to the activation of this system, it is usually necessary to remove some water ballast that has been applied under normal operation conditions. This can be done by pumps or compressed air as part of preparations for the storm surge.

m. Buoyancy tanks should be located as high as possible to increase stability during the gate floating for installation or maintenance outside the lock chamber. On the other hand, however, high center of gravity can introduce stability risks during the normal operation of the gate. Also, the draft of the gate during floating often requires a deeper position of the buoyancy tanks. The draft requirements usually cover issues like the sill depth, installation of the gates on its lower carriage, navigable depth and swell of the floating route, and the depth of a dry dock for maintenance. The gate freeboard during floating must also be sufficient to prevent wave overtopping that might cause stability issues. The required freeboard is commonly 0.40–0.80 m.

10–4. Rolling gate supports

For the vertical support, a distinction may be made between two types. These include two undercarriages (considered as the classical support system in Figure 10–12) and the wheelbarrow type, shown in Figure 10–12, with a single undercarriage and supported at the top by another carriage assembly.

a. Rolling gates typically are supported on two sets of carriages of four wheels each, though eight wheels may be used on larger gates.

b. The wheelbarrow system uses wheels riding on tracks at either side of the top of the gate recess. The Port of Antwerp Locks all use the wheelbarrow-type design (Figure 10–13). These are mounted to a cantilevered portion of the gate structure that remains in the recess when the gate is fully closed. The regular system provides simpler design of supports and recess and has performed adequately at many locations.

c. The wheelbarrow system, however, improves overall stability, as the gate center of gravity and hydraulic loading center of effort are generally located near the line of action between the supports. Also, the wheelbarrow system places fewer moving parts below the water. Wheel sets generally employ balance beams or some type of suspension system to equalize wheel pressures. See Figure 10–14 for the design of the Panama Canal Third Lane rolling gates. Submerged wheel assemblies would be an appropriate application for greaseless bearing components to reduce maintenance.

d. Wheelbarrow gates are more easily accessible for inspection and maintenance. For this reason, the gate is significantly longer since the gate is extended by the upper carriage. As a result, there is less favorable load distribution between the carriages. Loads generally act unsymmetrically, and the lower carriage bears a larger load share than the upper carriage. The right filling of the ballast can sometimes compensate for this discrepancy in loads. The gate is often ballasted so that the load is as evenly distributed as possible. However, this is not possible for all gates and under all circumstances, such as for tidal situations.

e. Replacement cycles vary with design and water conditions. However, in northern European applications, replacement of submerged wheels typically is done at five-year intervals and, for wheelbarrow-placed supports, 15 years is expected.

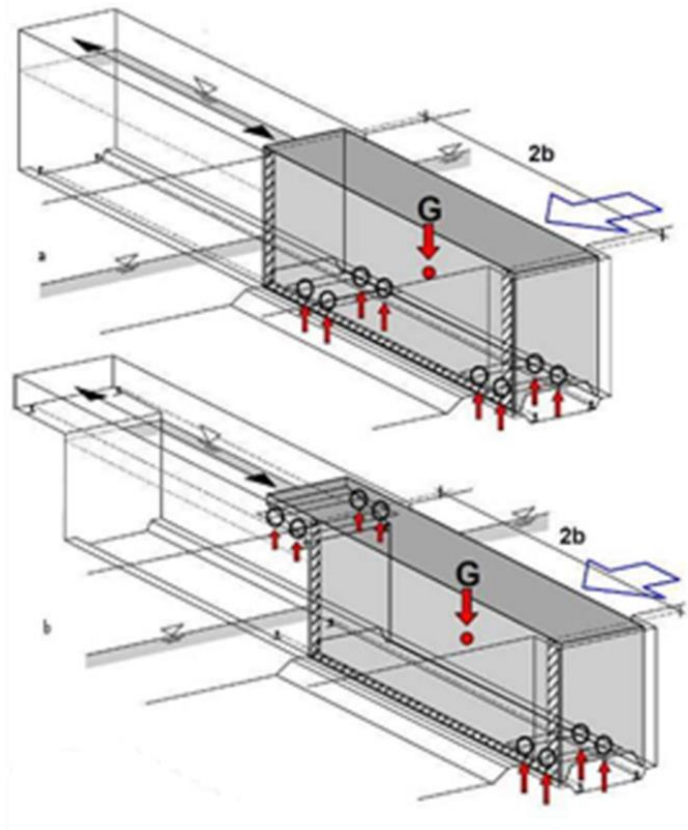


Figure 10–12. Rolling gate support arrangements, both a) classical type and b) wheelbarrow type (courtesy of R.A. Daniel, Rijkswaterstaat, Division of Infrastructure, Netherlands)

f. Nearly all of the gates at the Port of Antwerp use the wheelbarrow-type design. For a wheelbarrow-type gate, it is supported on the lower carriage and suspended to the upper carriage. This allows some lateral displacement of the gate toward its vertical contact lines in recess and the far end slot when the water head starts to build up.

g. The gate can then open after equalizing the water level at both sides. It can open when it comes free from its lateral support blocks. This can be detected by control devices and the control system of the rolling gate. If measures are also taken to do the same when the lower carriage is free of its support blocks, then the support system is self-centering. Both sets of the world’s widest rolling gates from Table 10–1, the Kieldrecht and the Berendrecht Lock gates in Antwerp, represent such a self-centering system.

Figure 10–13. Wheelbarrow gate, Van Cauwelaert Lock, Antwerp, Belgium

h. A wheelbarrow gate is more stable during opening and closing as it is supported at a high level, which is not the case with two lower carriages. The gate center of gravity and the resultant of residual hydraulic loads are both close to the diagonal connecting the two carriages. This improves the overall stability, which is important on large navigation and seaport locks. The wheelbarrow design also allows better conditions for self-centering with less need of side guides.

i. Some of the disadvantages of the wheelbarrow gate include higher construction costs and a more complex gate recess. More space is needed for the recess. Sealing usually requires a higher water head because of the friction in the hinges of the support system from the gate to the upper carriage, and, for that reason, it takes more time to seal the gate after closing. Floating stability (during transport for example) is adversely affected because the additional structure for the upper carriage support raises the center of gravity. The concrete support walls of the gate recess are heavily loaded by the rail track.

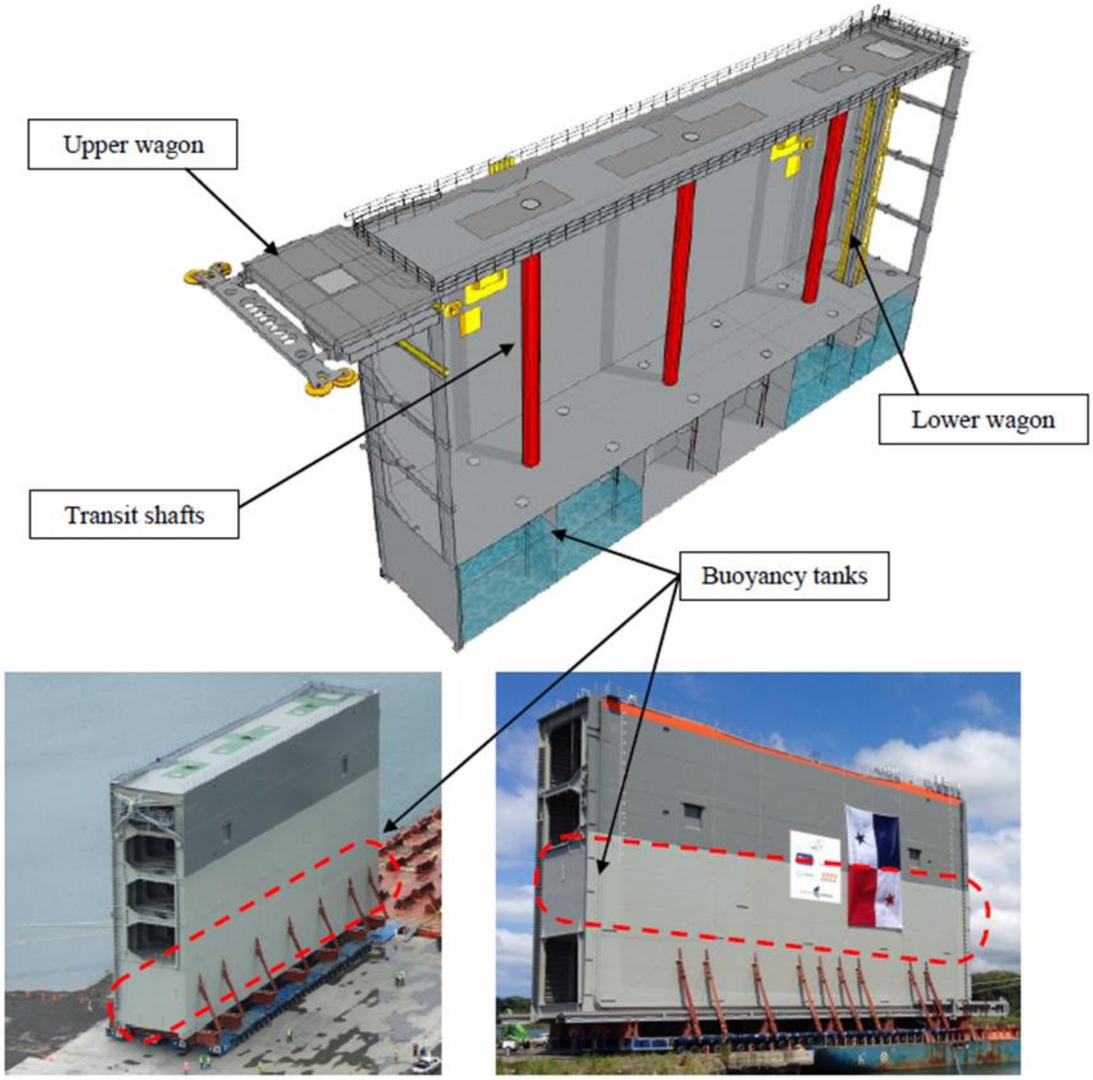


Figure 10–14. Wheelbarrow rolling gate system Panama Canal also showing buoyancy tanks and compression column (courtesy of Autoridad del Canal de Panamá)

j. In the classical support system, there are two undercarriage assemblies arranged near the gate ends. Both carriages are under the gate. The carriage units typically contain 4 wheels each. The wheel pressures are equalized by a system of balance beams. A rolling gate with both carriages below the gate needs only a rail track (or tracks) on the bottom of the rolling gate and has no limits to overhead space for navigation. The rail tracks, however, need to span the length of the gate, and hence, is very long. Both carriages are submerged, and therefore, not readily accessible for inspection and maintenance.

k. Advantages of the classical support system include:

(1) Relatively simple – the gate recess takes less space.

(2) Compact system with repeatable components.

(3) Lowest construction cost.

(4) Walls of the gate recess are free of rail track loads.

l. The disadvantages include:

(1) Unfavorable stability conditions during opening and closing – large overturning moment of hydraulic load while gate open or in motion.

(2) Many components, including long sections of the rail track, are underwater and are more time consuming and expensive to repair and service.

(3) Moment is introduced because the pulling force is not in line with carriages (may be minor, depends on height of gate).

(4) Self-centering of the gate can be an issue – needs side guides and expanding devices.

m. The disadvantages of the wheelbarrow type are advantages of a gate with two undercarriages and vice versa. The maintenance of both carriage types is more expensive; in particular, any inspection work requires divers. The same applies to the associated rail system.

10–5. Rolling gate machinery

Operating equipment is typically a mechanically driven cable system as shown in Figure 10–15. A typical system consists of a pair of cable drums located on the recess structure at the end away from the channel, with a continuous cable winding and unwinding off the top and bottom of each drum. The cables are looped through sheaves on either side of the channel end of the recess and fixed to the upper gate carriage. Winding the drums in either direction opens or closes the gate. Rollers or guide pads are used to support and guide the cables.

a. Some newer locks in Europe, including at Ijmuiden and Terneuzen in the Netherlands, use a rack and pinion design to move the rolling gate. The rack and pinion design eliminates some of the drawbacks of a wire rope drive but introduces other issues. This includes the need to ensure correct alignment of the rack and pinion.

b. Wire rope drive systems are the most common type of drive for rolling gates and are recommended for new construction. In the Port of Antwerp, wire rope drives are essentially a standardized system. The drive acts like a winch to either open or close the rolling gates. The wire rope is a continuous loop that spools off both the bottom and top of the drum. The wire ropes attach to the upper carriage: one directly at one side, the other via a turning wheel at the far end of the gate chamber. The motor is operated either forward or reverse to open or close the gate.

c. A typical operating speed of a rolling gate is 0.3 meters per second, but this can vary depending on the size of the gate. Increasing the gate speed will increase the hydraulic loads on the gate and increase the size of the operating machinery. The gates of the new lock at Ijmuiden will operate (open or close) in 4 to 5 minutes, depending on the salinity of the water. The Kaiser Lock has an opening or closing speed of 5 minutes, as do the new Panama Canal rolling gates. Lock filling or emptying time is generally more important than gate operating time because if the filling or emptying time is too fast, then mooring forces are too great. Thus, the lock filling and emptying times are often greater than the gate operating speed.

Figure 10–15. Rolling gate machinery, Van Cauwelaert Lock, Antwerp, Belgium

d. The faster the gate moves, the more power it requires. This is due to the increased drag in the water, inertial forces, and the force needed to move the gate in and out of the recess with the increased speed. On the other hand, increased operating speed might reduce the time ships need to pass through the lock, and hence, will increase the yearly capacity of the lock. However, the benefits of increasing the opening or closing time (by 1 minute, for instance) can be considered negligible and will be outweighed by the cost of the increased size of machinery components. A 5-minute opening or closing time is a good average and is recommended.

e. The basic mechanical components of wire rope drives include:

(1) Wire rope drums with ropes.

(2) Tensioning system that keeps the same length and tension in operating ropes.

(3) Motors, electric or hydraulic, often supported by a smaller auxiliary motor.

(4) Gearboxes for speed and torque conversion from motors to drums.

(5) Torque tubes or shafting between the drum and gearbox.

(6) Couplings between both wire rope drums.

f. A hydraulic drive system using a hydraulic motor that, in turn, drives the wire rope winch is another possibility, and this system is shown in Figure 10–16. Hydraulic cylinder drive systems generally are not feasible. This is because of the long drive distances that lead to extraordinary long hydraulic cylinders.

Figure 10–16. Wire rope winch drive at North lock, IJmuiden, Netherlands

g. Wire rope systems do have some drawbacks. The wire rope spooling off the drum can become twisted, creating torsion in the rope. The wire rope winches at Berendrecht Lock use an alternate lay of wire rope to prevent torsion of the wire rope as it spools on and off the drum. In other words, both left and right lay rope is used side by side (see Figure 10–17 and Figure 10–18). A guide system is required for the wire ropes as it spools off the drum.

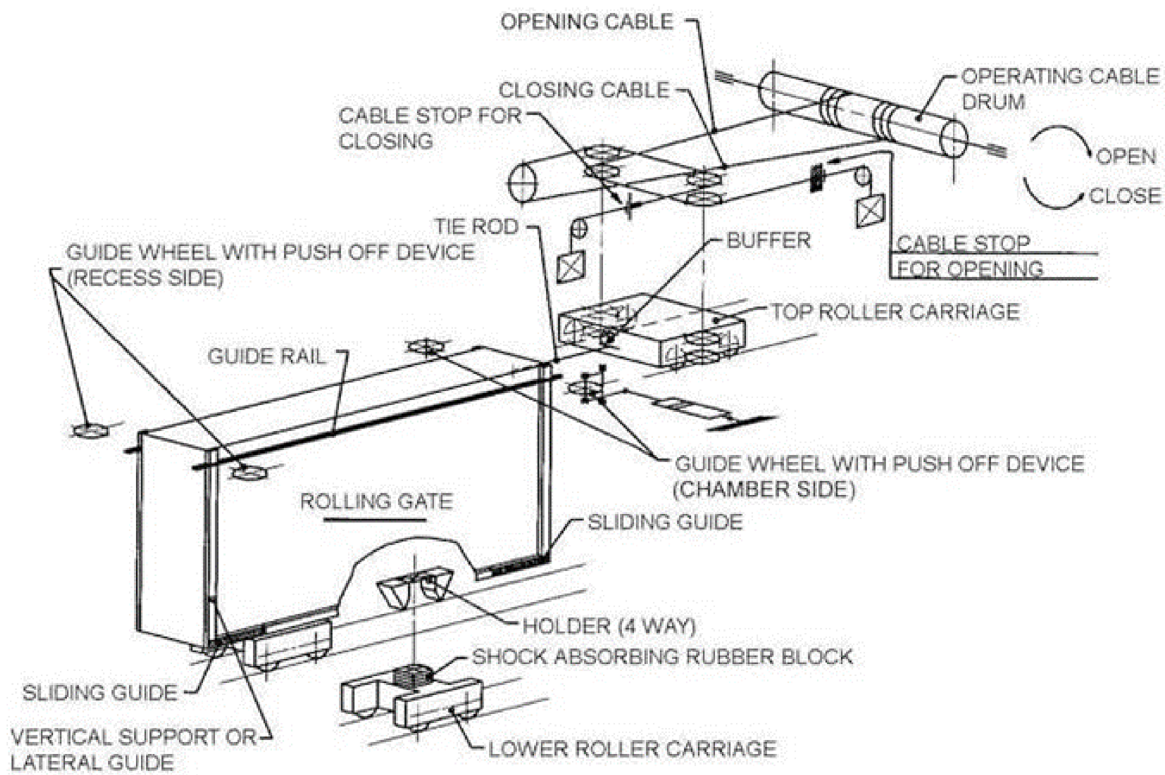


Figure 10–17. Wire rope drive machinery layout
(from Design of Locks – Netherlands, Rijkswaterstaat)

Figure 10–18. Machinery and alternate lay of wire rope, Berendrecht Lock

10–6. Maintenance

Rolling gates need to be designed to minimize maintenance. Many of the components of a rolling gate are underwater. A cofferdam system allows for inspection and access to the supports and wagons. This system has been incorporated into many rolling gate structures in Europe.

a. In Belgium, both rollers and wear pads have been used for the wire rope guide system. The rollers have tended to seize, and these are slowly being replaced with wear pads. A debris-removal system needs to be incorporated into the design. The gate and the roller carriages should be equipped with track clearers to prevent them from getting stuck.

b. A waste grid should be positioned at the bottom of the gate, in front of the roller carriages. Sediment and debris need to be controlled as the gate moves across the lock chamber. The Belgian locks in Antwerp use mixers and a venturi system to keep debris from settling as the gate is moved. See Figure 10–19.

Figure 10–19. Zandvliet Lock, Belgium, mixer for sediment control

10–7. Drum gates

Drum gates are buoyant gates of hollow steel construction that are installed between spillway piers and attached to the spillway by a hinged connection. In the lowered (open) position, the gates sit in a recess chamber built into the concrete spillway. When fully lowered in the concrete recess, the top surface of a drum gate forms the crest of the spillway ogee. Drum gates do not require machinery to operate like other dam gates. The gate drum is constructed as a circular sector in cross section, formed by a skin plate reinforced with internal bracing.

a. In the open/lowered position, a drum gate forms an overflow-type spillway (Figure 10–20). To raise a drum gate, a system of pipes and valves are used to fill the concrete recess, usually with water from the upstream reservoir. The buoyant gate floats on top of the water as the recess is filled.

b. In a raised position, floating on top of its recess filled with water, a drum gate forms a barrier to regulate or stop water passage. Like hinged crest gates, drum gates spill only from over-topping flow. In the raised position, side seals are used to seal against the adjacent spillway piers and prevent water passage around the sides of the gate.

c. To lower a gate, a system of pipes and valves, separate from the pipe and valve system used to fill the recess, is used to drain water from the concrete recess. This typically is done by a gravity flow system on the downstream side of the gate. Drum gates are not common at USACE sites but have been used successfully on privately owned dams and Bureau of Reclamation dams over the past 100 years. A listing of some of the Bureau of Reclamation drum gates is shown in Table 10–2.

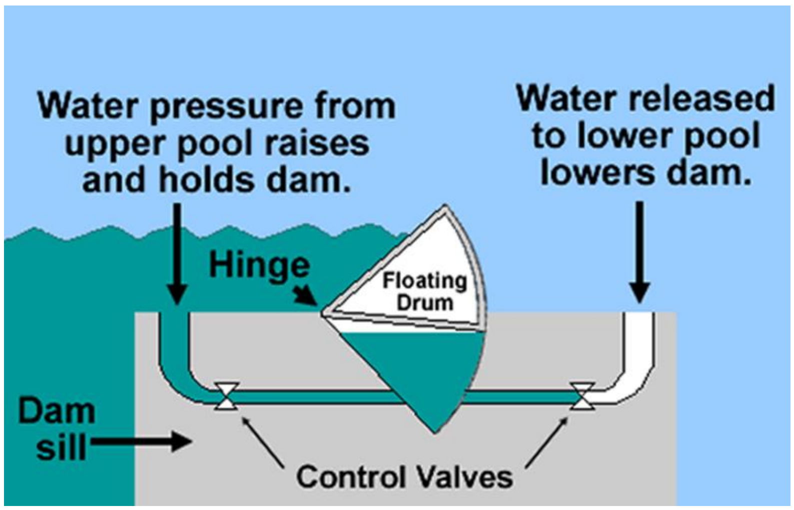


Figure 10–20. Drum gate

d. Buoyancy forces are also the only forces that are used to set the gate in the desired position. Whether the drum gate is hinged on the upstream side or downstream side is one of the primary differences between drum gates currently in service. While these gates can operate reliably, they do have vulnerabilities that need to be understood and monitored for successful operation. Proper function of the concrete recess, filling and draining system, and gate features critical to the buoyancy of the gate are necessary for reliable operation.

e. The main failure mode of a drum gate, unintentional lowering, is usually caused by one of these systems. An operational failure of a drum gate could result in the uncontrolled release of water and loss of the upstream reservoir water elevation. Maintaining water level in the float recess is critical to the operation of a drum gate. Leakage of the drain system could result in unintended lowering of a gate. Often, the supply system is sized to provide water at a faster rate than the drain system. This allows for a method of holding a gate in the raised position in the event of a failure of the concrete float recess draining system.

f. Maintaining buoyancy of a gate is critical to successful gate operation. Drum gates are typically of welded steel construction and rely on welds for structural integrity and to seal the structure from water penetration. The structure must be inspected regularly to ensure adequate performance of the water seal welds. Access to the inside of the gate needs to be considered for inspection and maintenance. Typically, a gravity drain system is used inside the gate to help maintain gate buoyancy if there is water leaking into the hollow gate. The drain systems use a flexible hose to drain water that collects inside the gate to the downstream side of the dam or a drain line in the concrete section of the spillway.

g. A major advantage of drum gates is the elimination of an expensive electric motor or hydraulic operating system. Using the buoyant system to operate the gates also minimizes the size and strength requirements for the piers relative to other common spillway gates. Another advantage is the minimal power requirement to operate the gates. The main energy used to operate the gates is hydrostatic pressure provided by the forebay.

h. A major disadvantage is the need to seal the hollow interior of a drum gate, which can make fabrication more complicated than other common spillway gate types. Also, the design and construction of the concrete spillway is more complicated. The interior of a drum gate is typically classified as a confined space that requires training for maintenance and inspection activities.

i. Despite their limitations, drum dates were constructed in large sizes as indicated in Table 10–2. An example is the Grand Coulee Dam on the Columbia River, included also in Table 10–2. The 11 drum gates in the central spillway of this dam are each 41.15 m (135 ft) long and 8.53 m (28 ft) high (Figure 10–21). Including the removable flashboards, the height of these drum gates is 9.14 m (30 ft).

Table 10–2
Service life of the United States Bureau of Reclamation drum gates taken from lock gates and other closures in hydraulic structures based on year 2022

Dam name	Completion Year	Years of Service	Number of Gates
Arrowrock, ID	1915	106	6
Black Canyon, ID	1924	97	3
Tieton, WA	1925	96	6
Guernsey, WY	1927	94	2
Easton, WA	1929	92	1
Hoover, NV/AZ	1936	85	8
Grand Coulee, WA	1942	79	11
Friant, CA*	1944	54	3
Shasta, CA	1945	76	3

*Two drum gates of Friant Dam were replaced with air bladder (Obermeyer) gates in 1998.

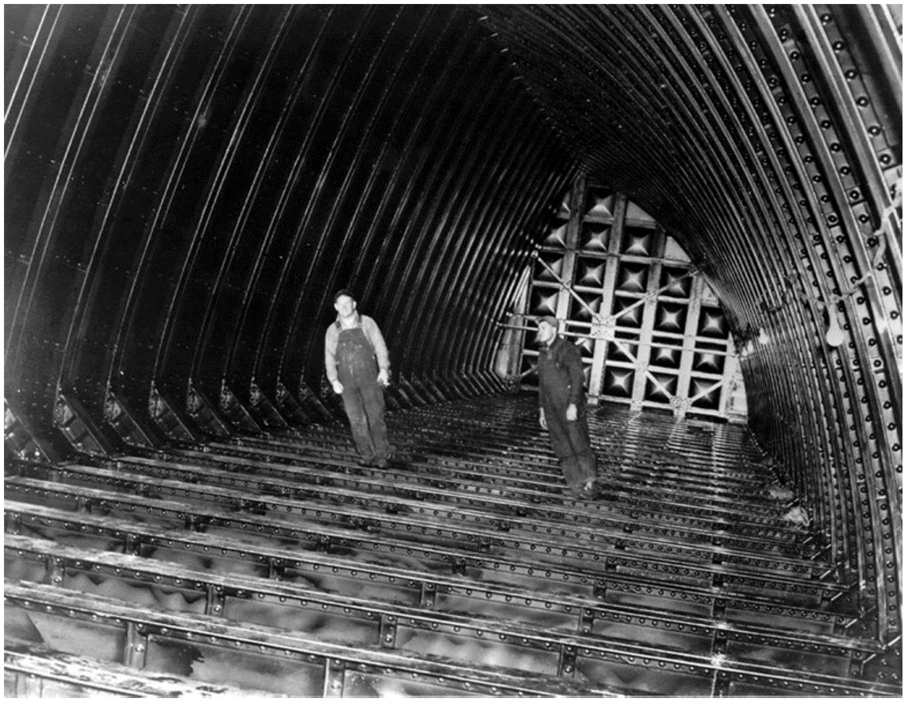


Figure 10–21. Grand Coulee drum gate (courtesy of Bureau of Reclamation)

j. A cross section of the Grand Coulee Dam spillway gates is presented in Figure 10–22a, while Figure 10–22b shows the construction works on one of the drum gates. As shown, the drums are entirely riveted.

k. The main advantage of a drum gate facing upstream is that the downstream hinge location makes it possible to abandon the drum recess and reduce the sizes of spillway structure. The upstream reservoir itself keeps then the gate afloat.

(1) This allows for an automatic adjustment of water level in a certain range, but gives few means, if any, to control this adjustment. Yet, if that control is not required or provided in another way, drum gates facing upstream can be used.

(2) Otherwise, upstream-facing drum gates with crest recesses can be considered, although this loses the advantage of a small-size spillway. It also gives more leakage into the recess since its free edge is harder to seal the than the hinged edge. Gates facing upstream must also be structurally secured against flipping over in case that the upstream water level exceeds the controllable range.

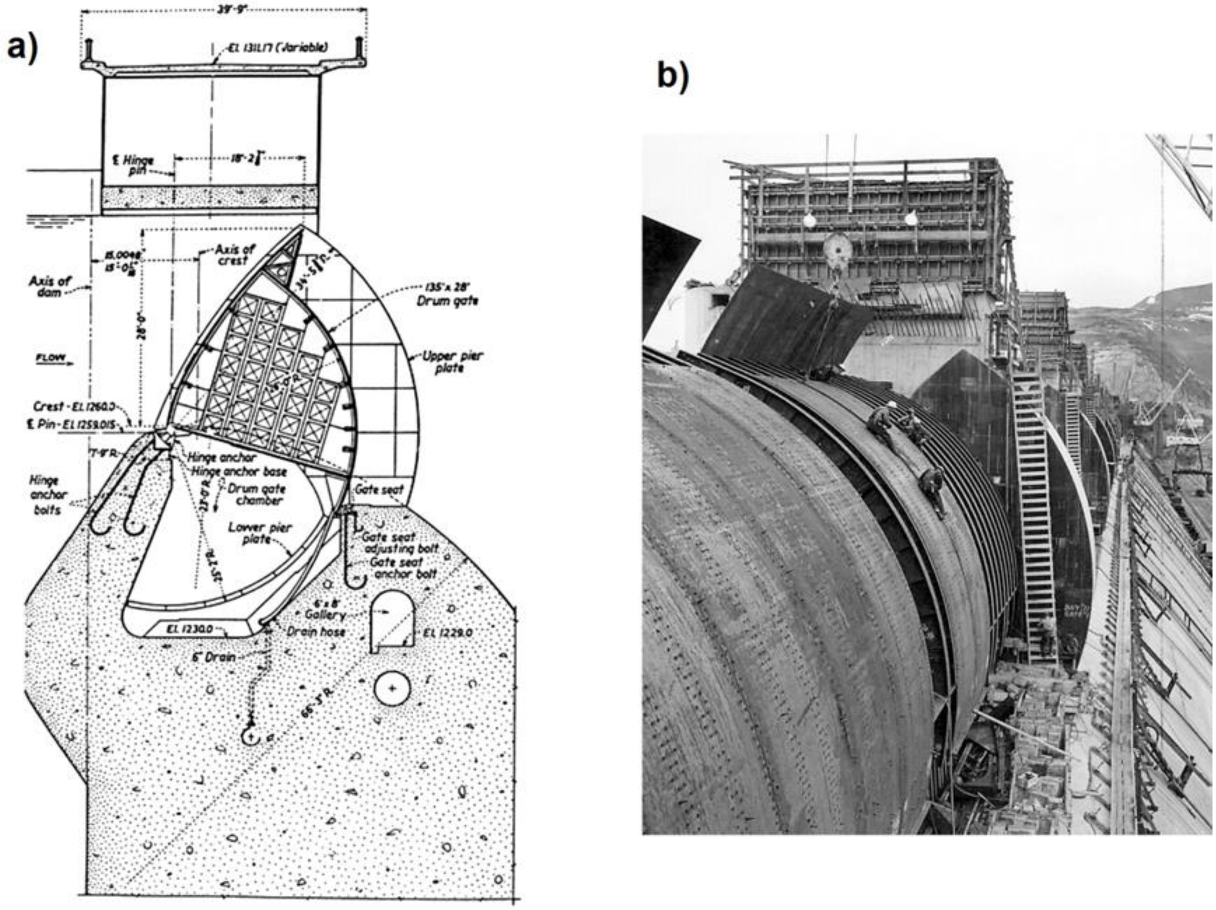


Figure 10–22. Drum gates of the Grand Coulee Dam in construction: a) cross section of the spillway (Bureau of Reclamation); b) gates under construction in December 1940 (photo from the University of Idaho Library and Bureau of Reclamation)

10–8. Bear trap gates

Bear trap gates operate with a similar concept to drum gates but use two gate leaves to form the barrier against water passage. The downstream gate leaf is a buoyant leaf and works with the float chamber to close (raise) the gate system. Like drum gates, bear trap gates use a float chamber formed by a recess in the spillway concrete to operate the gate leaves. The leaves form a broad inverted V in the raised and intermediate positions. Applying upper pool pressure to a chamber under the leaves raises the gate. The downstream gate leaf is usually a hollow buoyant leaf or contains a buoyancy tank on its free-edge side. It works together with the float chamber to raise the gate system. The two leaves support each other and have a sliding seal at their juncture.

a. The float chamber is filled and drained with a system of pipes and valves like that of a drum gate (Figure 10–23). However, sometimes the operation of bear trap gates is assisted by air or hydraulic cylinders. To lower bear trap gates, the float chamber is drained.

b. When in the fully open (lowered) position, both gate leaves lay flat on the spillway with the downstream leaf tucked under the upstream leaf. The operation of a bear trap gate system is more complicated than most other gates. Bear trap gates are not common at USACE facilities, so discussion is limited to a brief description and a discussion of major advantages and disadvantages. Specific design guidance for bear trap gates is provided in the Fort Belvoir Engineer School Design Manual, Canalization of the Upper Mississippi River and Ohio River (USACE, The Engineer School 1939).

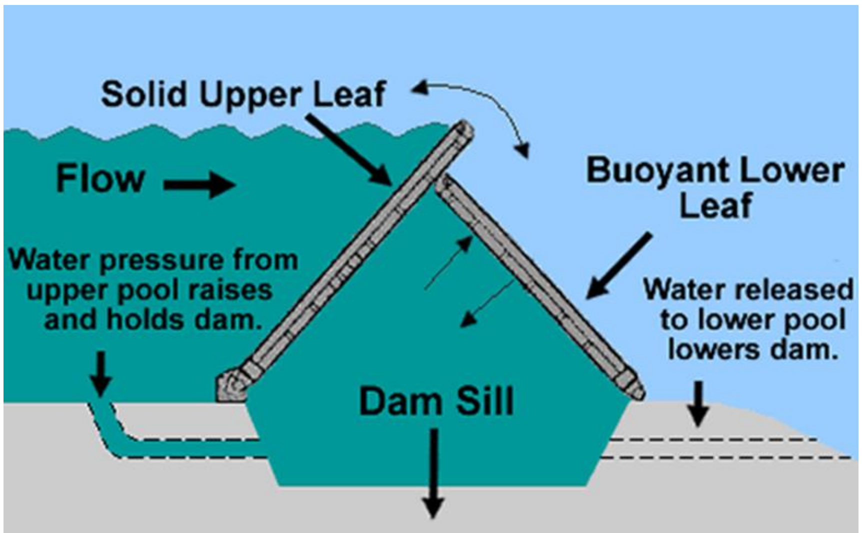


Figure 10–23. Bear trap gate

c. The advantage of bear trap gates over drum gates is simpler design and fabrication of the gate leaves. Like a drum gate, a major advantage of bear trap gates is the elimination or minimization of expensive electric motor or hydraulic operating systems. While the operating system for bear trap gates is more complicated than a drum gate, they are still relatively simple, inexpensive, and have low power requirements than most other spillway gates. Using the buoyant system to operate the gates also minimizes the size and strength requirements for the piers relative to other common spillway gates.

d. Bear trap gates share the same disadvantages as drum gates. In addition, the dual-gate leaves of bear trap gates create the need for a more intricate and complicated sealing system for the float chamber.

e. A general structural system of a bear trap gate, including the loads that act on the structure, is shown in Figure 10–24 from the text book “Lock Gates and Other Closures in Hydraulic Projects” (Paulus and Daniel 2018). The drawing below refers to gate operation with overtop and with the lower pool level below the dam crest. Other situations (no overtop, higher lower pool level, gate “folded” in horizontal position) result in slightly different schemes. Following are the basic relations that define the equilibrium of the situation as drawn in this figure.

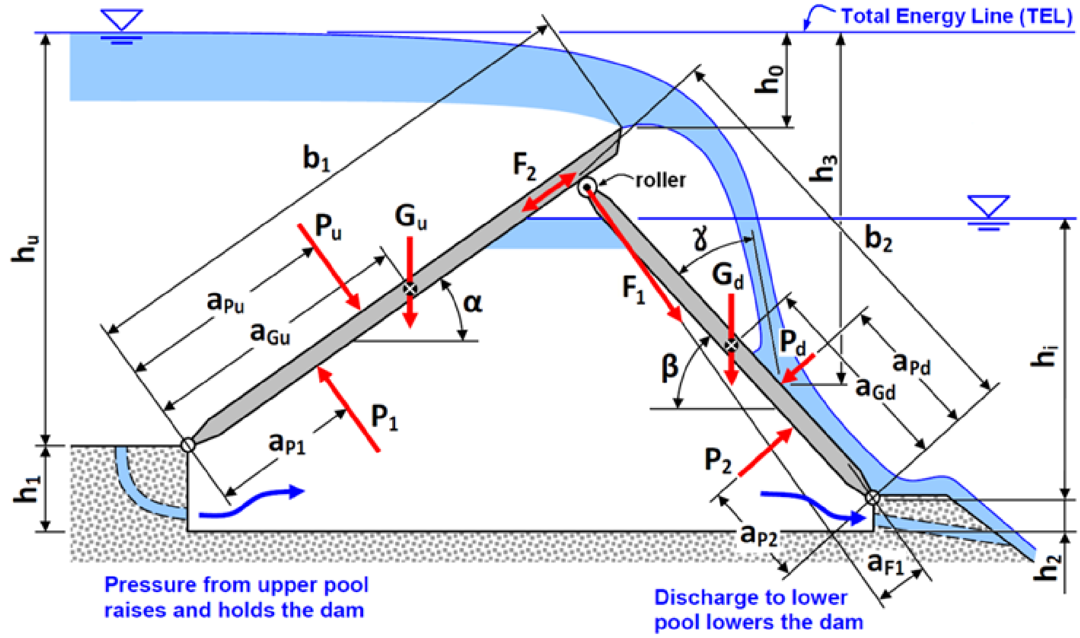


Figure 10–24. Bear trap gate system, general scheme for equilibrium conditions (Paulus and Daniel 2018)

f. Symbols in Figure 10–24 represent the following:

h_u	water level in upper pool
h_i	water level in float chamber
b_1, b_2	widths of gate upper and lower leaves
h_1, h_2	heights of gate upper and lower leaf hinges above recess bottom
G_u, G_d	weights of gate upper and lower leaves, decreased by their buoyancy if significant
ρ_i	specific gravity of water
P_u, P_d	outer water pressure on respectively upper and lower gate leaf
P_1, P_2	inner water pressure on respectively upper and lower gate leaf
F_1, F_2	longitudinal and lateral load from upper leaf on lower leaf (reactions to these loads are $\boldsymbol{R_1}$, $\boldsymbol{R_2}$ and have reverse directions)
a_{P1}, a_{P2},	moment arms of indicated resultant loads
μ	coefficient of roller friction

g. The Ohio River bear trap gates were typically 100 ft long and 13 ft high and were used in conjunction with navigation wicket gates to build up head pressure. As the wicket gates are raised, this builds up head pressure, allowing the bear trap gates to open. Compressed air can also be used to aid in the initial raising operation.

(1) The details of this design practice can be found in Fort Belvoir Engineer School Design Manual, Canalization of the Upper Mississippi River and Ohio River (USACE, The Engineer School 1939). This manual also discusses the differences between Parker and Lang bear trap gates and provides some general design guidelines.

(2) It recommends, for example, constructing float chambers with the intake and discharge areas of 0.25 ft^2 per 100 ft^3 of volume under the leaves when fully raised. The intake inlets should preferably be raised above bottom and covered with gratings to keep out drift.

h. Bear trap gates were used extensively on the Ohio River until the late 1920s and early 1930s (Figure 10–25). Lock and Dam 52 recently had one of the last functioning gates. It is one of the 50 movable dams built by USACE on the Ohio River between 1879 and 1929. Figure 10–26 shows the arrangement of this dam, including the location of bear trap gates. Note that these gates operate in conjunction with wicket gates in the manner already explained.

Figure 10–25. Bear trap gate in the Ohio River

i. Bear trap gates can prove difficult to maintain. Silt or sand deposits in or under the gates may make it impossible to fully lower or raise the gates. Bear trap gates are usually large installations, and their repairs are costly. Floating marine plant is often necessary to access the gate.

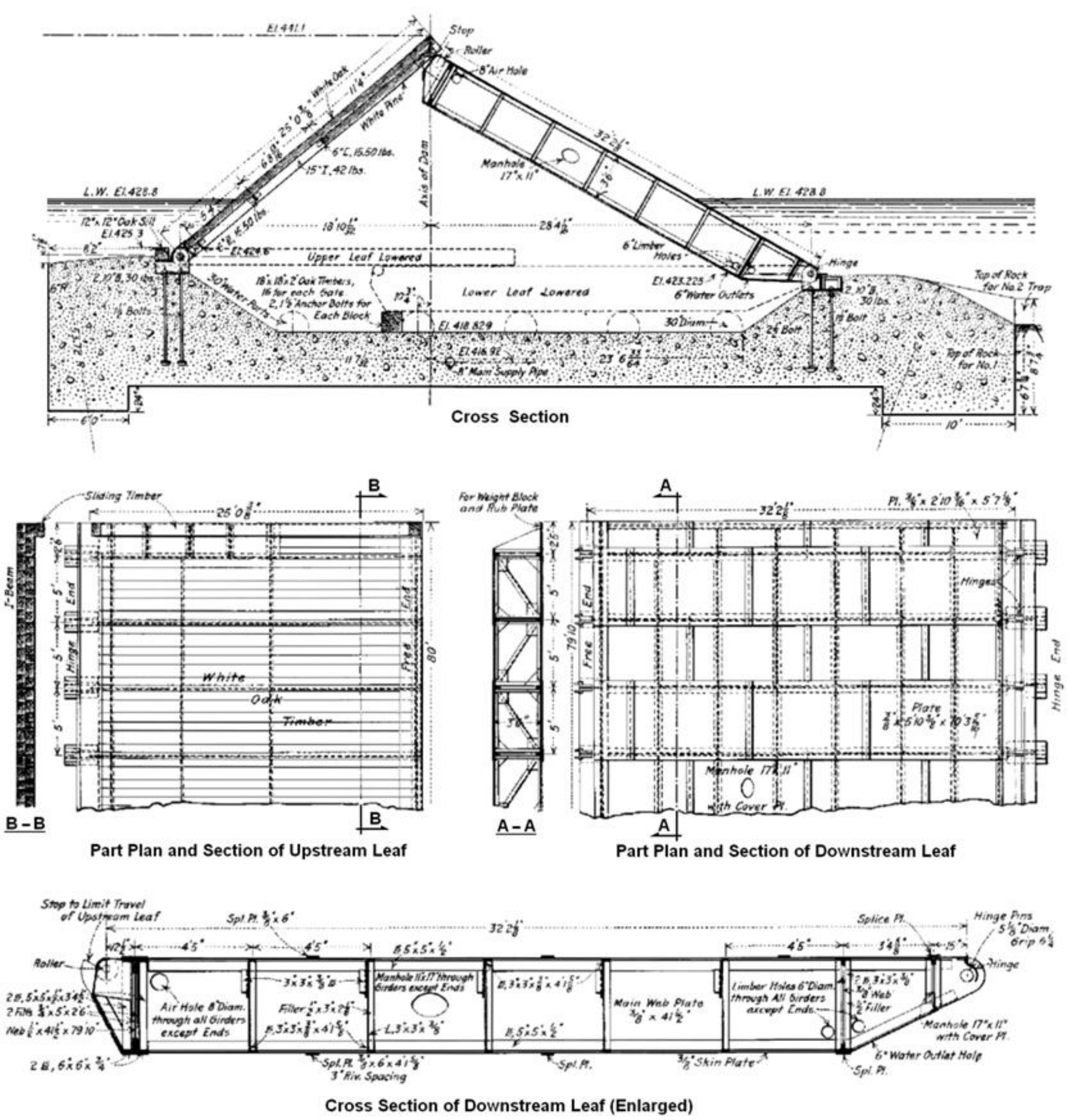


Figure 10–26. Dam layout with bear trap gates in the Ohio River Dam No. 37 near Cincinnati, Ohio

Chapter 11
Dam Gate Operating Machinery

11–1. General description

Dam gates are used to regulate water flow over a spillway. This chapter focuses on the operating machinery used for the most common USACE dam gates. It gives a designer's perspective on the major considerations and best practices relevant to the design of dam gate operating systems. Consult Chapter 2 for information on selecting individual machinery components for these gate systems.

11–2. Tainter gates

Tainter gates are typically considered the most economical and suitable type of gate for controlled spillways (Figure 11–1). Compared to other gate types, tainter gates are lighter in weight and generally have smaller hoist requirements. A major advantage of the tainter gate is its curved skin plate, which is concentric with the gate trunnion. This design feature works to focus the resultant hydrostatic loads acting on the surfaces of the gate skin plate through the trunnion. This results in no moment arm between the resultant hydrostatic load (acting on the skin plate) and fulcrum of the gate.

Figure 11–1. Conventional spillway tainter gate

a. Design considerations. This prevents moments caused by the hydrostatic loads, applied to the gate, which otherwise would have to be resisted by the hoist machinery. Tainter gate design also provides lifting points for the hoist machinery at a greater radius from the trunnion. The larger radius provides mechanical advantage and allows the hoist equipment to apply less force to hoist a gate (Figure 11–2 and Figure 11–3).

Overall, these advantages help to reduce the size of the operating machinery compared to other common gate types.

b. Operating machinery. Tainter gates are typically operated with wire rope or engineered chain hoists. Some gates are also operated with hydraulic cylinders. A dogging device is recommended to allow the gate to be held in the fully open position without using the hoist. Machinery and the supporting platforms are typically mounted on the piers between gates and must be located above maximum water elevation and in a position that clears the gate as it swings.

c. Service factors. Tainter gate hoist systems rarely experience anything but constant and uniform hoisting loads. It is usually valid to assume that shock, impact, and vibration factors will have a negligible effect on the hoist system. Ice loading may need to be considered in northern climates. Service factors applied to the components of the hoist machinery system should be as discussed in Chapter 2. However, service factors should be selected based on the anticipated conditions for each individual application. If shock, impact, or vibration loading is anticipated, engineering judgment should determine appropriate service factors.

d. Lifting point locations. Hoist lifting points for a tainter gate vary with the type of gate (submersible/non-submersible) and hoist machinery system used. See Figure 11–4. To maximize mechanical advantage, lifting points are typically located on a structural member as close to the skin plate as possible. Lifting points are typically on the upstream curved surface of the gates but can also be connected to the downstream face. Connecting to the downstream face is uncommon and reduces the mechanical advantage of the hoist system. It can also reduce the operating range of the gate as the ropes, chain, or cylinder interfere with the swing path of the gate.

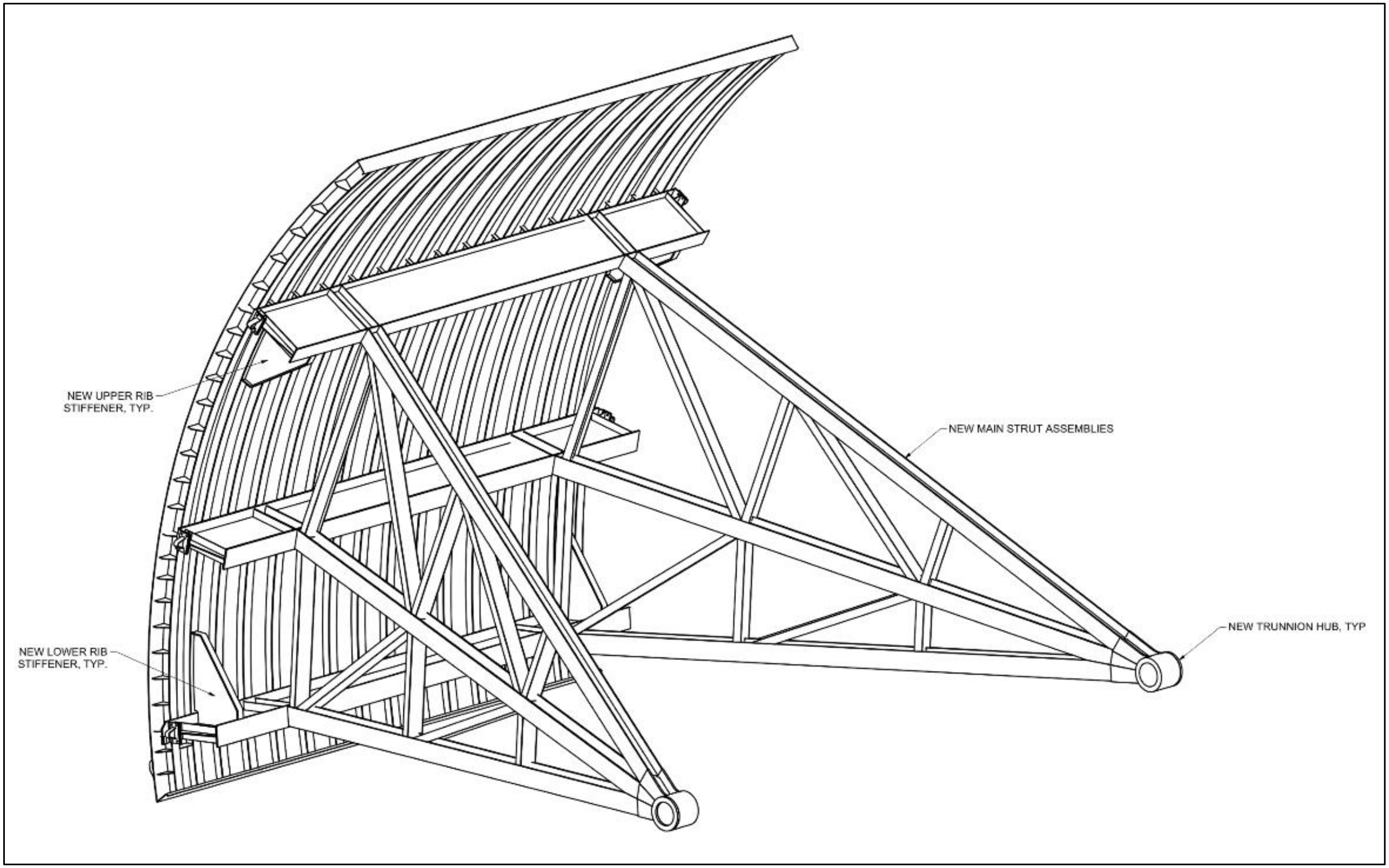


Figure 11–2. Spillway tainter gate isometric

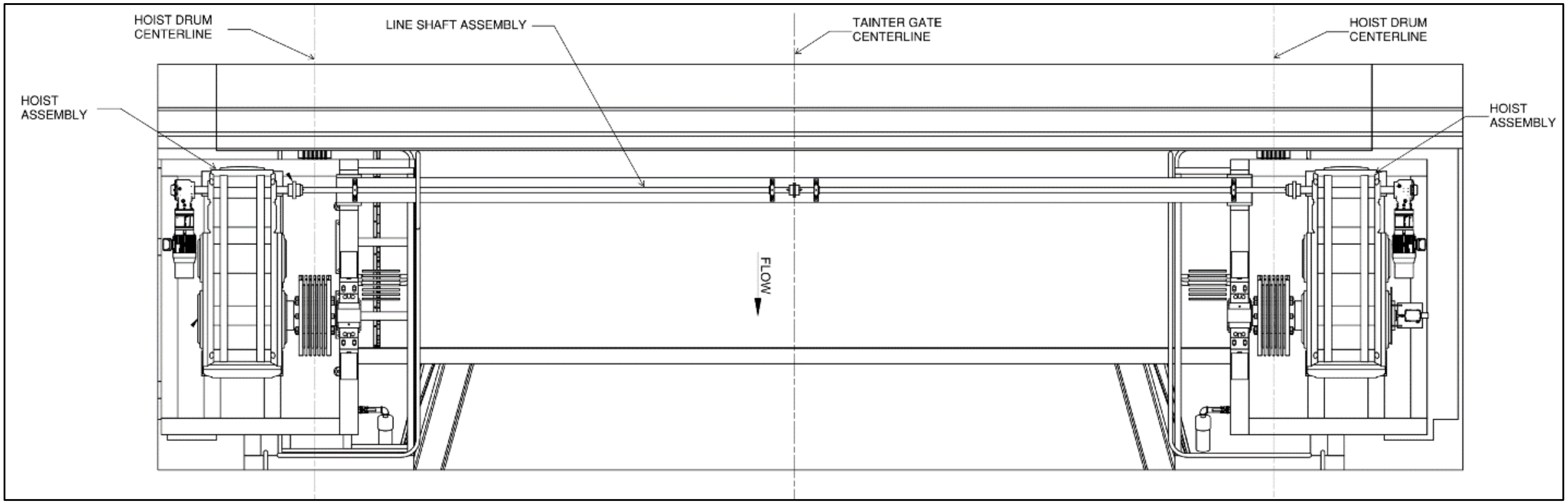


Figure 11–3. Overall spillway tainter gate hoist machinery

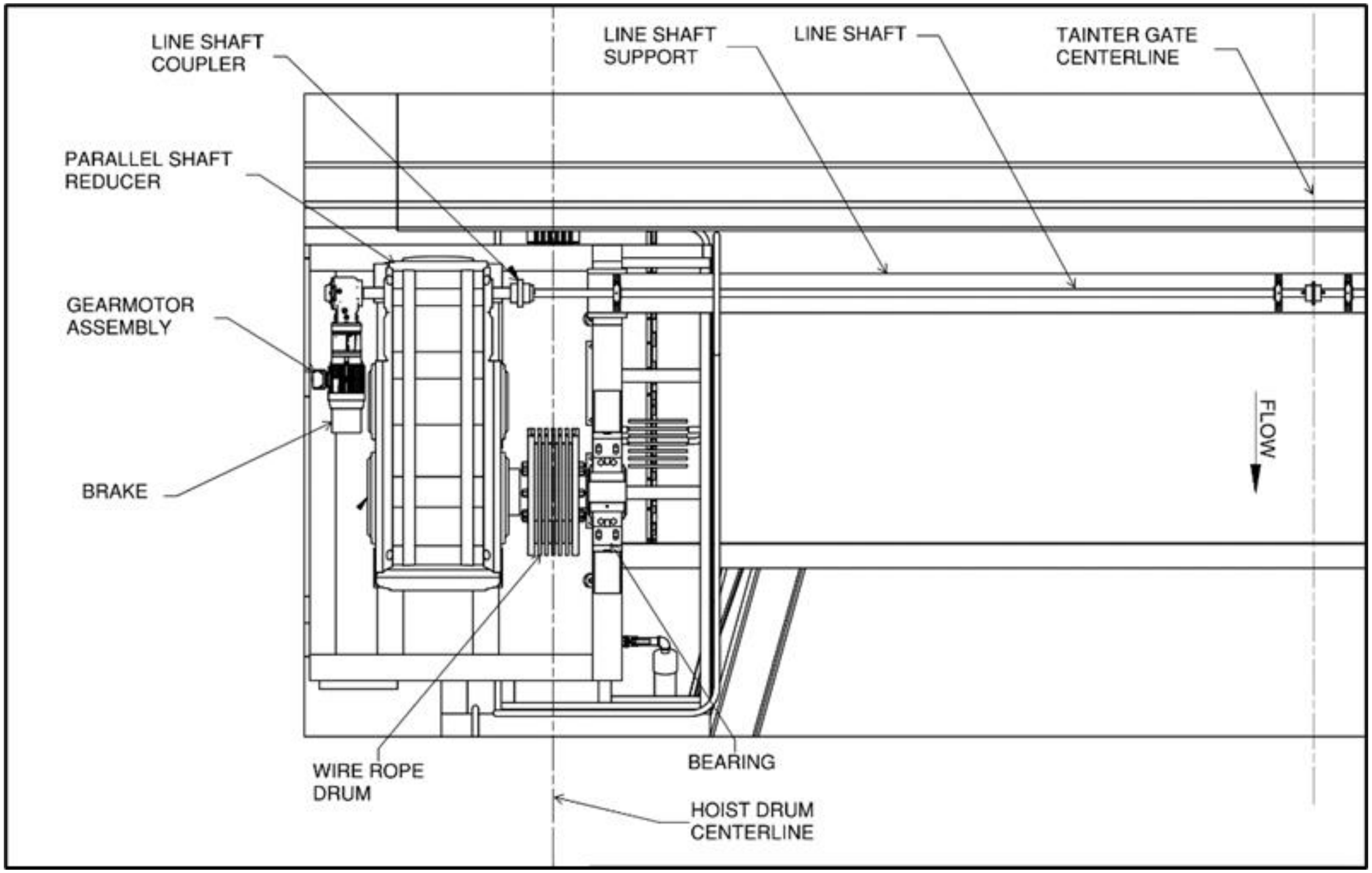


Figure 11–4. General hoist machinery layout

e. Lifting points. To maximize the gate travel, the lifting points are typically located on a structural member near the bottom of the gate. There are typically two lifting points, one on each side of the gate. Locating them requires balancing the load sharing between lifting points. The balance of lifting loads directly affects the amount of structural distortion and deflection a tainter gate will experience as it is being hoisted. Hoist system designers will need to coordinate lifting point locations with the structural engineer. The hoist drums must also be located and aligned directly over the lifting points to prevent racking of the gate during operation (Figure 11–3).

f. Hoisting speed. A hoisting speed of 1 ft/min has been found satisfactory for most installations. Generally, this speed is used as a guideline to determine the power requirements of the hoist motor and reduction requirements for the overall hoist gear ratio. The mechanical designer should coordinate the operating speed parameters or requirements with the hydraulic engineer and the operating staff. Hoist speeds, however, should not exceed 2 ft/min.

11–3. Tainter gate mechanical hoist components

Reference Chapter 2 for information and requirements for specific mechanical components. Component features specific to tainter gate hoists are discussed below.

a. Motors. Motors used to hoist tainter gates are typically squirrel-cage induction, high-torque, high-slip, NEMA Design D motors. Electrical design may dictate other NEMA designs, such as NEMA B for VFDs. All motors must be rated for continuous duty and sized to drive the gate without overload during any portion of the operating cycle. To account for increased friction and other unknowns as the gate and machinery ages, design motors such that the normal operating loads produce a motor torque near 75% of full load torque. Protect motor windings with winding heaters or encapsulation.

b. Redundancy. In circumstances where a tainter gate functions as a critical damming surface, hoist function must include a redundant motor operator. Generally, two systems can be provided. One system consists of a lever-operated line shaft clutch, where the clutch can engage the adjacent spillway hoist motor. Alternately, two motors can be provided for a single hoist system where the redundant motor is back driven during hoist operation. When back driving a motor, the designer should carefully account for the inertial impact to the system when selecting the desired load-limiting device. Back driving a motor through a high-reduction gearbox can create a surging effect as the back-driven motor accelerates, which may trip a load-limiting device. This also creates impact loads on the machinery.

c. Speed reducers. Many types of speed reduction can be used successfully on tainter gates. See Figure 11–5. Worm reducers have historically been used as the primary speed reducer.

(1) Worm reducers of ratios above 30:1 are typically not back drivable. That also provides a secondary means, in addition to the brake, to hold the gate in a lifted

position. Coordinate back-driving parameters of worm reducers with the manufacturer. The efficiencies of worm gear boxes must also be coordinated with the manufacturer.

(2) Parallel shaft reducers and open gearing are frequently coupled with a worm reducer to provide the remainder of the required reduction as these reducers have much higher efficiencies than worm reducers. It is recommended to factory test worm reducers for efficiency since this can have a significant effect on motor hp requirements. Cycloidal and helical bevel reducers may also be appropriate for tainter gate hoist machinery systems as they provide higher efficiencies with similar ratios to worm gear reducer. However, these reducers can still add significant resistance and have caused operational issues when back driven as part of a redundant system.

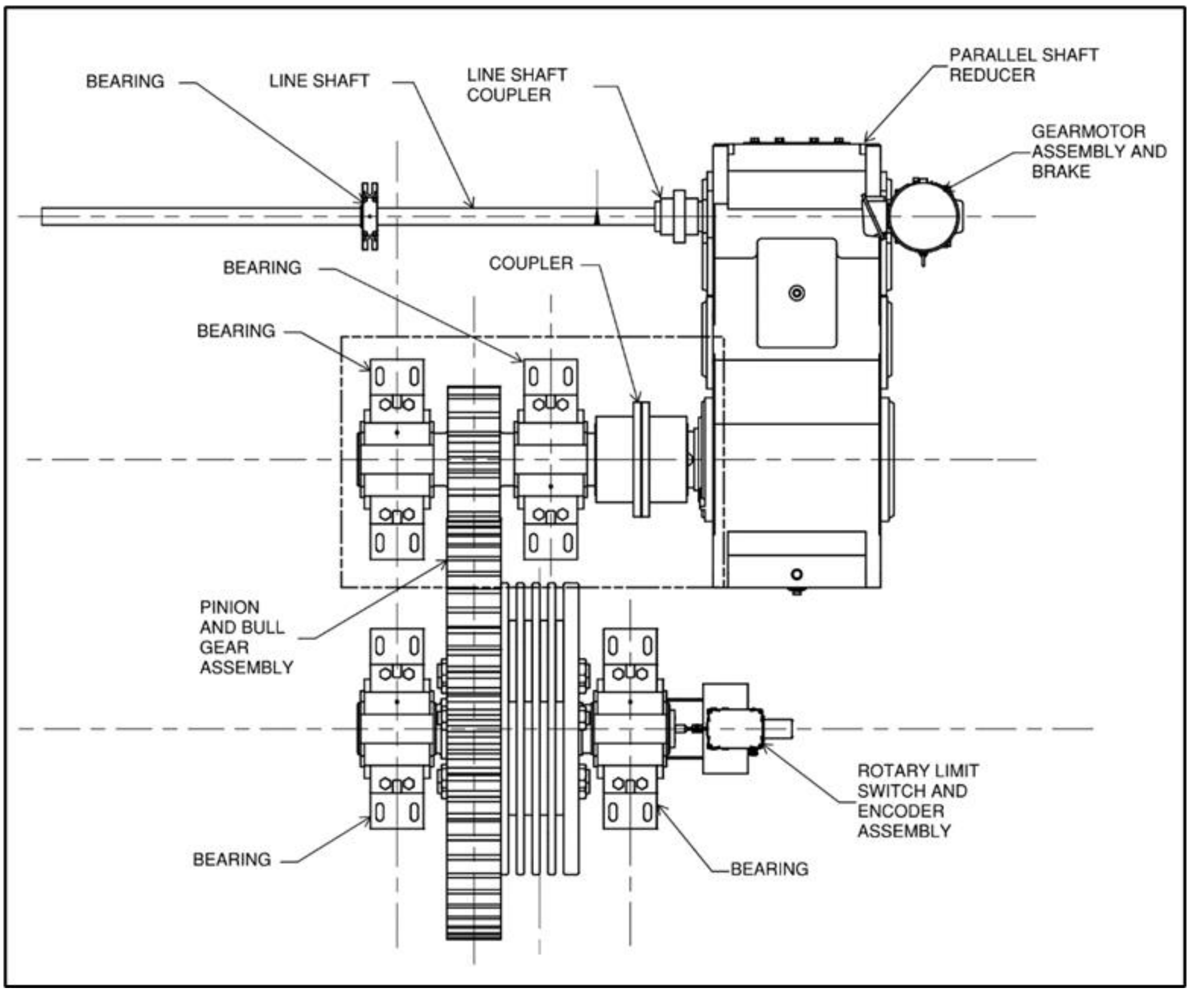


Figure 11–5. General hoist machinery layout with bull and pinion gear assembly

d. Brakes. Typically, tainter gate brakes are drum brakes specified with the features discussed in Chapter 2. Alternate industrial brake types may be considered, such as spring-set or caliper-type disc brakes, but the unit features should be comparable to the drum-type brake as described in Chapter 2. For critical hoist applications, a redundant brake must be provided and it must feature fail-safe operation.

e. Couplings. Tainter gate hoist systems commonly use a combination of rigid and flexible couplings to transmit torque between shaft sections of the drive train. Couplings used in the drive train of tainter gate hoist equipment are highly recommended to be a type that is considered to have high torque-carrying capabilities. The most common types of flexible couplings used for tainter gate hoists are gear couplings and grid couplings.

f. Lifting point connections. Tainter gate lifting points must be designed to accommodate the rotational motion of the gate travel. This connection design should be coordinated with the structural engineer. Designs typically allow for rotation of individual ropes via a bridge socket and U-bolt that sits on a pin (Figure 11–6).

(1) A machined U-bolt spacer helps limit high-contact stresses between the pin and U-bolts and locks in U-bolt alignment. Recent designs have incorporated fabric-reinforced, self-lubricating bushings for the U-bolt spacer to facilitate rotation. This spacer also provides insulation against galvanic corrosion when stainless wire ropes are used. See Figure 11–6 below for a typical arrangement.

(2) It is important that the designer consider wire rope tension measurements and adjustments when designing the connection. Individual wire rope tension will require adjustment at regular intervals over the service life of the tainter gate. Sufficient clearance must be provided on the sides, between wire ropes, and behind such that mechanics can attach a socket to turn the bridge socket bolts to adjust tension.

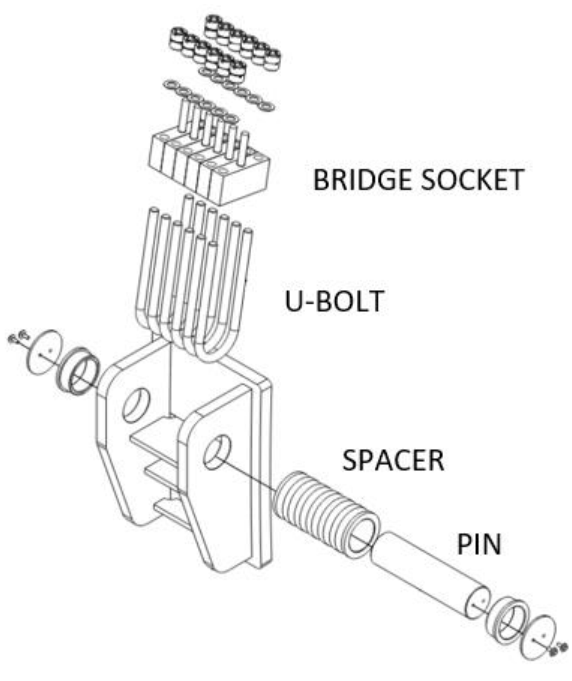


Figure 11–6. Typical lifting connection detail

g. Position indication. Different devices have been used successfully for position indication on spillway gates. The position indication devices listed below may also be considered for other gate types. The designer should evaluate the gate's operational needs when determining the type, location, style, redundancy, etc., of position indication devices. Often, a combination of devices will be used to meet the position indication requirements for a gate hoisting system. Sometimes, multiple devices are needed to provide indication for both local and remote operation.

(1) *Local indication*. Local position indication devices can be used only for local gate operation because they do not provide a feedback signal.

(2) *Dial indicators*. Dial indicators are one of the most popular means of local position indication (Figure 11–7). Dial indicators are driven off a shaft in the hoist machinery drive train. They use a gear reduction so that full gate travel results in no more than one revolution of the dial. The dial face is marked with desired openings for reference.

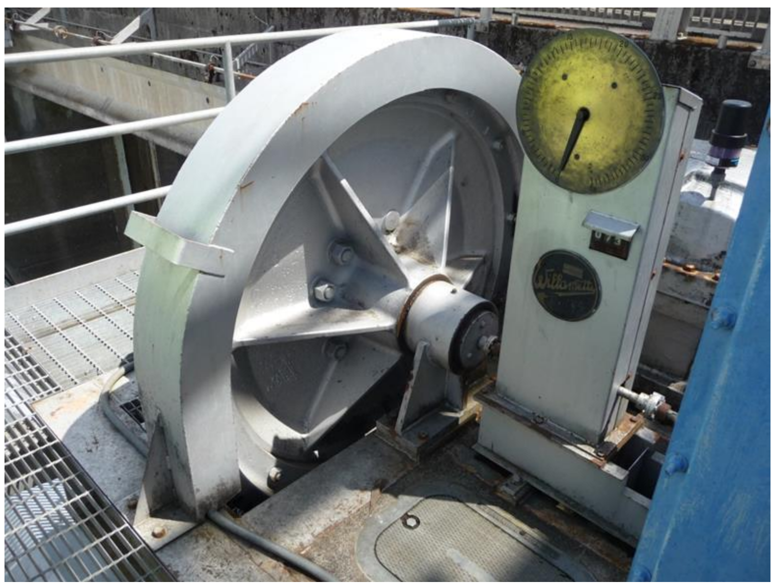


Figure 11–7. Dial indicator

(3) *Staff gauge*. A gate staff gauge (Figure 11–8) is a simple method of providing local position indication. A gauge is mounted to the gate's upstream skin plate or other convenient location. As the gate is operated, the gauge moves past a reference marker mounted to the pier face. The gauge has markings for the relevant gate openings. Since a tainter gate has a curved surface, the designer will need to determine the relationship to the actual linear opening of the gate. Designers should consider the visibility of the gauge from the gate operator's location and the effects of ice or debris to which the gauge will be exposed.

Figure 11–8. Staff gauge

(4) *Remote indication*. The need for remote gate operation has increased the use of electromechanical position indication devices. Selection of such devices requires coordination between the mechanical and electrical engineers. Designers must comply with the current applicable requirements for remote control gate operation within USACE. See Chapter 18 of this manual for additional information.

(5) *Rotary encoders*.

(a) Rotary encoders are one of the most common electromechanical position indication devices used. They are driven off a shaft or operating cylinder in the hoist machinery and are used to count rotations of the encoder device. The count of shaft rotations is calibrated to the gate position. Encoders can be driven off any shaft for electric motor hoists. However, more accuracy usually can be obtained from the higher resolution (more counts) of a high-speed shaft.

(b) If a rotary cam limit switch is used, a rotary encoder is most often coupled to a factory supplied output shaft. The output shaft can be supplied with a gearset to maximize resolution; this assembly should be coordinated with the electrical engineer. Rotary encoders are typically regarded as one of the most accurate electromechanical position indication devices.

(6) *Inclinometers*. Inclinometers are mounted directly to a gate and used to measure a gate's opening angle relative to the direction of gravity and the gate's linear opening. They are not used as commonly as encoders because they typically must be installed at locations on the gate where accessibility for maintenance can be an issue.

h. Limit switches. Tainter gate limit switch assemblies are typically the rotary cam or traveling nut style. Many of the older tainter gate limit switches (for example, on the

Mississippi River) are the traveling nut type. Limit switches are driven from the hoist machinery or hydraulic operating cylinders. Redundant limit switches must be provided for the fully open and fully closed gate positions (two upper and two lower switches within the limit switch assembly). Often, the operational uses of a gate require additional switches for intermediate positions.

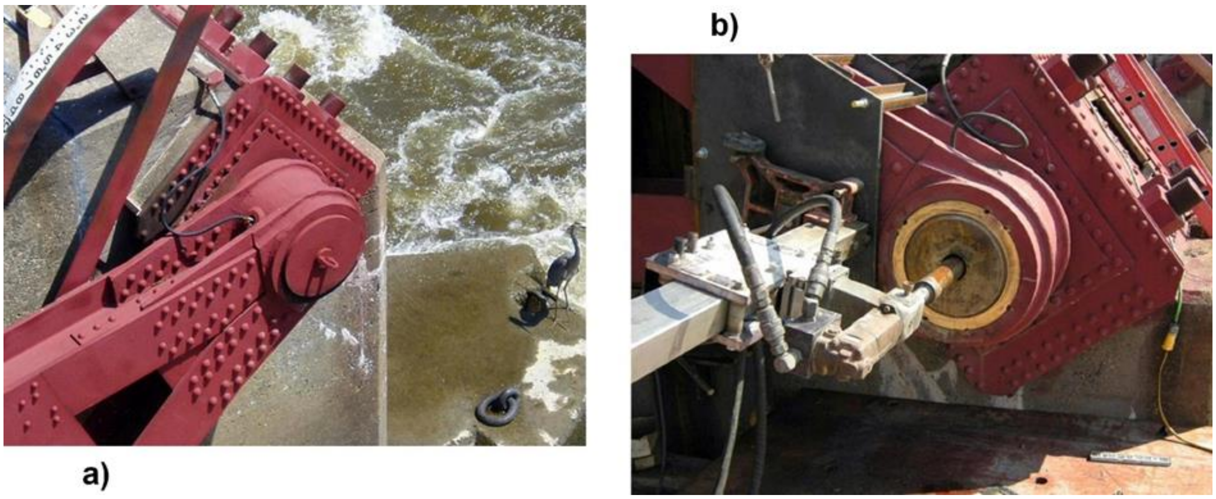
i. *Trunnion bearings*. Trunnion bearings are the main support bearings of a tainter gate (Figure 11–9). They support the major loads, including hydrostatic and gravity, to which a gate is exposed. The design of the trunnion is often shared by the mechanical and structural engineers, with the mechanical engineer focusing more on the bearing design.

j. The most common types of bearings are discussed below. Bearing recommendations for new trunnion bearings are ASTM B148 Alloy C95400, ASTM B 584 Alloy C93200, and ASTM B271 (either Alloy C95400 or C93200). Depending on the diameter required, the designer may also need to research the availability for the specific alloy. The choice of bearing type depends on many factors including the width of the gate and the magnitude of the loading. Other factors include the trunnion arm design if they are straight or angled with thrust load. The lubrication choices whether self-lubricated or greased is a consideration. Whether the gate is new or rehabilitated is yet another consideration.

Figure 11–9. Tainter gate trunnion bearing

(1) *Straight sleeve*. Straight sleeve bearings are the most common bearing style used for tainter gate trunnions (see Figure 11–10). They are typically interference fit into the trunnion hub and if necessary, use a thrust washer to support thrust loading. Of the

different common bearing types, straight sleeve bearings are the most economical and simplest to design and construct. They also provide the most bearing area for the required size envelope. While they have a smaller allowance for misalignment, it is typically enough to accommodate the amount inherent from reasonable structural tolerances.



a) b)

Figure 11–10. Straight sleeve-style trunnion bearing Lock and Dam 11, Mississippi River

(2) *Spherical*. Spherical bearings can accommodate the largest amount of misalignment. See Figure 11–11. Use of spherical bearings typically trades bearing area for misalignment capabilities. They are most common on wide tainter gates where the standard structural tolerances can create large misalignment at the trunnions. Spherical bearings typically add significant complexity and cost to the design of a trunnion bearing system.

Figure 11–11. Spherical bearing for Whittier Dam gate

(3) *Lubrication*. Trunnion bearings have relatively low surface speeds and rely on boundary layer lubrication. Grease lubrication systems typically are used and consist of grease lines that connect to grease grooves in the bearings. An automatic (Farval™ style) grease pump or manual grease pumps are used to supply the pressurized grease.

(4) *Exercising gate.* Exercising and lubricating a gate without hydrostatic load on a regular basis is highly recommended because it helps ensure the lubricant is spread between the bearing contact surfaces. For regular operation, it is highly recommended that lubrication is started before the start of gate travel and is continued for the extent of gate travel. Trunnion bearing lubricant properties must comply with the recommendations of EM 1110-2-1424 and INDC TR 2018-01.

k. Self-lubricated trunnion bearings. Self-lubricated bearing materials have been used successfully as the main trunnion bearings for tainter gates. In general, self-lubricated bearing materials are good substitutions for greased bronze bearings that move slow enough to establish only boundary layer lubrication. The primary advantage of a self-lubricated trunnion bearing system is the reduction of labor to grease the bearings and maintain a grease lubrication system. Self-lubricated bearings also provide a more reliable lubrication system because the primary lubrication is provided by the bearing material and not by the supplied grease.

(1) Despite the more reliable primary lubrication system of self-lubricated materials, a minimum coefficient of friction of 0.3 should still be used for design purposes (see discussion of trunnion bearing coefficients of friction later in this chapter). This coefficient of friction is based partially on a degraded effectiveness of the lubrication

system due to the intrusion of water, dirt, debris, etc., between the bearing surfaces. This remains a valid assumption for self-lubricated materials.

(2) Designers should consider self-lubricated trunnion bearing design features that help seal the bearing from the intrusion of water, dirt, debris, etc. Even though most self-lubricated bearing materials are durable enough to function in dirty environments, the coefficient of friction can be impacted negatively and is likely to reduce bearing life. Sealing of a self-lubricated bearing can be performed with a physical bearing seal. Another common sealing method is to use supplied grease.

(3) Since the supplied grease is intended as a seal and not the as the primary lubricant for the bearing, the lubrication frequency can be minimized. Also, the consequences of failure of a supplied grease lubrication system (such as a clogged grease line) intended for sealing are much less severe than that used as the primary lubricant. Selection and design of self-lubricated materials must follow the guidance established in EM 1110-2-1424, INDC TR 2018-01, and earlier in Chapter 3.

11–4. Wire rope electric hoists

Wire rope electric hoists are one of the most common tainter gate hoist types. They have been used extensively at USACE dam sites and have a long, successful operating history. See Figure 11–12.

a. Overview. Wire rope electric motor hoists usually consist of two similar, but opposite, hand hoist units mounted on piers, connected, and synchronized by a line shaft or torque tube, and arranged to lift each end of the gate. The machinery drive train typically consists of an electric motor that drives one or more gearboxes. Typically, a pinion gear is mounted on the output shaft of the final gearbox, which is used to drive a bull gear attached to a wire rope drum. Brakes for these systems are spring-set drum brakes and typically are located on the input or output shaft of the first reducer. Plates 60 to 64 show common machinery layouts for wire rope electric hoist systems.

b. Wire rope drums. Wire rope drums for tainter gate hoists are typically designed to spiral-wrap each rope directly on itself. This is necessary because multiple wire ropes are typically needed for hoisting a gate. The direction the rope wraps on the drum, with respect to the gate, usually does not matter from a structural loading perspective.

(1) However, designers should consider that the direction the rope is wrapped on a drum affects the direction of the open gear mesh contact forces and resulting loading of the gearboxes and external bearings.

(2) The most common method of driving a hoist drum is to mount a pinion gear on the output shaft of the final reducer, which drives a bull gear integral to the hoist drum. The direction of rope wrap on a hoist drum determines if the contact force on the pinion loads the final reducer housing in compression or tension.

Figure 11–12. Wire rope electric motor hoist

c. Wire rope. The selection of wire rope for gate operation should follow EM 110-2-3200. Settlement of the wire ropes and gate system components can cause individual wire rope tensions to change over time, resulting in uneven load sharing between individual ropes.

(1) Tainter gate wire rope hoists should be designed to allow tension adjustments to be made to each of the individual wire ropes. Designers also should consider developing requirements for the allowable deviations of tension values to determine when re-tensioning is necessary. This should include tension values on each side of the gate, which can affect the distortion/deflection of the gate structure.

(2) Figure 11–13 shows one of the most common methods for allowing individual rope tension adjustments. This design uses nuts on the threaded ends of U-bolts to adjust tension for each wire rope. The U-bolts wrap around a pin spanning between the gate connection ears. This allows the U-bolts and hardware to pivot around the pin as the gate is lifted and the angle between the ropes and gate changes. See Plates 60 and 61 for typical sketches of this gate connection style.

Figure 11–13. Wire rope gate connection

d. Chain electric hoists. Chain electric hoists usually consist of two similar, but opposite, hand hoist units mounted on piers and arranged to lift each end of the gate (Figure 11–14). The machinery drive train typically consists of an electric motor that drives one or more gearboxes. Usually, a pinion gear is mounted on the output shaft of the final gearbox, which is used to drive a bull gear attached to the chain drum or sheave or sprocket.

(1) The chain-lifting feature depends on the number and type of chains. The features commonly used are pocket wheels, grooved drums, or sprockets (Figure 11–15). Brakes for these systems are spring-set drum brakes and are typically located on the input or output shaft of the first reducer. Plates 67, 68, and 69 show typical pocket wheel and chain gate connection details.

(2) Designers should reference Chapter 2 for types of chain-lifting features (pocket wheels, grooved drums, and sprockets) and chain designs. Tainter gate chain hoist systems should be designed to allow for tension adjustments to each of the individual hoist chains.

Figure 11–14. Hoist chain gate connection

Figure 11–15. Chain drum

e. Hydraulic cylinder hoists. Hydraulic cylinder hoists usually consist of two hydraulic cylinders, one mounted on each pier and arranged to lift each end of the gate (Figure 11–16). Typically, the cylinders are trunnion-type, mounted in cardanic rings that are supported by hoist frames cantilevered over the side of the pier. Tainter gates can sit idle for long periods of time and leave the cylinder rod exposed to elements. The designer must account for this condition in cylinder rod selection and coating system. See Chapter 5 of this manual.

(1) Piston rods are usually connected through a spherical bearing to a lower framing member on the downstream side of the gate. Plate 65 shows a general arrangement of a direct-connected, hydraulic cylinder-type tainter gate hoist. Plate 66 shows details of the mounting arrangement. Individual hydraulic power units usually are mounted in rooms at the top of each pier, although an arrangement with a single power unit is possible.

(2) As much valving as possible is mounted in manifolds connected directly to the cylinder ports. This includes a pilot-operated check valve on the rod end port used to hold the gate in a raised position. This arrangement minimizes interconnecting piping and the potential for leakage or failure.

Figure 11–16. Olmsted Dam hydraulic-driven tainter gates

f. Cylinder synchronism. Hoist cylinders are kept in synchronism by the hydraulic controls. Usually, position indicators mounted internal to each cylinder provide a signal, relative to cylinder stroke, to the control system. The system generates an error signal that is used to control a small proportional valve. The valve is used to bleed oil from the rod side of the lead cylinder, when raising, and from the rod side of the lag cylinder, when lowering. For small gates or gates that are infrequently operated, such as on flood control spillways, a simpler system using a flow divider might provide sufficient synchronization.

g. Olmsted Dam. The gates are lifted and lowered by hydraulic cylinders mounted to the dam piers and connected directly to the gate side arms (Figure 11–16). Hydraulic pressure for the cylinders is provided by HPUs located at the top of each pier in a machinery house (Figure 11–17). The hydraulic drive cylinders and HPUs were manufactured by Bosch Rexroth.

(1) The gates are operated using 2 hydraulic cylinders per gate, working in tandem with each other. See Table 11–1. Gate travel speed is approximately 8 in. per minute. HPU 2, 3, 4, and 5 are shared by the adjacent tainter gates. HPU 1 and 6 are not shared. Vibration issues have been experienced with the cylinders since installation. At the writing of this manual, the vibration issues are being mitigated and corrected. The vibration problems at Olmsted Dam are likely caused by the hydraulic power system and, in particular, the cylinder rod. One probable source of vibration is related to stick slip between the cylinder rod and the rod seals.

Figure 11–17. Olmsted Dam hydraulic power unit

(2) The control system is currently set up so the pressure differential (delta P) between each cylinder governs. The current setup keeps the two cylinders within 200 psig of each other. Both encoder and pressure differential variables can be set by a systems user with elevated privileges.

Table 11–1
Operating data for Olmsted tainter gate cylinders

	Bore Dia.	Rod Dia.	Stroke	Operating Speed
Olmsted	580 mm	250 mm	14.275 m	8.2 in/min

h. Rack-and-pinion hoists. Some older tainter gate installations are operated with a rack mounted to the skin plate of the gate, driven by a pinion on the final reduction of the electric motor-driven machinery. These rack-and-pinion systems are not used for new installations, but still are being used at some USACE sites.

11–5. Tainter gate mechanical system analysis

The designer must also reference EM 1110-2-2107. The normal load required to lift a tainter gate is a function of the external loads applied to the gate (hydrostatic forces, gravitational forces, friction forces, etc.). To hoist a gate, the motor or hydraulic cylinders must overcome the various forces acting on the gate. Calculating required motor or cylinder sizes is performed by creating a free-body diagram and applying operating loads and reactions. See Figure 11–18 and Figure 11–19.

a. Snapshot approach. The diagram is created as a snapshot of the operating loads acting on the gate at a particular instant of time. With the snapshot approach, it is valid to use dynamic or static coefficients of friction. Use of a dynamic coefficient of friction would represent a steady-state moving gate. Use of a static coefficient of friction would represent the instant of time just before incipient motion and transition to dynamic friction.

b. Coefficient of friction. Since both will be experienced by a gate during operation, the most conservative (largest) coefficient of friction, between static and dynamic, must be used. The friction forces applied to the free-body diagram will always act in a direction that opposes the motion of the gate. After applying the operating loads to the diagram, a summation of moments and forces can be used to solve for the reaction forces, which can then be used to determine required motor or cylinder sizes.

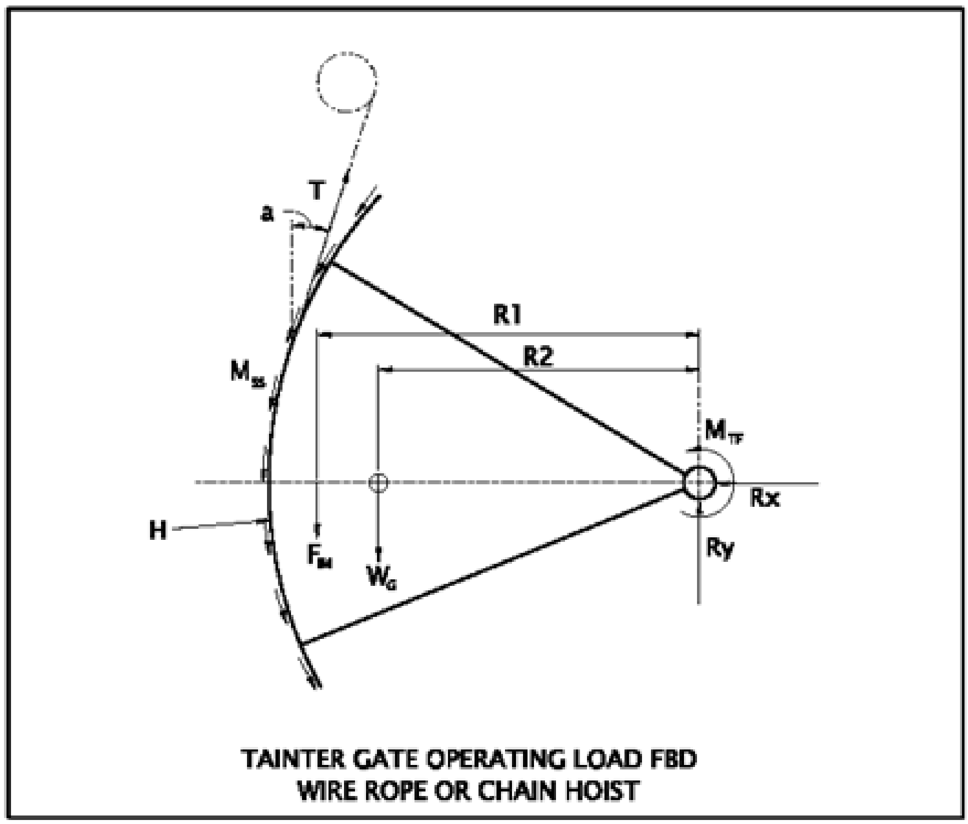


Figure 11–18. Wire rope hoist example, free-body diagram

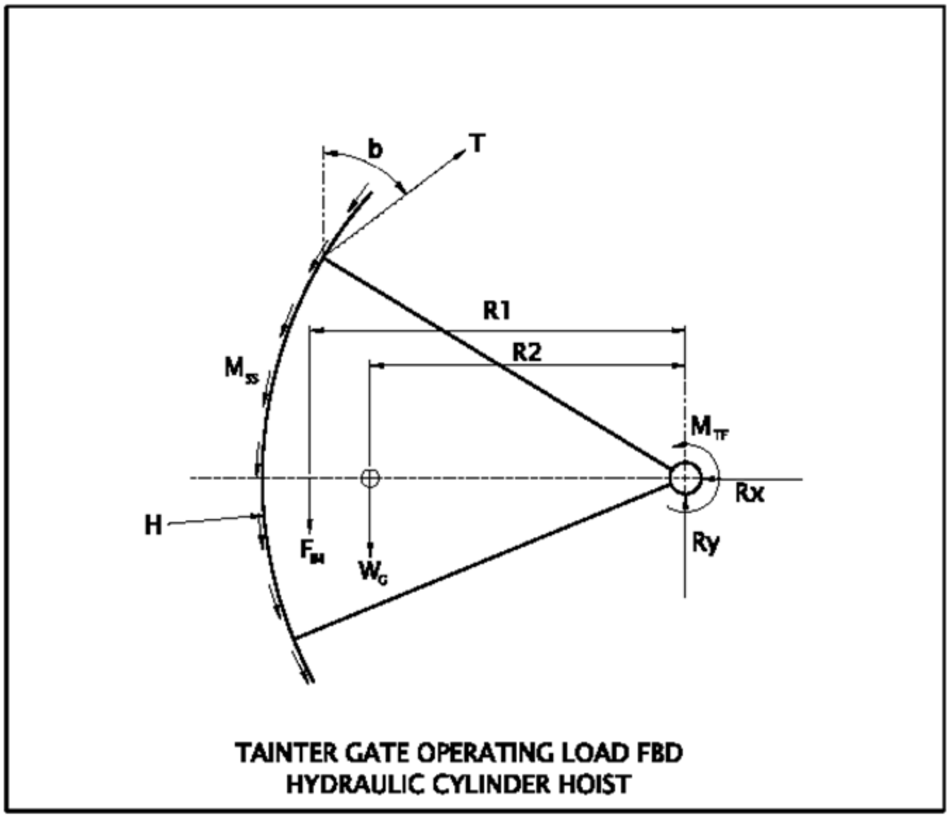


Figure 11–19. Hydraulic cylinder hoist example, free-body diagram

c. Operating loads. The maximum normal load the operating machinery will experience is typically at the gate position, at which the moment arm between the gate center of gravity and trunnion is maximized.

d. Hydrostatic load (H). As discussed at the beginning of this chapter, tainter gates are designed so that the curvature of the skin plate is concentric with the gate trunnion. This focuses the resultant hydrostatic load acting on the skin plate through the trunnion. This eliminates direct moment contributions from the hydrostatic load that otherwise would affect the required hoist loads. The assumption that the hydrostatic load acts through the trunnion is valid for most cases. However, this assumption is based on the geometry specific to a gate. Some gates are designed with surfaces that hydrostatic loads act on that are not concentric with the trunnion. The applicability of this assumption needs to be assessed on a gate-by-gate basis.

e. Hydrostatic loading. While in most cases the hydrostatic load does not directly apply a moment to a tainter gate, in almost all cases it contributes significantly to normal forces. These normal forces generate friction that does apply a moment. The hydrostatic loads typically contribute greatly to the total reaction force at the trunnion. The trunnion reaction forces (reactions on the main bearing and any thrust surfaces) are the normal forces used to calculate the trunnion friction. Also, the hydrostatic load typically contributes to the normal force caused by the gate side seals contacting the pier faces.

f. Gate weight (W_G). Calculations of gate weight must include estimates for components that have significant weight contributions. Components to consider include the gate coating system, weld material, and fasteners. Engineering judgment must be used when determining the components needed.

g. Ice and mud (F_{IM}). Reasonable estimates should be made for other factors such as ice, mud, or debris that can accumulate on gate surfaces. The potential for ice and mud buildup varies widely among climates and locations. Engineering judgment should be used to make reasonable, site-specific estimates for ice, mud, and debris weights.

h. Trunnion friction (MTF). The trunnion friction load must be calculated based on the reaction forces at the trunnion. This typically involves two separate reaction forces: one acting on the trunnion main bearing and the other acting on the trunnion thrust surface. The trunnion bearing coefficient of friction depends largely on the condition of the bearing and how well it is maintained.

(1) Realistic coefficients of friction for a well-maintained, lubricated bronze bearing are typically within a coefficient of friction range of 0.1 and 0.2. A minimum coefficient of friction value of 0.3 should be used for design purposes. The 0.3 value can be experienced in cases where greasing and other necessary bearing maintenance are not performed at the designed lubricating intervals, or in cases where water, dirt, debris, etc., get between the bearing surfaces. Maintenance of a trunnion bearing performed at time periods longer than the designed maintenance interval (or the intrusion of water, dirt, or debris) are conservative yet reasonable operating conditions that must be accounted for in the design coefficient of friction.

(2) Some tainter gate bearings are believed to have experienced higher coefficients of friction than 0.3. In almost all cases, maintenance was stopped for extensive periods of time, or the lubrication system experienced a failure, such as a clogged grease line, that prevented the lubricant from reaching the bearing. Designers should use engineering judgment to determine acceptable coefficient of friction for which these conditions are anticipated. Trunnion bearings must be designed to comply with the bearing pressure requirements in Chapter 2.

i. Seal friction (M_{SS}). The side seal friction is a function of the preset force in the seal and the hydrostatic pressure on the seal surface. See EM 1110-2-2107 for the method used to calculate the side seal friction.

11–6. Tainter gate design criteria

The components of new or rehabilitated tainter gate hoist systems must be designed to comply with the criteria in Chapter 2. Any loading criteria deviation deemed required by the designer must be comprehensively documented and archived. The analysis and justification for all design requirements must be fully documented in the project DDR. In most cases, the designer should evaluate three load cases for a two-sided lifting condition. Where gates are lifted using a single connection point, the designer needs to evaluate only load cases A and B. If the project is only replacing individual machinery components or wire rope, the existing project design criteria can be followed. Many times, older machinery and wire rope were only designed with equal loading and may have a reduced wire rope factor of safety from 5.0.

a. Load case A (normal operation): The normal expected operating load with the hoisting load split 50/50 between each side of the gate in a tainter gate with two lifting points. This load case corresponds with Load Combination 3 in Chapter 10 of EM 1110-2-2107 for structural loads. In operation, the motor is ideally 75% to 80% of full load torque (FLT) and must be less than 100% FLT. However, machinery components and wire rope must be designed using the FLT of the motor. Machinery components including wire ropes must be designed for a factor of safety of 5 based on the ultimate tensile strength as described in Chapter 2.

b. Load case B (jammed gate): An overload scenario where the gate has become jammed in the gate slot and is unable to move. The maximum hoisting load is applied (up to locked rotor torque as defined in chapter 2) in full to a gate with a single lifting point and split 70/30 between lifting points on a gate with two lifting points. This is considered an overload scenario, and components are allowed to reach 75% of yield for fabricated components. Wire rope loads must not exceed 70% of the breaking strength. Purchased components should be coordinated with suppliers or manufacturers to determine the appropriate factors to applied on top of those already assumed by the manufacturer. This load case corresponds with Load Combination 5 in Chapter 10 of EM 1110-2-2107 for structural loads.

c. Load case C (single-sided lifting): An overload scenario where one side of the hoist has failed, and the gate is racked in the slot and riding against slot walls as it is raised. Maximum lifting force and torque is applied to one side of the gate only. Components are allowed to reach up to 95% of yield for fabricated components and to be consistent with the criteria in Chapter 2. Wire rope loads should not exceed 70% of the breaking strength and must not exceed 75% of the breaking strength. If utilizing load limiting devices, Load Case C often governs, and determines the load limiter set point. See Chapter 2 for requirements of load limiting devices.

(1) The designer is cautioned that often the actual machinery loads cannot be determined with certainty, and, under locked rotor motor torque, the yield point can be exceeded. It is recommended to keep components to reach up to 75% of yield point for that reason under Load Case C.

(2) Load Case C corresponds with Load Combination 4 in Chapter 10 of EM 1110-2-2107 for structural loads.

(3) Purchased components should be coordinated with suppliers or manufacturers to determine the appropriate factors to be applied on top of those already assumed by the manufacturer. The lifting load for this case is provided by the structural designers and must include friction from contact between side bumpers or rollers on the gate and the embedded guides in the wall.

(4) All loads provided by structural for Load Case C should be unfactored as the mechanical allowable based on allowable stress design and not LRFD as described in EM 1110-2-2107.

(5) Design and installation of new hoists on old gates require analyzing how single-sided lifting will affect the structure. Designers must coordinate any change to the machinery that might increase operating loads with their structural team. Load Case C should also be evaluated from a dam safety perspective. In many cases, the safest position of a tainter gate or vertical lift gate is in the closed position if one side of the hoist machinery fails.

11–7. Types of hoist primary movers

Hydraulic cylinder hoists should be designed to support and operate the entire gate from one side. The maximum hoisting load is limited by the hydraulic system relief valve setting. The factors of safety listed in Chapter 2 for normal and overload conditions apply. The hydraulic system should be designed such that the normal operating loads require an operating pressure at least 10% less than the listed working pressure to allow for increased friction and inefficiencies as the system ages.

a. For electric motors, the maximum hoisting load is the locked rotor torque of the motor or the load-limiting device set point. Locked rotor torques can exceed manufacturer rated values such as the typical 280% FLT for NEMA D. Load-limiting devices, as described in Chapter 2, are used to limit the maximum torque to a lower value. Custom-wound motors are another means of limiting the torque to a known value, although there are limitations to how close the locked rotor torque can be set relative to the full load torque. Designers are encouraged to work closely with motor manufacturers to determine the motor characteristics that are possible as they design the machinery system.

b. Regardless of the means of limiting, the motor should be sized such that normal operating loads are near 75% to 80% of FLT.

c. A motor service factor of 1.15 is also recommended.

11–8. Tainter gate variations

a. Submersible tainter gates. Submersible tainter gates are like conventional tainter gates but are designed to be lowered to a submerged position that allows unrestricted flow through the gate channel or the passage of vessel traffic. Submersible tainter gates are used at USACE sites for both spillway and navigation lock applications. A general arrangement of a submersible tainter gate is shown in Plates 57 and 58.

(1) Although any hoist type could be used for a submersible tainter gate, greater distance between the machinery (located on the top of the piers above the gate) and lowest gate elevation (submerged position) tends to make hydraulic cylinder and screw stem hoists less feasible hoisting options. Wire rope-and-chain hoists are the most

common choices because they can accommodate the greater distance between hoist machinery and gate (Figure 11–20).

(2) Gate connections for submersible tainter gates are located near the skin plate on the top horizontal girder or other convenient structural member on the concave side of the gate. This location is most often chosen because it usually maintains an unobstructed path to the machinery for the full range of gate motion. Figure 11–20 shows this gate connection location and a common gate connection style for a submersible navigation lock gate.

(3) Submersible tainter gates are used on spillways as a method of providing unrestricted flow (gate in the fully lowered position). They also can allow the passage of vessel traffic during times when restricted flow is not needed.

Figure 11–20. Common gate connection style and location for submersible tainter gates

b. Lock gates. Submersible tainter gates are successfully used as the primary operating gates in navigation locks such as the USAF Lock and Ice Harbor Lock. See Figure 11–21. While the hoist machinery usually has many similarities to non-submersible tainter gates, there are typically a few key differences. Navigation lock tainter gates are required to span the width of the navigation lock, which tends to create a different aspect ratio from spillway tainter gates. Navigation lock tainter gates tend to be much wider than they are tall.

(1) During normal lockages, the tainter gate is below the sill. With a tainter gate used in the lock chamber, the lock can be used as a spillway to pass flood flows. The lock can also be used to pass ice and debris.

(2) The width of the gates and need for clear space across the lock (to pass vessel traffic) directly affect the feasibility of using a mechanical means, such as a torque tube or line shaft, to synchronize sides of a hoist. Synchronization typically is done by power selsyn motors. Typical hoist systems consist of a rope drum, open gear set, speed reducer, brake, hoist motor, and power selsyn. The hoist drum is typically mounted on a cantilevered shaft of a size adequate to prevent excessive error in the mesh of the final drive pinion and gear due to shaft deflection.

Figure 11–21. Upper St. Anthony Falls navigation lock submersible tainter gate

(3) The need to accommodate vessel traffic efficiently might require hoisting speeds other than the 1 ft/min guideline recommended earlier in this chapter. Hoisting speeds should be coordinated to make sure the necessary time per lockage parameters is being met. Most often, navigation lock submersible tainter gate hoists are sized to operate a gate from full open to closed, and vice versa, in 2 to 3 minutes.

c. Piggyback tainter gates. A piggyback tainter gate also could be described as a tainter gate sitting on top of another tainter gate. Piggyback tainter gates are used as a means of releasing water from two different elevations (not simultaneously).

(1) The bottom gate seals against the spillway concrete ogee. The top of the bottom gate is designed with its own ogee shape to accommodate overtopping flow when the top gate is hoisted. The top unit resembles a short conventional tainter gate that seals against the ogee of the lower gate and is held in the closed position only under its own weight.

(2) When the bottom gate is hoisted, the top gate is lifted with it. Piggyback tainter gates are chain hoisted with standard chain-hoist systems. One end of the chain is connected to the bottom gate. The other end of the same chain is connected to the top gate. The top gate is hoisted by first lowering the bottom gate to the fully closed position. The machinery then is operated in the same direction that lowers the bottom gate. This first pulls the slack out of the section of chain between the machinery and top gate, then starts to hoist the top gate. The Pittsburgh District owns and operates piggyback tainter gates and can be contacted for further information.

d. Sydney tainter gates. A Sydney tainter gate is a conventional tainter gate that can be hoisted by its dedicated hoist equipment vertically after the gate is lifted to its highest point of rotational travel.

(1) The typical operation of a Sydney gate is the same as a conventional tainter gate. Sydney tainter gates are designed with vertical guide slots in the concrete piers through which the trunnion pin can slide.

(2) If extremely high flows are encountered, the entire gate can be lifted vertically, past its typical operating range, to move it out of the flow. As the gate is lifted vertically, the trunnion pin slides through the vertical guide slots in the pier. Sydney gates are advantageous when high river flows requiring unrestricted water passage are at a much higher elevation than typical river flows. The Pittsburgh District owns and operates Sydney tainter gates and can be contacted for further information.

11–9. Vertical lift gates

Vertical lift gates are a common type of dam gate and discussed in Chapter 9 of this manual. They are used in many different applications including spillways, control towers, and regulating outlets.

a. Machinery is typically located on a structural feature above the gate. The design criteria discussion for tainter gates directly applies to vertical lift gates. For most dam applications, vertical lift gates must be operated under differential head conditions.

b. The differential hydrostatic pressure can create large transverse forces, creating large friction forces as a gate is being operated. Rollers or slides are needed on the downstream side of the gate to reduce friction between the gate and guides to allow hoisting of the gate. Chapter 9 is dedicated to vertical lift gates for all applications and should be referenced for further information. The structural design of vertical lift gates is covered in EM 1110-2-2107.

11–10. Hinged crest gates

Hinged crest gates are mounted with a hinged connection at the crest of a spillway. See Figure 11–22. Hinged crest gates are raised to achieve a closed position and lowered to achieve an open position. They can be designed to allow overtopping flow at any height through their range of travel.

a. Crest gate design. This functionality is most used at USACE sites to provide a method of maintaining required navigation depths during periods of low river flow. Like wicket gates, hinged crest gates can provide unrestricted navigation when in the lowered (open) position. Hinged crest gates also have the capability to completely stop river flow if the upstream pool is held below the top elevation of the gate. This function can be used to increase upstream storage capacity.

Figure 11–22. Hinged crest gate, torque tube-style (viewed from the downstream side)

b. Operating machinery. Hinged crest gates are often moved using hydraulic cylinders as shown in Figure 11–23 and Figure 11–24. Hydraulic cylinders are usually the most efficient and cost-effective means of operating hinged crest gates. Hinged crest gate operating machinery opens and closes the gate by rotating it about the hinged pivot point. In addition to lifting or lowering the gate, the operating machinery might need to be designed to hold the gate at any position between open and closed.

c. Bearings. All bearings associated with hinged crest gates should be of the self-lubricated type and designed according to the criteria in Chapter 3. Often the bearing will be underwater and inaccessible for maintenance. Greased bearings will also introduce grease into the waterway.

d. Dogging devices. Dogging devices also can be used to hold the gate at fully closed (raised) or any intermediate position. It also is recommended to provide dogging devices to hold the gate in the open (lowered) position to prevent flow vibration and gate movement if the hydraulic operating cylinder(s) are removed. This allows a method to perform maintenance, repair, or replacement of the mechanical operating system.

Figure 11–23. Coon Rapids Dam hinged crest gate (dewatered condition)

Figure 11–24. Hydraulic cylinder connection detail, Coon Rapids Dam

e. Pressure relief systems. Pressure relief systems should be considered for the hydraulic operating systems of hinged crest gates located on navigable waterways where vessel impacts could cause unacceptable damage to a gate.

(1) These systems use a pressure relief valve to rapidly release hydraulic fluid from the cylinder bore into an auxiliary reservoir sized for the maximum volume of hydraulic fluid that can be contained in the cylinder bore.

(2) This system is activated only by a spike in the cylinder pressure and relies on no electrical devices for its operation or activation. After impact release, the hydraulic fluid in the auxiliary reservoir must be drained into a suitable container and manually returned to the HPU's main reservoir.

f. Redundancy. A backup HPU should be provided to allow operation of the gate if the primary HPU experiences a failure. The gate cylinders for multiple gates should be supplied with hydraulic power from at least two main HPUs, as well as from two separate accumulator HPUs. Typically, all HPUs are in a control tower. The main hydraulic system raises and lowers the dam gates one at a time.

g. Debris detection systems. Debris buildup behind closed hinged crest gates can inhibit operation. Some installations have incorporated detection systems to notify the operator of buildup.

h. Operating system design. In addition to supporting hydraulic and gravitational loads, hinged crest gate operating systems should be designed to operate a gate with ice and debris impact load applied to the top of a gate. A conservative ice loading on the gate of 5 kips per linear foot is suggested and is used by the gate manufacturers. The designer can revise this value based on the specific site conditions and in coordination with the gate manufacturers.

i. Cylinder-operated torque tube gates. Cylinder-operated, torque tube hinged crest gates use one or more hydraulic cylinders located at the end(s) of the torque tube to apply torque to lift or lower the gate as shown in Figure 11–25. The torque tube extends between piers and is supported by intermediate bearings. Figure 11–25 shows the cylinder embedded in the concrete pier.

(1) The ends of the torque tube extend into a gallery in the piers, which house the operating hydraulic cylinder(s) and HPU. The torque tube penetration into the piers is sealed to prevent water from entering the gallery when the pool elevation is above the torque tube.

(2) The gate leaf is cantilevered off a rigid connection to the torque tube. To operate the gate, the torque generated by the hydraulic operating cylinders must overcome the torque created by loads acting on the gate leaf that are not acting through the center axis of the torque tube.

(3) The primary advantage of a cylinder-operated, torque tube hinged crest gate is that the operating machinery can be enclosed in the pier gallery. Doing so provides maximum protection for the operating machinery that otherwise would be exposed to weather, water, debris, etc. Locating the machinery in an enclosed gallery can also provide better containment for hydraulic fluid leaks.

Figure 11–25. H.K. Thatcher torque tube-style hinged crest gate

(4) The primary disadvantage to the operating machinery of a cylinder-operated torque tube gate is the larger cylinder size requirement. The effective cylinder moment arm used to apply torque to the torque tube changes as the gate is rotated through its motion. The cylinder must be sized to operate the gate when its effective moment arm is shortest. Torque tube gates also have practical size limits for the gate leaf. The gate size tends to be limited by the strength of the rigid connection to the torque tube, which supports the cantilevered gate leaf. Torque tube hinged crest gates also require packing gland seals at the pier penetrations, which periodically require replacement.

j. Pierless cylinder-operated torque tube. A different style of torque tube hinged crest gate that locates the operating machinery in a dry gallery below the gate has been developed. This eliminates the need for piers that would otherwise create additional navigation obstacles. Like the torque tube gate described above, a pierless gate would require shaft seals to prevent leakage into the dry gallery. See Appendix B and Plates 73 and 74. These plates show the torque tube supported between two bearings that are the torque tube penetrations into the dry machinery gallery. Split seals and chevron packing is provided around the shaft at the bearing supports to prevent water leakage into the machinery gallery.

(1) *Advantages*. The primary advantage of this system is there is no need for piers to house the operating machinery, therefore, eliminating navigation obstacles.

(2) *Disadvantages*. The primary disadvantage of this system is the need for a dry gallery below the hinged crest gate to access the machinery.

k. Crest-mounted lifting cylinders. Crest-mounted lifting cylinder hinged crest gates use one or more hydraulic cylinders mounted on the spillway crest below the gate. The hydraulic cylinders are attached to the back of the gate and are loaded in compression as they support the weight of the gate and other operating loads. Typically, a recess in the concrete foundation below the gate is needed to accommodate the required length of hydraulic cylinder.

(1) *Advantages*. Crest-mounted lifting cylinders eliminate the need for piers. Gates can be built directly adjacent to one another. These gates can provide unrestricted vessel navigation when the gates are fully opened.

(2) *Disadvantages*. Installations that have a spillway crest submerged by the downstream pool require the crest-mounted cylinders to be designed for operation in a submerged environment. Hydraulic system leaks end up directly in the waterway.

l. Pier mounted tension cylinders. Pier-mounted cylinder hinged crest gates attach to the pier and upstream side of the gates. Operation by an actuator mounted to the pier rather than the crest is the most common arrangement of a hinged crest gate. See Figure 11–24. The cylinders are loaded in tension as they support the weight of the gate and other operating loads. The operating hydraulic cylinders are loaded in tension and do not need to be designed for a buckling, therefore, reducing the required cylinder size. The primary disadvantage is that a pier is required at each end of a gate to mount the operating hydraulic cylinders. For this reason, the hinged crest gates of this system are most economical in combination with wide gates.

11–11. Roller Gates

Roller gates are large cylindrical gates suspended between spillway piers that are raised or lowered through diagonal slots in the piers. Roller gates are used to regulate water flow and have been designed so flow can pass over or under the gate.

a. Roller gates typically are designed so their maximum hoisted elevation is above flood conditions on the river. This allows for unobstructed flow in flood situations. Roller gates were a popular gate choice worldwide in the early 1900s. Numerous roller gates were installed in the 1930s in USACE districts, including the St. Paul, Rock Island, St. Louis, and Huntington Districts. See Figure 11–26. Most of these installations are still in service today and are approaching 100 years of operation. However, roller gates are not typically used in new installations for several reasons discussed below.

b. The lower cost and other operational advantages of tainter gates have made new installations of roller gates obsolete. The transition from roller gates to tainter gates is captured in Chapter VII of Gateways to Commerce: USACE's 9-Foot Channel Project on the Upper Mississippi River. Specific design guidance and criteria for roller gates is provided in Fort Belvoir Engineer School Design Manual, Canalization of the Upper Mississippi River and Ohio River (USACE, The Engineer School 1939).

Figure 11–26. Roller gate, Mississippi River

c. Roller gates are chain hoisted from one end only of the gate through angled slots in the gate's supporting piers. The angled slots contain inclined racks that interface with cogs on the ends of the gates. The rack-and-cog design allows the gates to move or climb up the racks (Figure 11–27).

d. The structural design of a roller gate is based primarily on a stress analysis for the true critical position of the gate. This critical position, or the loading condition which causes maximum stresses, is typically determined from a curve drawn to represent the maximum resultant water loads through the range of possible gate positions.

e. The drive machinery for roller gates is typically mechanical gear driven with a pinion gear and a large herringbone gear (Figure 11–28). Roller gates are chain hoisted from one end of the gate through angled slots in the gate's supporting piers. The angled slots contain inclined racks that interface with cogs on the ends of the gates. The rack-and-cog design allows the gates to move or climb up the racks as the chain hoists the gate. The chain hoists are mounted permanently on the piers above the gates and are operated with electric motor hoist equipment. Maintaining and lubricating these chains is difficult and has always been an issue with roller gates. The large size of these chains makes replacement very difficult. Chain typically requires double side bars for more strength.

f. Maintaining roller gates is difficult and is another reason they are not used anymore. Although the outside of the gates can readily be painted, the inside of the gate is not accessible for inspection and maintenance. Most roller gates in use have never been removed for service.

g. Roller gates are some of the widest available. Most USACE roller gate installed are between 60 and 110 ft wide. This allows the use of fewer gates to regulate flow. Another main advantage is that roller gates can pass flow over or under the gate. The ability to pass flow over the gate allows superior ice and debris passing capabilities. Many roller gates are used throughout the winter months to pass flows while adjacent tainter gates are not used. Roller gates require no drive synchronization since the gate is driven from one side only.

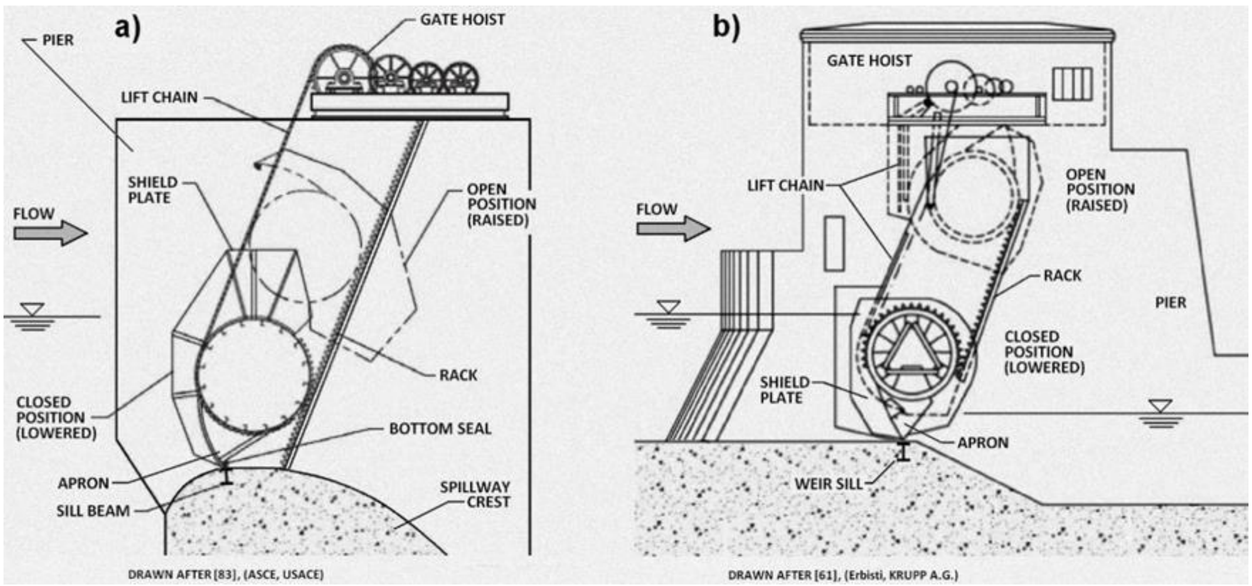


Figure 11–27. Roller gate schematic

Figure 11–28. Roller gates on the Mississippi, drive machinery:
a) driven end and machine room on pier; b) view inside machine room

h. Roller gates are known to produce dangerous undercurrents or rollers, which can be hazardous to river users (Figure 11–29). Anything drawn into the dam most likely is pulled under the gates by the strong undercurrents. The safe clearance distance at Lock and Dam 15, on the upper Mississippi River in the Rock Island District, is 600 ft upstream and 150 ft downstream of the gates. High piers are required to lift the gate out of water and to house the drive machinery.

Figure 11–29. Roller gate detail

Chapter 12
Tow Haulage Systems and Floating Mooring Bitts

12–1. Introduction

This chapter discusses and provides engineering design guidance for tow haulage systems and floating mooring bitts (FMBs).

12–2. Winch or tow haulage systems

Winch or tow haulage systems at navigation locks move commercial barges or vessels through the lock chamber. When a tow is longer than the lock chamber (see Figure 12–1), it must be split and locked through in two or more sections, with the towboat remaining with the last section. These systems are often provided for 600-ft lock chambers. Some means must be provided to pull the first section out of the chamber so that the chamber can be prepared to lock the next section through.

Figure 12–1. USACE – Typical 3-barge-wide and 15-barge tow configuration

a. A commercial tow consists of a towboat pushing multiple barges and a typical configuration is 3 barges wide x 5 sections long for a total of 15 barges (see Figure 12–1). The tow (barge sections) needs to be split in half or broken apart to lock through the chamber (see Figure 12–2). Once the barges are split, the winch or tow haulage system is used to pull the first barge section through the chamber while the tow boat remains with the second barge section. The winch (and towing bitt discussed below) typically pulls the first barge section to the end of guide wall and past the miter gates.

b. Locks with dimensions of 110 ft wide x 1,200 ft long do not require a tow haulage system since the tows do not have to be split apart. The tow haulage unit should always be on same side with the upstream and downstream approach walls (guide walls) for the tow haulage unit to function properly.

Figure 12–2. USACE – Typical barge tie off to fixed mooring bitt

c. The alignment and distance from a winch drum to the first (lead) sheave is set to provide the proper fleet angle. The recommended fleet angle is 3° (see Figure 12–3). In some cases, sliding sheaves (Figure 12–4) and orientation of the winch unit can be used to minimize the fleet angle.

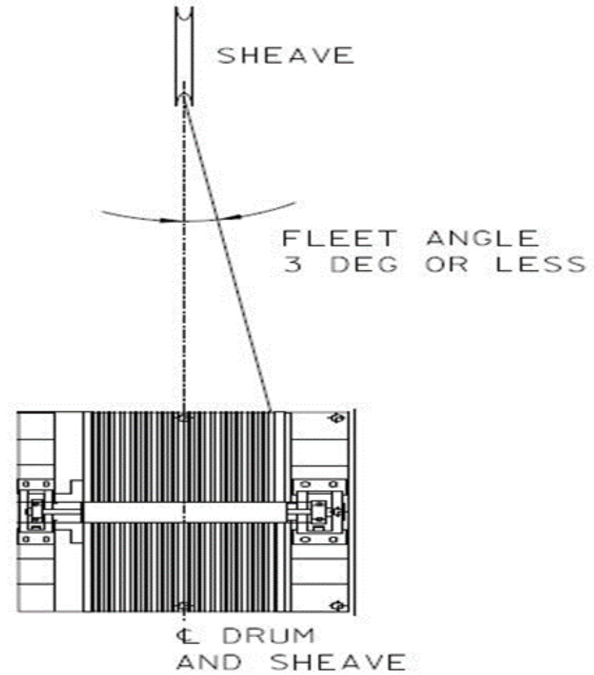


Figure 12–3. Fleet angle for winch drum

Figure 12–4. Existing Kentucky Lock – sliding sheave

12–3. Types of tow haulage systems

The two most common types of tow haulage systems are the single reversible unit and two single units. The tow haulage system for two single units may include the counter-torque control, non-counter-torque control, or the fairlead system.

a. Single reversible unit (also known as rope-on/rope-off system). This is the simplest system that requires minimal maintenance. It has been in operation in the Nashville District for over 50 years. Since 2005, many single-winch units with bull gears and pinions (Figure 12–5) in Nashville District have been replaced with new winch units using planetary gearboxes (Figure 12–6). This system consists of a single reversible tow haulage unit and two cables, which pull a wheeled towing bitt along the top of the lock wall or guide walls between specified points. The hoist drum is designed so that as the cable (wire rope) is paid out at one end the grooved drum, it returns to another end of the drum.

(1) *Rope system*. The rope-on/rope-off system is very simple and requires minimal maintenance due to few moving parts. In addition, it is less expensive than the two winches and two VFD systems. Major components include a drum, planetary gearbox, encoder and limit switch, and VFD. VFDs should be placed above the 100-year flood event if possible. The planetary gearbox can be reused by changing the fluid as required if submerged under water during a flood event.

Figure 12–5. Cheatham Lock – original single winch unit with bull gear and pinion

Figure 12–6. Cheatham Lock – new single winch unit with planetary gearbox

(2) *Drum hoist*. The drum hoist can be placed anywhere between the ends of the rails of the traveling bitt. To achieve the recommended pulling load and speed of the towing bitt, a single layer of wire rope is recommended. The length of the cable on the drum equals total travel plus 2.5 dead wraps.

(3) *Drum.* The minimum diameter of the drum and sheave is 18 times the diameter of the wire drum (Figure 12–7). To maximize the life of the wire rope and to achieve the require speed (110 ft/min–130 ft/min) and pulling capacity (12,000 lbf nominal) at the towing bitt, drum diameter between 3.5 ft and 5.5 ft should be considered. A large drum size will ensure that the fleet angle between the drum and the first sheave stay below 3° and eliminate the need to use multiple layers of wire rope on the drum. Each additional layer of wire rope will reduce the pulling capacity of the towing bitt by about 8%.

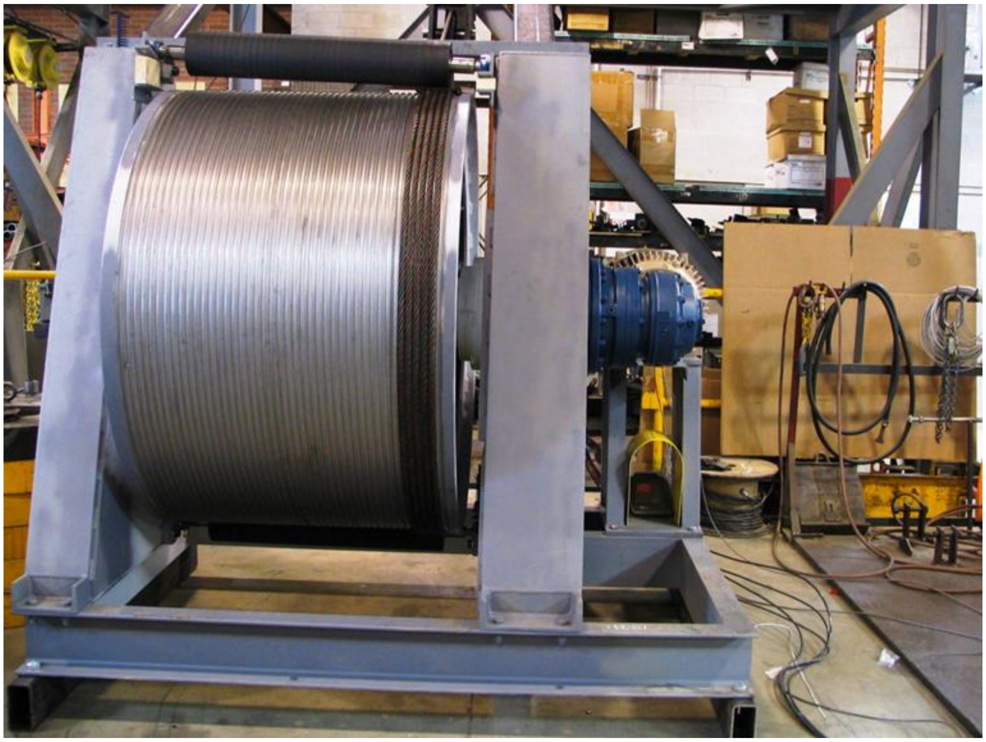


Figure 12–7. Pickwick Auxiliary Lock – drum for rope-on/rope-off system

(4) *Limit switch.* The limit switch is directly mounted to one side of the drum and communicates with the VFD and the encoder to stop the towing bitt at the end of travel and overtravel. See paragraph 12–9 for tow haulage control details.

(5) *Encoder and motor*. The encoder is mounted at the back of the motor and communicates with the VFD to determine the location of the towing bitt on the rail system (Figure 12–8) . Knowing the exact location of the towing bitt on the rail system allows the limit switch to set the end of travel and end of overtravel of the towing bitt. The motor must be rated for inverter duty with the service factor of 1.15 or 1.25.

(6) *Planetary gearbox*. The previous design used a bull gear, pinion, and high-speed gearbox for the winch unit. This system requires regular greasing and oil change. All bull gears, pinions, and high-speed gearboxes have a long lead time and high cost. Planetary gearboxes (such as the Brevini™ Gearbox) are off-the-shelf items and cost much less than the bull gears. The planetary gearboxes are recommended for electric winches of the tow haulage system. In lieu of using a flexible coupling between the motor and the planetary gearbox to handle misalignment, a flange supplied by the gearbox manufacturer should be used.

Figure 12–8. Cheatham Lock – encoder and electric motor

b. Two single-drum hoists with counter-torque control (hydraulically operated). This system consists of two single-drum hoists located on opposite ends of the lock (upstream and downstream) adjacent to the miter gate recesses (Figure 12–9). These winches pull against each other in counter-torque fashion. The winch system operates with one winch in hauling mode and the other in hold-back mode. The control system controls the speed, maximum line pull, and hold-back tension. Either winch can be operated in hauling or hold-back mode depending on the direction of the tow. This approach eliminates slack problems, allowing the wire rope to track over sheaves and spool in winch drums properly.

(1) To make room for the hydraulic power unit, the counter-torque system normally uses small drums with several layers of wire rope (see Figure 12–10). Each additional layer of wire rope normally reduces the pulling capacity of the towing bitt by 8%. As a result, wire rope is oversized to account for this loss. One-inch diameter wire rope is the typical size of this system to achieve the pulling minimum pulling capacity of 12,000 lbf. Drum diameter should be properly sized to provide the required torque and/or speed. The required 1-in. diameter of wire rope will increase the size of the sheaves to be used for the tow haulage system and increase the cost to replace the wire rope. This system is widely used by Pittsburgh District and Little Rock District.

Figure 12–9. Braddock Lock – torque-control tow haulage layout

Figure 12–10. Murray Lock – torque-control tow haulage winch with hydraulic power unit

(2) Hydraulically powered systems need to have the HPU protected against high water. To simplify maintenance of the counter-torque system, using electric winches needs to be considered. The counter-torque system with the electric winch is like the rope-on/rope-off system except that the counter-torque system will require two electrical winches and two VFDs, while the rope-on/rope-off system requires only one electric winch and one VFD.

c. Two single-drum hoists without the counter-torque control. This second type of two single-drum hoists are used by many sites on the Mississippi River. Like the counter-torque tow haulage system, this system consists of a pair of single-drum hoists, usually operated by hydraulic power unit (Figure 12–13). Again, electric winches can be used in lieu of an HPU.

(1) One hoist is on the top of the lock guide wall upstream from the upper gate bay. The second usually is downstream from the lower lock gate on the lower guide wall. Often, the downstream unit is not used. Rather, the tow is flushed out of the chamber by cracking open a culvert valve.

(2) The downstream winch unit is used when the tailwater and pool elevations are nearly the same, or during flood conditions. The tow haulage unit always should be on the guide wall side, and upstream and downstream approach walls (guide walls) must be located on the same side of the lock for the tow haulage unit to function properly.

d. Two single-drum hoists with fairleads. The free end of the winch line is spooled off the drum and goes through a fairlead mounted on the lock wall (Figure 12–11). Many winch units also use a level-wind system (Figure 12–12 and Figure 12–13) to ensure the wire rope is evenly spooled off and wound back on the drum. The line then is fastened to a bitt on the back barge of the first section. The barge's sections are pulled out of the chamber and attached to a towing bitt. Once the barges reach the end of the guide wall, they are attached to check posts or line hooks until the second section is locked through. This system is widely used for projects on the Upper Mississippi River.

Figure 12–11. Typical tow haulage with fairlead on the Upper Mississippi River

Figure 12–12. Mechanical winch unit with level-wind system

Figure 12–13. Hydraulic-operated tow haulage unit with level-wind system

12–4. Types of towing bitts

Towing bitts, also known as traveling kevels, traveling mules, mules, traveling bitts, traveling mooring bitts, and others. For simplicity, the term towing bitts will be used in this document. All tow haulage units should be furnished with a towing bitt installed on a rail system. The towing bitt and the tow haulage winch work as a system to move the unpowered tow out of the lock chamber.

a. There are three main types of towing bitts. First with a throw-off plate (Figure 12–14), second with the horn assembly (Figure 12–15), and finally, one in the recess (Figure 12–17). Nashville District uses all these types of towing bitts. For the towing bitt with the throw-off plate, the hawser rope loops around the vertical post of the towing bitt and it is automatically thrown off the post when the towing bitt passes through the trip-off plate located near the end of the rail. It is unknown if this type of towing bitt would work well for high-head projects.

b. The towing bitt with the horn assembly is the most used for many projects throughout USACE. The horn assembly can be placed at 45° upward or 0° with the horizontal line. Some towing bitts in Nashville District have the adjusting rod to adjust the tension in the wire rope as needed. The towing bitt is mounted on a rail that is fastened to the concrete. A hawser line furnished by the tow is slipped over the traveling bitt and fastened back to the barge.

Figure 12–14. Existing Kentucky Lock and Old Hickory Lock – towing bitt with kick-off plate and trip-off plate

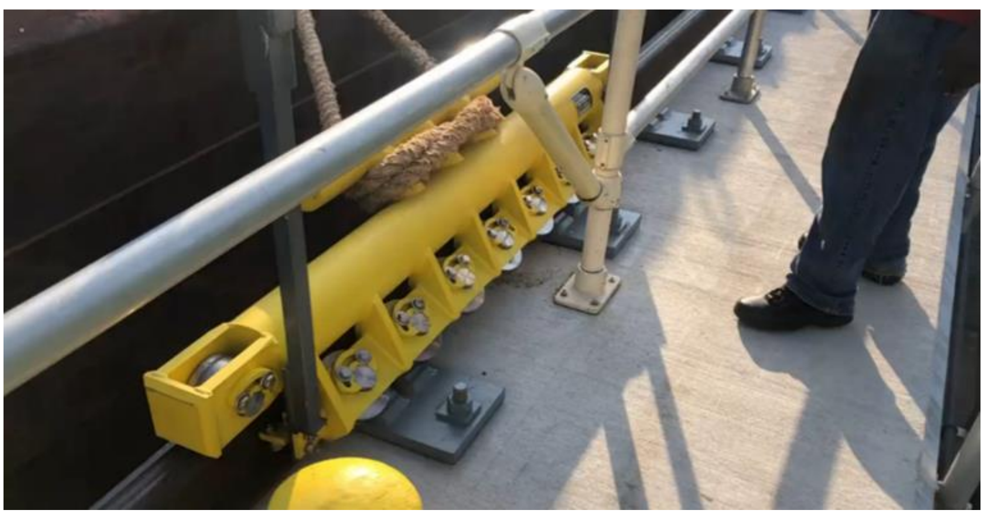


Figure 12–15. Lock and Dam 6 – towing bitt with horn assembly at 45 degree upward

12–5. Tow haulage hawser forces

The hawser forces imparted on the traveling bitt can be significant. Hawser loads in this case are generated by barges checking their movement by tying to a line hook on the kevel.

a. The loads in this case are generated by the momentum of the barge, whether the barge is loaded or unloaded, and also wind and wave forces. EM 1110-2-2602 requires a load of 160 kips for hawser loads. Recent design analysis done by USACE has confirmed this value. The 160 kip rope loads are the breaking strength of commonly used 2-in. diameter synthetic ropes when doubled around the bitt. It is impractical to design a towing bitt for 160-kip rope load. To ensure the system is protected, a means of ductile failure can be incorporated into the base plates to provide yield versus sudden failure, as shown in Figure 12–16.

b. The following failure modes are not ductile and must be avoided:

(1) Anchor bolt or concrete failure.

(2) Rail dislocation (“popping out”) due to rail clip deflection or yield.

(3) Shearing of welds within the traveling mooring bitt.

(4) Bitt rolling off the end of a deflected or yielded rail at a rail joint.

(5) Progressive, zipper-type failure of rail supports.

c. With the exception with the failure of the rail system (2011) and the failure of the towing bitt (2014) at Lock and Dam 7 (St. Paul District), the history of additional bitt failures in other districts or of previous failures in the St. Paul District is mostly unknown.

Figure 12–16. Lock and Dam 7 – rail misalignment and failure of towing bitt

d. The recessed type is very safe, since the towing bitt and wire rope are both located in the recess (Figure 12–17). It prevents the towing bitt from falling into the river and protects field personnel from being injured by the breaking wire rope. It should not be used in cold climates where snow and ice would clog the recess. In addition, it is very difficult the replace the wire rope, since the wire rope tube (Figure 12–18) is embedded in concrete.

Figure 12–17. Pickwick main lock – towing bitt recess

Figure 12–18. Pickwick main Lock – wire rope in embedded concrete

e. A towing bitt located 12 in. below the top of the lock wall is shown in Figure 12–19. This layout will likely require trenching to place the wire rope. It also limits the floatation of the FMBs. As the result, it may not be feasible to install the FMBs on the same lock wall with the tow haulage system. It is unsafe for field personnel to perform regular maintenance with this type of tow haulage system layout.

f. A towing bitt located at the top of the lock wall is shown in Figure 12–20. This is the most common type of rail layout and should be consider for the new lock, if feasible.

g. A towing bitt located on top of the concrete parapet wall is shown in Figure 12–21. If the rail interferes with the operation of the FMBs, then the parapet wall (about 3-ft height) is provided to allow the FMBs to float above the top of the lock wall. In this case, rail for the tow haulage system needs to be located on top of the parapet wall.

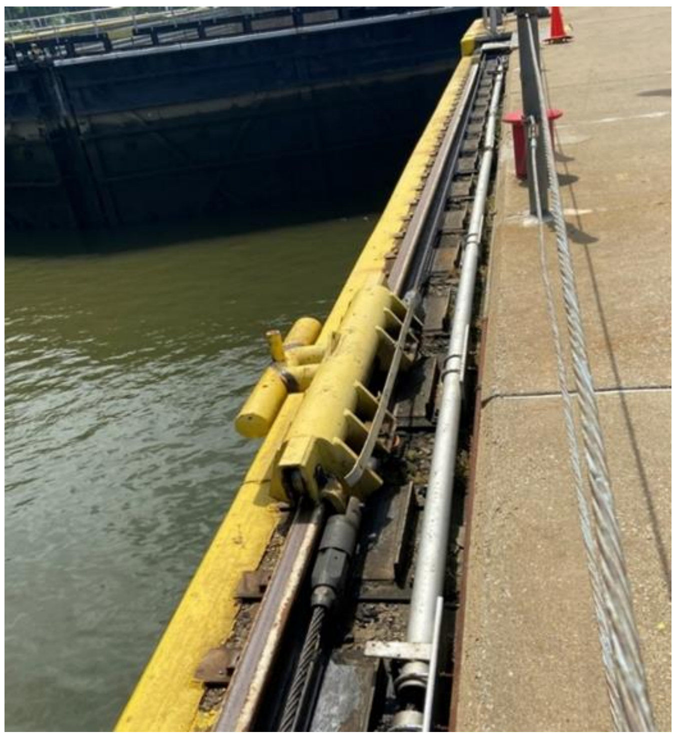


Figure 12–19. Existing Montgomery Lock – rail located 12 in. below top of the lock wall

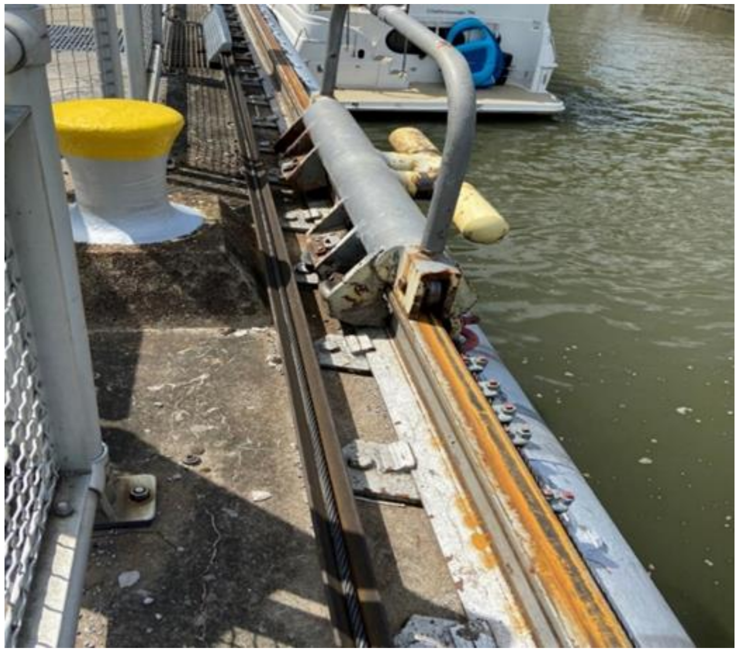


Figure 12–20. Existing Chickamauga Lock – rail located at top of the lock wall; towing bitt with horn assembly at 0 degree with the horizontal plane

Figure 12–21. Murray Lock – rail located at top of the parapet wall

12–6. Rail system

The rail should be 140 #, 136 #, or 132 # A.R.E.A type. It should be located 12 in. below the top of the lock wall, at the top of the lock wall, or at the top of the parapet wall. The designer will need to verify what rail is commercially available. The layout of the sheave system is simple when the rail is located 12 in. below the top of the lock wall, since the wire rope, sheave, and towing bitt are relatively located on the same plane. However, it creates an unsafe situation for maintenance of the equipment, and it also limits the floatation of the FMBs. Therefore, this layout is rarely used. Many projects have the rail on top of the lock.

a. The gap between rail sections should be provided to accommodate thermal contraction and expansion (Figure 12–22). The width of this gap depends on the temperature during the installation of the rails. Rail gaps should not be more than 1/4 in. during installation for any temperature to minimize rail misalignment. In addition, rail keys must be provided at the joints to prevent misalignment of the rail. Continuous rail can be incorporated to limit rail joints to prevent gaps that foul the bitts. To make the rail work in this manner, it should be fixed in the center and free to expand and contract in un-fixed plates. Continuous rail has been used in the St. Paul District.

b. Additional rail plates and rail clips should be installed as close to the joints to possible to keep the rail in place. If not properly installed, rail misalignment could occur and prevent the movement of the towing bitt (Figure 12–23). Rail misalignment can cause the towing bitt to stop. This poses a safety risk to lock personnel and barge operators because the mooring lines can snap and the towing bitt can break and launch into the air.

c. Due to the past failures and the cold climate, the St Paul District recently used a continuous rail with a fixed-center baseplate. All other baseplates have a self-lubricated spray wear material to allow thermal expansion and contraction. Thermite welds are used for rail clip connections. It is important that rail clips be custom-made to provide adequate overlap between the rail clips and rail baseplates. Off-the-shelf rail clips are normally used for gantry crane rails and may not be suitable for the tow haulage rail system due to the direction of the load acting to the rail.

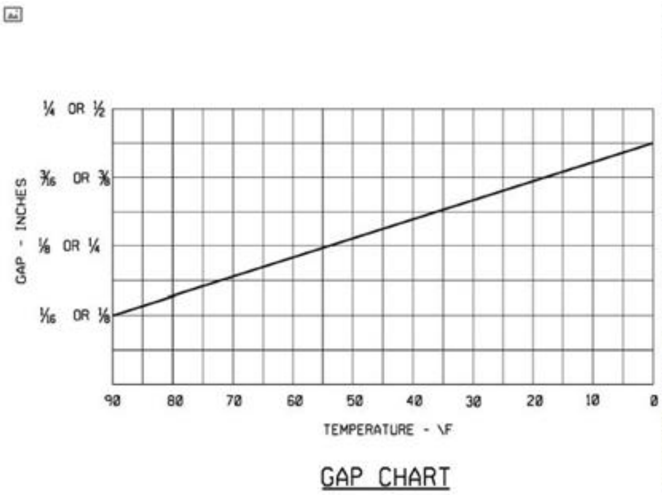


Figure 12–22. Old Hickory Lock – rail gap chart and rail key

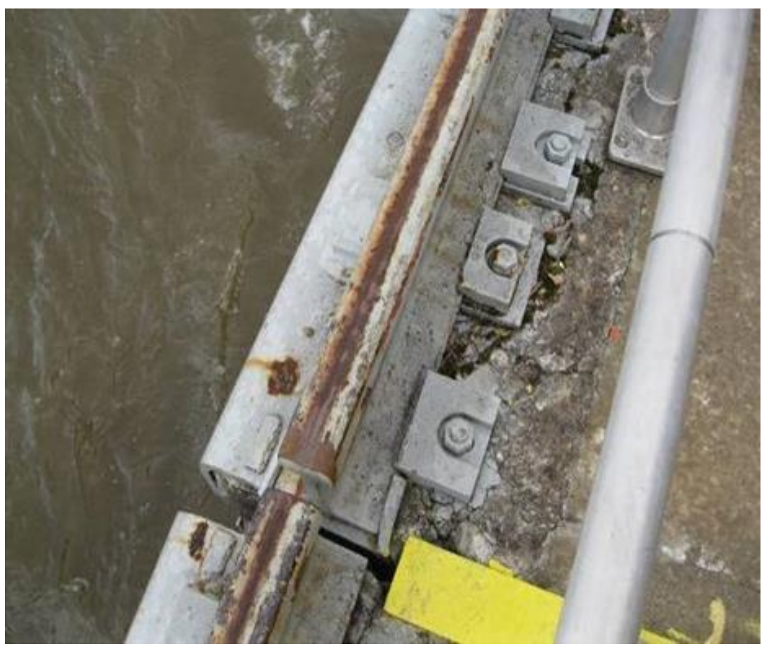


Figure 12–23. Too much gap in rail section of towing bitt

d. The beginning and end stops must be removable to allow the traveling mooring bitts to be removed from the rails for servicing. The traveling mooring bitt must be designed to allow removal without disassembly. See Figure 12–24.

Figure 12–24. Old Hickory Lock – end sheave and towing bitt stop

12–7. Wire rope

Preformed wire rope must be specified. Wire rope may lose tension over time due to thermal contraction and expansion. The towing bitt should be furnished with an adjusting rod to adjust the tension on the wire rope as needed. A take-up sheave can also be used to adjust the tension of the wire rope. See Figure 12–25.

a. To achieve the pulling capacity of 12,000 lbf with the safety factor of 5, bright IWRC, Extra Extra Improved Plowed Steel (EEIPS), 3x36 classification, 3/4-in. diameter with the breaking strength of 32.4 tons. Using bright wire rope requires regular lubrication to prevent corrosion and to ensure proper operation of the tow haulage system.

b. It is not recommended to use galvanized steel wire rope or stainless steel wire rope due to their reducing breaking strength and galvanic corrosion (stainless steel wire rope). The 3/4-in. diameter is suitable only for winches with a single layer of wire rope. For each additional layer on the drum, the pulling capacity will be reduced by about 8% of the total capacity. As the result, 1-in. diameter (minimum) wire rope, IWRC, EEIPS, 6x36 classification should be used to achieve the pulling capacity of 12,000 lbf for drum with multiple layers.

c. Synthetic rope has become more mainstream for pulling and lifting equipment. It is lightweight and easy to handle. Therefore, synthetic rope with proper breaking strength can be suitable to use on the air tugger or the capstan on the approach walls to clear the barges from the lock (miter) gates. Regular inspection of the synthetic wire rope should be performed and replaced as needed to make sure that it is in good working condition. Since synthetic rope is prone to abrasion and damage caused by ultra-violet rays and chemicals, it is not recommended for use on the tow haulage system at this time.

Figure 12–25. Old Hickory Lock – towing bitt with adjusting rod for tensioning wire rope

12–8. Approach wall equipment

Approach wall equipment includes auxiliary tow haulage units, capstans, air tuggers, and traveling check posts, also known as retriever systems. Several existing and new projects have the auxiliary tow haulage systems on the upstream approach wall and/or downstream approach wall.

a. The auxiliary tow haulage system on the approach wall normally has the same velocity (100 ft/min–130 ft/min) and pulling capacity (around 9,000 lbf to 12,000 lbf) as the tow haulage system in the lock chamber. They act not only as backup systems for the tow haulage system in the lock chamber but can also act as the traveling check post to guide the barges out of the lock chamber. The auxiliary tow haulage systems, traveling check post, and check post on the approach walls prevent the barges from getting loose and becoming stuck in the spillway gates during the release of water through the spillway gates.

b. When using the auxiliary tow haulage system to guide the first barge section, the towing bitt should slow down and come to rest near the end of the guide wall so that the barge section can be tied off and moored to wait for the next barge section.

c. The traveling check posts (also known as the retriever systems) are located on the upstream and/or downstream approach walls. See Figure 12–26. They are like the tow haulage system in the lock chamber except that it does not have the capacity to pull the barges. It consists of a winch unit, sheaves, rails, wire rope, towing bitt, controls, and other equipment. This will eliminate the need for the lock operator to walk the length of the guide wall and return (retrieve) the towing bitt manually. The motor for the winch unit of the traveling check post is about 2 hp to 5 hp. The wire rope has the diameter of 1/4 in. For comparation, a typical tow haulage system has a motor of 30 hp to 50 hp and the wire rope of 3/4-in. to 1-in. diameter.

d. In general, the rail system of the traveling check post should run the length of the guide wall to allow the first barge section to completely clear the lock chamber and the lock gates. Once the barge section and towing bitt reach the end of the guide wall, the first barge section is tied off and moored. The first barge section must completely clear the lock gates for the second barge section to lock through.

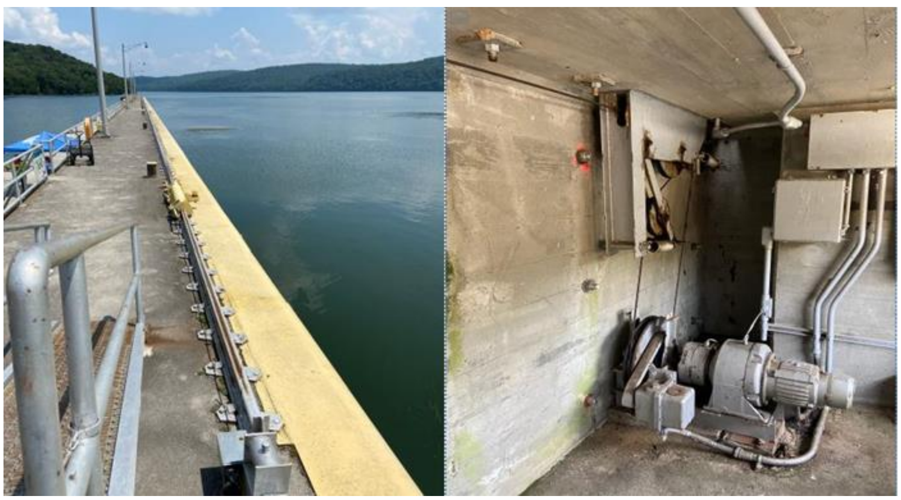


Figure 12–26. Nickajack Lock – traveling check post (also known as retriever system)

e. If the barges do not completely clear the lock gates, air tuggers or capstans have been commonly used throughout projects in USACE to pull the barges out of the lock chamber so that the gates can be closed. See Figure 12–27. New air tuggers and capstans should have pulling capacity between 8,000 lbf and 12,000 lbf, depending on the size of the lock chamber. For 110-ft x 600-ft locks and larger, 12,000 lbf pulling capacity is recommended. For safety, always install screen to protect personnel from wire rope during operation. In lieu of an air tugger or capstan, an electric winch can be considered for new project.

Figure 12–27. Old Hickory Lock – capstan

12–9. Tow haulage controls

Controls for the lock chamber tow haulage system should be in the upstream and downstream control shelters of the lock. See Figure 12–28. In addition to the controls at the lock, some projects in Nashville District also have controls at the winch unit for ease of testing and maintenance or at a location near the face of the lock chamber to provide better observation of the towing bitt. It is important that the lock operator see the barges that are being pulled during the entire operation. Therefore, the lock operator should operate the tow haulage unit from the lock wall opposite the tow haulage unit.

Figure 12–28. Barkley Lock – tow haulage control at lock control shelter

a. For the rope-on/rope-off system with a single winch unit with kick-off plate that has been used in Nashville District, the major components of the tow haulage controls include the following items:

(1) *Upstream start-on-stop button*. This allows the towing bitt to travel downstream of the lock.

(2) *Downstream start-on-stop button*. This allows the towing bitt to travel Upstream of the lock.

(3) *Torque (control) switch*.

(a) Prior to the availability of VFDs, the towing bitt was usually started with full load (9,000 lbf to 12,000 lbf) and full speed (about 100 ft/min). As the result, many wire ropes snapped at the start of tow haulage operation. With VFD, a torque control is provided to initially start the tow haulage at a low torque to provide about 1,000 lbf pulling capacity to prevent the wire rope from snapping. The torque can then be slowly increased to provide additional power to pull the barges out of the lock chamber. The torque control switch is divided into 10 increments.

(b) Increasing the torque provides more power and increases the pulling load at the towing bitt.

(4) *Speed readout*. Speed for the towing bitt should be between 110 ft/min and 130 ft/min for no load, between 60 ft/min and 90 ft/min for empty barges, and between 50 ft/min to 80 ft/min for fully loaded barges.

(5) *Load readout*. Load readout should be between 0 lbf and 12,000 lbf (nominal). Maximum load should be less than the maximum allowable load of the wire rope based on the safety factor of 5.

(6) *Kick-off (plate) button, end of travel, and overtravel*. This button is applicable only to towing bitts with kick-off plates (on top of the towing bitt). For safety reasons, the VFD is programmed to stop a few feet prior to reach the trip-off plate (on the vertical frame) to release tension on the hawser. This point is the limit for end of travel. For safety reasons, the lock personnel has to push and hold the kick-off button to move the towing bitt through the trip-off plate to unhook the hawser from the vertical post on the towing bitt. The towing bitt will stop when the lock personnel release the trip-off plate button or the towing bitt reaches the limit of overtravel.

(7) *Emergency stop*. The emergency stop is used in case the trip-off plate button (Figure 12–29) and the end of overtravel fail to function. The emergency stop can also be used to completely cut off power to the tow haulage system to prevent the towing bitt from traveling past the end of the rail and falling into the river.

Figure 12–29. Existing Kentucky Lock – towing bitt kick-off plate and trip-off plate

b. For the torque-control system, there will be two winches and two VFDs. The winch system operates with one winch in hauling mode and the other in hold-back mode. The control system controls the speed, maximum line pull, and hold-back tension. Either winch can be operated in hauling or hold-back mode, depending on the direction of the tow (Figure 12–30).

Figure 12–30. Barkley Lock – tow haulage control at winch unit

c. Wireless belly boxes have been requested by field personnel as an option for the operation of the tow haulage system. The use of wireless operation will need approval from the USACE Critical Infrastructure Cybersecurity MCX (UCIC-MCX) to assure that the system is secured and authorized according to applicable USACE policy. For safety, end of travel for the towing bitt and emergency stop should be incorporated into the wireless operation.

12–10. Summary of design guidance for tow haulage system

Motor, drum size, gearboxes, bull gear, pinion, etc., should be designed to achieve the velocity of 110 ft/min to 130 ft/min and pulling capacity of 12,000 lbf (nominal) based on the safety factor of 5 for the towing bitt under no-load condition. With empty barges, the velocity of the towing bitt should be the range of 60–90 ft/min. With fully loaded barges, the velocity of the towing bitt should be between 50 and 80 ft/min. A hawser furnished by the tow is slipped over the towing bitt and fastened to the back barge as before.

a. Motor should be rated for inverter duty and have the service factor of 1.15 or 1.25.

b. Use the torque-control switch to slowly increase the force on the towing bitt.

c. The towing bitt travel and the winch unit need to provide the required velocity and pulling capacity to pull the unpowered barges out of the lock chamber to completely clear the lock chamber and lock (miter) gates. For this reason, the end sheaves and end of travel for the towing bitt should be placed as near the miter gate as possible without interfering with the miter gate anchorage or other structural items.

d. End of travel, overtravel, and emergency stop should be included in the design to prevent the overtravel of the towing bitt.

e. Rail gap for thermal contraction and expansion must be determined based on the temperature during installation. Use rail key to prevent misalignment.

f. For cold climates, continuous rail with fixed-center baseplates can be used. All other baseplates should have a self-lubricated wear material to allow rail contraction and expansion. To prevent new rail from transferring load across the monolith joint, four (4) 1-in. diameter dowels will be installed.

g. All wheels/rollers of the towing bitts should have grease fittings. Apply grease to pin and bushings regularly.

h. Failsafe/ductile failure mode should be considered for the design of the towing bitt and rail system.

i. Maximize the contact and welding between the main tube and connecting plates.

j. Per EM 1110-2-2104, design load criteria for the towing bitt should be a 53-kip usual load with a 2.2 design factor, an 80-kip unusual load with a 1.6 factor, or a 160-kip extreme load with a 1.0 factor.

k. Hawser load applies from 45° downward to 45° upward from the horizontal line.

l. Wire rope size and type: IWRC, EEIPS/XXIPS, 6x36 wire rope. The minimum size of wire rope is 3/4-in. diameter with the breaking strength of 32.4 tons. Bright wire rope is recommended.

m. Winch with one layer of wire rope is recommended. When using winch with multiple layer of wire rope, each additional layer will reduce the pulling capacity of about 8%. As the result, 1-in. diameter wire rope will be needed for drums with multiple layers of wire rope.

n. If the existing tow haulage system has 5/8-in. diameter wire rope, reusing the same diameter of steel wire rope is acceptable. Make sure to call out new wire rope as IWRC, EEIPS, 6x36 classification.

o. Provide level-wind feature on winch units as applicable.

p. Hydraulic drives should provide for inherent speed control.

q. Hydraulic drives should have removable (plug-and-play) power units. These can be disconnected and stored during flood conditions.

r. All controls should be installed above flood levels.

12–11. Floating mooring bitts

FMBs provide a means to secure vessels inside the lock chamber during a lockage. This is opposed to securing vessels on top of the lock chamber to fixed bollards or posts that are imbedded in the lock or having lock personnel handle lines.

a. The mooring bitts raise and lower with the water elevation in the lock chamber. Due to that, they typically provide a more stable means for securing vessels as the lock is filled and emptied. Double-post FMBs are generally recommended. See Figure 12–31.

b. Many improvements have been made in filling and emptying system designs in recent years. This includes reduction of turbulence in the lock chamber and elimination of overfill and overempty situations by improving culvert valve operation. However, it is still necessary to use FMBs to keep barges and pleasure craft from drifting into the lock gates and bumping into each other, and to compensate for any human error in the filling and emptying process. For example, the turbulence in the lock chamber could result in greater than normal forces on the vessels when using only one culvert for lock filling and emptying.

c. Other items to be included in the design of the FMBs include light fixtures. Provide a light fixture at the top of the floating mooring bitt recess to accommodate the maintenance and/or inspection of the FMBs. Light fixtures should be easily removed to allow the removal of the FMBs for maintenance or replacement. Other items for consideration include the following:

(1) Lifting lugs should be provided to ease the installation and removal of the FMBs. In addition, another set of lifting lug(s) should be incorporated in the design to allow divers to quickly connect rope to the sunken FMB to bring it to the water surface.

(2) A vent pipe (1.5-in. diameter) with U-bend and screen should be incorporated in the design to allow water to get inside the FMBs if they get stuck in the FMBs recess. This will prevent the situation where the sunken FMB can quickly shoot up as the water in the lock chamber starts lowering.

(3) A compressed-air connection should be incorporated in the design to force the water inside the FMBs out after the sunken FMBs are brought to the water surface.

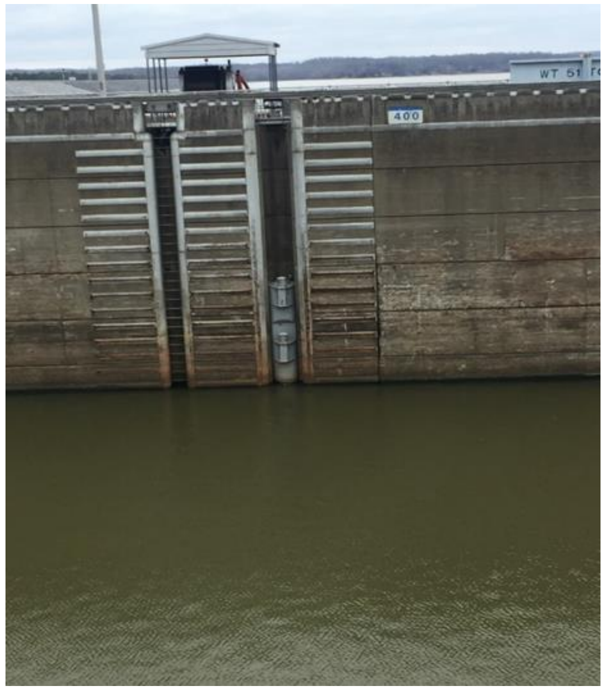


Figure 12–31. Barkley Lock – double-post floating mooring bitt

d. Four to eight FMBs are usually provided in each chamber wall, depending on the length of the lock chamber, with variable spacing to fit tows of different size barges. The distance from the first kevel to the bow of the barge is approximately 21 ft to 23 ft. As a result, FMBs should be no closer than 30 ft from the upper gate and 75 ft from the lower gate in the mitered position to help protect the gates from barge overtravel. Common barge configurations are shown in Table 12–1. Common dimensions are shown in Figure 12–32.

e. The location of the miter sills also affects the location of the FMBs. The FMBs are recommended to be about 25 ft from the miter gate sills as applicable. Other FMBs in the lock chamber are spaced to accommodate as many barge configurations as possible.

Table 12–1
Common barge configurations

Barge Configuration	Dimension (ft)
Super Tanker	300 x 54
	297.5 x 54
Jumbo	200 x 35
	197.5 x 35
	1195 x 35
Stumbo	195 x 26
Standard	175 x 26
Sand and Gravel	145 x 25

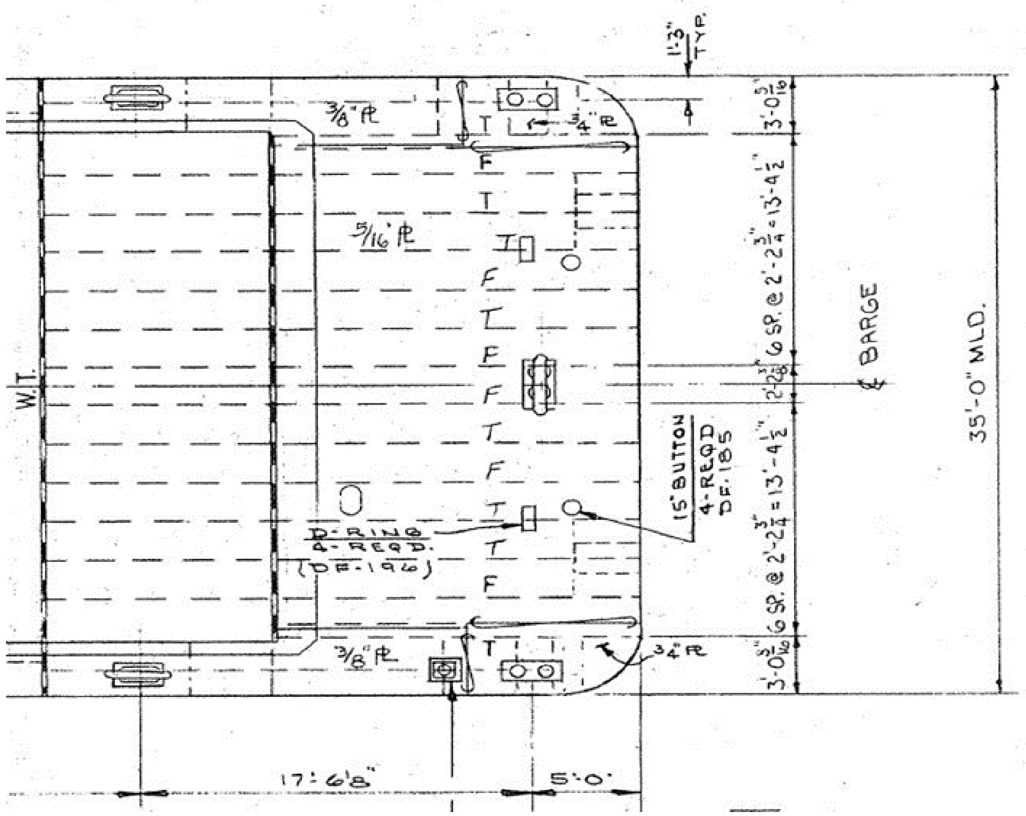


Figure 12–32. Barge dimensions (courtesy of HBC Barge, Inc®)

f. For a 110-ft x 600-ft lock, it is recommended that 12 FMBs be provided to accommodate all barge configurations. Table 12–2 shows the proposed locations of the FMBs at the Chickamauga Lock replacement to accommodate all barge configurations.

Table 12–2
Chickamauga Lock replacement – floating mooring bitt locations

Description	STA. Numbers (Land wall and River wall)	Notes
Upstream (U/S) Miter Gate Pintle	0+00.00	
U/S Miter Sill	0+06.00	
U/S FMB (1st set FMB)	0+30.00	24 ft from the U/S miter gate sill and 30 ft from U/S miter gate pintle
2nd set FMB	0+82.00	52 ft from U/S FMB
3rd set FMB	2+22.50	192.5 ft from the 1st FMB
4th set FMB	3+96.50	175 ft from the 3rd FMB
5th set FMB	5+47.00	51 ft from downstream (D/S) FMB
D/S FMB (6th set FMB)	5+98.00	23.5 ft from D/S miter sill and 77 ft from D/S miter gate pintle
D/S Miter Gate Recess	6+12.50	
D/S Miter Sill	6+21.50	
D/S Miter Gate Pintle	6+75.00	

g. A floating cylinder is an integral part of the system. FMBs consist of a watertight floating cylinder or tank that rises and falls as the lock chamber water level raises and lowers. This floating cylinder is mounted with wheels that ride inside steel guides in the mooring bitt recesses. Guide and reaction rollers are used to resist mooring rope loads and reduce frictional losses as the bitt travels up and down. See Figure 12–33.

Figure 12–33. Barkley Lock – double-post floating mooring bitt with rollers (old design)

h. The FMB guide and reaction rollers normally require regular greasing for proper operation. Due to environmental concerns about grease getting in the waterways, Portland District used a greaseless bearing at Bonneville Lock. Over time, the guide recesses for the FMB may not stay plumb due to settlement or possibly alkali aggregate reaction or other factors. The misalignment of the guide recesses create the issues of stick-slip operation and galling of the steel rollers and steel embedded guides. To resolve these issues, Nashville District have been using UHMWPE guides to replace their FMBs when funding is available.

i. UHMWPE guides can be cut in the shop by the contractor or can be cut in the field to provide ½ in. clearance between the UHMWPE guides and the embedded guides. Thickness of the UHMWPE guides are 2.5 in. They can be used for both circular FMBs and non-circular FMBs. See Figure 12–34.

Figure 12–34. Existing Chickamauga Lock – single-post floating mooring bitt with ultra-high molecular weight polyethylene guides, non-circular type

j. It is desirable to have double-post FMBs, spaced at levels to accommodate the height above water level of either loaded or empty barges. Usually, a vertical spacing of about 6 to 8 ft for the two posts will be required with the lower post being about 5.0 ft to 5.5 ft above the water elevation. A double-post or bitt system provides an upper bitt for larger commercial vessels and a lower bitt for smaller recreational vessels. See Figure 12–35. Also, a double-bitt system allows variance in barge height, depending on whether they are loaded or unloaded. The barge heights above the water level can vary up to 8 ft. FMBs are also useful in high head locks where there are large variations during the filling and emptying process.

Figure 12–35. Barkley Lock – double-post floating mooring bitt with ultra-high molecular weight polyethylene guides (new design)

k. Over time, the FMBs may float lower due to debris build up around the FMB surfaces. Therefore, it is recommended to design the FMBs to float higher than the required floatation. Steel ballasts can be added or removed to adjust the floatation of the FMBs. For some projects, a concrete extension or concrete parapet wall may be required to allow the FBMs to extend above the top of the lock wall. See Figure 12–36. The height of the concrete extension should be based on the maximum operating pool elevation and should not be more than 7 ft above the top of the lock. Single-post FMBs can be used if the double-post FMBs are not suitable due to the interference with the tow haulage rails or other factors. See Figure 12–37.

Figure 12–36. Olmsted Lock – floating mooring bitt concrete extension

Figure 12–37. Wheeler main lock – single-post floating mooring bitt with ultra-high molecular weight polyethylene guides

l. The wheels should be as large in diameter as practical with a minimum of 12 in. to resist high stresses from overloading and impact. Axles should be as large in diameter as is practical to resist bending. Stops (or feet) should be provided at the bottom of the floating mooring bitt to prevent the bottom wheel from striking the floor of the recess and bending the axles. Stops should incorporate rubber bumpers to cushion the impact.

12–12. Floating mooring bitt design loads and guidance

One trend in navigation is for the towing industry to use stronger lines, including synthetic lines. Synthetic lines are now used for checking and tying up the larger tows. This, in turn, has created the need for larger and stronger FMBs. The FMBs sometimes are used to help decelerate tows in the lock chamber. This puts additional stresses and loads on the entire floating mooring bitt assembly. The 2-in. synthetic lines now in use have a breaking strength up to 160,000 lbf, compared to the 31,000-lbf breaking strength of new 2-in. manila lines that were the criteria used for the original development of the FMBs.

a. Per EM 1110-2-2104, design load criteria for the floating mooring bitt should be a 53-kip usual load with a 2.2 design factor, an 80-kip unusual load with a 1.6 factor, or a 160-kip extreme load with a 1.0 factor. This should also be the design criteria for the floating mooring bitt.

b. Hawser load applies from 45° downward to 45° upward from the horizontal line.

c. EM 1110-2-2602 provides some additional guidance. All affected components of the floating mooring bitt should be designed for 160,000-lbf load or 712 kN at normal working stresses. This force is derived from the parting strength of a doubled line, reduced by a factor of 0.75 to account for unusual loading. Design the mooring bitts for deceleration of the tows in the lock chamber. The PIANC WG 106 Report also provides design guidance for FMBs.

d. One significant issue with FMBs is the tendency for them to stick during travel. This also is called stick-slip operation. Stick-slip operations result in unsafe conditions for the vessels using the lock. At Bonneville Lock, the mooring bitts started to stick almost immediately after the lock became operational in 1993. Several design changes were made, but the problem persisted until the FMBs were redesigned with greaseless bearings.

e. If greased bearings are used, aluminum bronze is recommended for wheel bushings because it will perform better under heavy axle loads than most materials readily available. Grease fittings should be provided for the lubrication of the wheel bushings and axles. Submerged wheels will require grease lines extending to the top of the tank. All grease lines should be in the interior of the tank to prevent damage to the grease lines from debris and ice.

f. Prior to early 2000s, there were several projects in Nashville District that had the stick-slip operation issue of the FMBs. This issue was caused by the misalignment of the FMB guide recesses as the result of concrete growth known as alkali-aggregate reaction and other factors. Using self-aligning, self-lubricated bearing/rollers or UHMWPE guides was considered as an option to replace existing rollers. See Figure 12–38.

(1) There were concerns that the self-aligning, self-lubricated bearing/rollers would not resolve the issue of stick-slip operation and galling between the rollers and embedded guides.

(2) Self-lubricated materials may become swollen when submerged in water and prevent the rollers from operating properly. In addition, self-aligning, self-lubricated bearing/rollers are more expensive than the UHMWPE guides. As the result, the decision was made to use UHMWPE guides to replace the guide and reaction rollers. The FMBs with UHMWPE guides have been in operation in Nashville District since 2007 without any issues. Thickness of each UHMWPE plate is about 2.5 in. and can be cut in the field to allow the clearance of 0.5 in. between the UHMWPE guides and the FMB recesses.

Figure 12–38. Cheatham Lock – ultra-high molecular weight polyethylene guides for floating mooring bitts

12–13. Floating mooring bitt advantages and disadvantage

a. Advantages:

(1) Minimizes and reduces labor for site staff. Vessels do not have to tie off to bollards or check posts on the lock wall. Reduces line handling for site staff.

(2) FMBs are at the same elevation as the water level in lock. This provides a more stable tie off as the lock is emptied or filled.

(3) They provide a level of safety to the personnel of the vessel and the lock because the FMSs float with the vessel.

(4) Can provide quicker lockage by reducing line handling.

(5) For high-head locks, it is generally safer to tie off to the FMBs than to the top of the lock wall.

(6) UHMWPE guides should be used for new FMBs or the replacement of the existing FMBs. UHMWPE guides can be custom-made in the field to provide the recommended 1/2 in. clearance between the guides and the FMB recesses the eliminate the stick-slip issue.

(7) UHMWPE guides are inexpensive and can be easily replaced.

(8) UHMWPE guides do not have galling issues with the embedded guides.

b. Disadvantages:

(1) Maintenance and upkeep of the floating mooring bitt system. The system requires more inspection and maintenance than the fixed bollards because of the mechanical parts.

(2) The FMBs can get stuck in the wall recesses when moving with the water level during filling and emptying of the lock chamber. When a ship is moored to such a floating bollard, this has potential life safety consequences and could capsize smaller recreational vessels. Mooring lines could snap. Also, the floating mooring bitt and rails can be damaged.

(3) The wear rate of the guide wheels has been an issue at various locks, specifically the lower wheels. They tend to diminish in diameter during use, especially if the material of the wheels is too soft.

(4) Although the mooring hooks are not designed or meant to decelerate vessel movement, they often are used as such. As a result, the hooks can break from the top of the assembly.

(5) The lubrication of the bronze bushings in the wheels has been an issue at some sites. It is a time-consuming and cumbersome job to lubricate all wheels regularly. Lubrication also can contaminate the waterway.

(6) Operation in ice conditions can be problematic. The FMB can be frozen in place.

c. Lessons learned. Optimize location and quantity of FMBs in the lock chamber. Provide a minimum of four floating bitts in chamber. Provide FMBs on both lock walls. The FMBs also need to be located near the lock gates for commercial tows.

(1) Provide FMBs for high-head, new lock construction and low-head, new lock construction.

(2) Double-post FMBs should be provided for all projects. Provide concrete extension as needed to allow the FMBs to extend above the top of the lock wall. Single-post FMBs can be provided as needed to avoid interference with the tow haulage rail or due to other factors. It is acceptable to have both double-post and single-post FMBs for the same project.

(3) Recess all components within the lock wall. A recess opening from 1.5 to 2.5 ft is recommended.

(4) The lower guide bars and embedded guides should be composed of stainless steel plate. Recommend the tank be composed of carbon steel (ASTM A572, Gr. 50) and be painted. Posts for new FMBs should be ASTM A519, Gr. 4130 HR, 10-in. diameter, thickness of 1.125 in. Posts with 8-in. diameter and 1.25-in. thickness is acceptable to accommodate existing FMB recesses.

(5) UHMWPE guides should be used in lieu of guide rollers and reaction rollers to prevent galling between the rollers and embedded guides. In addition, using UHMWPE guides can eliminate the stick-slip operation since guides can be custom-made to provide 1/2-in. clearance between the guides and the embedded guides.

(6) The top of the guides should be terminated in a yoke arrangement to assure that the floating mooring bitt cannot accidentally be propelled out of its recess by buoyancy. This arrangement also can provide a means of hoisting and storing the bitt out of the water when it is not in use. Locks with the top of their walls near the upper operating pool should have the guides extended above the wall to accommodate the floating mooring bitt.

(7) The location of guide wheels and rail anchors must be designed to prevent contact between wheels and bolts of the guiding structure. New wheels should be installed with enough resistance to prevent rapid wear.

(8) To decrease the maintenance on the rolling elements of the system, the wheels should be fitted with self-lubricating bushings. The material of the wheel shafts should be a hard stainless steel material.

(9) Provide sufficient fabrication and construction clearances to eliminate or minimize stick-slip operation.

(10) Install self-aligning and self-lubricating guide and reaction rollers.

(11) Minimize contact stresses on guide and reaction rollers. Keep stresses below manufacturer guidelines.

(12) Install self-lubricating thrust washers.

(13) Install self-lubricating guide plates.

(14) To prevent the bitt from being suddenly propelled upward because of sudden release after freezing or being jammed by debris, an automatic sinking device should be provided to permit the tank to fill with water. The water can be forced out later by using compressed air. The compressed air inlet connection must be extended above the lower pool when the floating mooring bitt is resting on the bottom of its recess.

Chapter 13
Inflatable Gates

13–1. Summary discussion

Inflatable gates provide an alternative to traditional steel gates. They are used throughout the world by the hydropower industry. Japan has been at the forefront of inflatable gate design and have their own design standards on these gates. However, in USACE, there is a lack of design guidance and design standards.

a. The designer should use the PIANC WG 166 Report for design criteria of these gates. The two main types of inflatable gates are a rubber gate (RG) and a rubber bladder supporting a pivoting steel plate, termed a steel rubber (SR) gate (see Figure 13–1). This terminology follows the PIANC WG 166 Report. The PIANC WG 166 Report also addresses where these gates have worked well and the limitations of these gates. The textbook “Lock Gates and Other Closures in Hydraulic Projects” (Paulus and Daniel 2018) also provides design criteria and details for inflatable gates.

b. RGs were developed and patented in the 1950s and 1960s. Firestone was one of the first companies to develop these, followed by Bridgestone. The SR gate was developed and patented by Obermeyer Hydro Inc. in the United States in the late 1980s. Inflatable gates perform a function like the traditional hinged crest gate used on navigation structures. Due to that, inflatable gates are often compared to hinged crest gates for cost, operation, and maintenance.

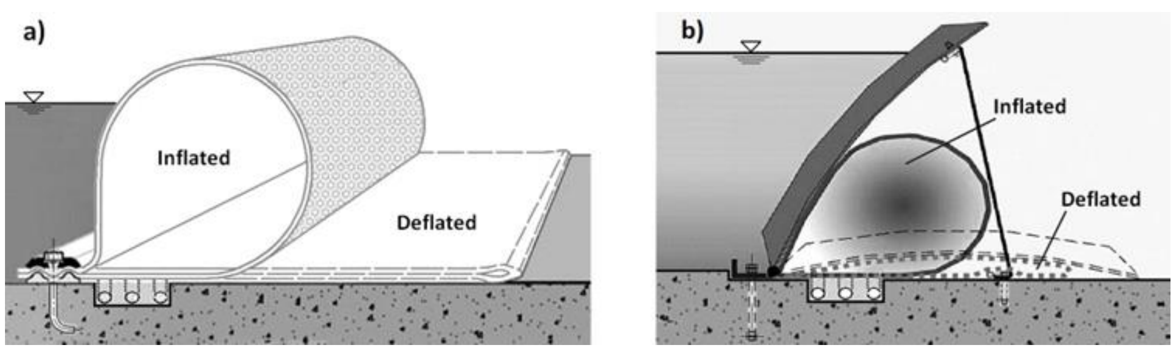


Figure 13–1. Two basic systems of inflatable gates: a) rubber gate and b) steel rubber gate (from Paulus and Daniel 2018)

c. Inflatable gates have some advantages over a traditional steel hinged crest gate. Painting requirements are minimized. They weigh considerably less than a steel structure and the foundation requirements are usually less. In general, these gates can be constructed off site, delivered to the site, and installed there using lighter equipment.

d. Traditional hinged crest gates are typically operated with hydraulic systems and hydraulic cylinders. This requires concrete piers and the supporting foundation and structure. Inflatable gates can span a much greater distance than a hinged crest gate system. Inflatable gates have been designed and constructed in sections over 100 m or 300 ft long.

e. Inflatable gates are operated with either water or air or a combination of both media. All these systems have worked well, and each have advantages and disadvantages. The water-inflated gates are less suited for operation in regions of extreme cold. As a rule, inflatable gates have a shorter design life over a traditional steel hinged crest gate. Under normal conditions, a typical design life for a RG is 30 years. The gate bladder is usually composed of rubber matrix and nylon or polyester (occasionally aramid) fabric. At present, the most suited rubber grade is ethylene propylene diene monomer (EPDM).

f. One primary use of inflatable gates is for small and medium size, run-of-the-river, hydroelectric plants. The inflatable gates are often RGs and are installed to replace older flashboard systems, or to increase the depth of an impoundment and provide crest control. (See Figure 13–2.)

g. At these facilities, the gate is fully inflated most of the time, while the pool elevation is controlled by turbine settings. Inflatable gates at hydropower structures have generally worked well at passing ice and debris. The bladders also need to be designed so they can be in sunlight for many years. Ultraviolet light accelerates the aging of rubber. Insufficient attention to this can cause early deterioration of the rubber.

Figure 13–2. Rubber gate of the Palmer Falls hydroelectric plant, New York

h. The primary disadvantage of RGs is a lack of standards, design, and other guidance worldwide. The Japanese Industrial Standards (JIS) offer one of the few formalized sets of design rules for these gates. However, the various inflatable gate manufacturers have developed standardized design criteria and manufacturing methods. Table 13–1 is taken from "Lock Gates and Other Hydraulic Closures" and provides a summary of inflatable gate installations.

Table 13–1
Partial list of dam sites with large inflatable gates from "Lock Gates and Other Hydraulic Closures in Hydraulic Projects"

Dam Site	Location	No. of gates x L [m] x H [m]	Construction year	System – inflating (RG/SR – air/water)
Rampsol Barrier	Kampen, Netherlands	3 x 60.0 x 8.20	2002	RG – water and air
Villers Dam	Villers d. Mouzon, France	1 x 17.7 x 2.10	2005	SR – air, 3 bladders
Auxonne Weir	Auxonne, France	3 x 52.5 x 1.40 1 x 46.5 x 1.40	2010	SR – air 8 bladders in gate
Alès Dam	Gard, France	1 x 23.0 x 1.50	2002	RG – air
Lechbruch Dam	Bavaria, Germany	3 x 45.83 x 1.10 1 x 24.75 x 3.15	2002	RG – water
Kiebingen	Tubingen, Germany	2 x 23.0 x 3.40	1998	RG – air
Wertach Dam	Türkheim, Germany	2 x 16.0 x 3.70	1998	RG – air
Oberhofer Dam	Bayern, Germany	1 x 22.0 x 2.30	2001	SR – air, 8 bladders
Marklendorf Weir	L. Saxony, Germany	2 x 23.6 x 2.20	2006	RG – water
Bahnitz Dam	Brandenburg, Germany	2 x 30.3 x 2.40	2007	RG – water
Bannetze Weir	L. Saxony, Germany	2 x 21.0 x 2.35	2009	RG – water
Pocaply Dam	Czech Republic	1 x 21.0 x 1.60	1998	RG – water
Naruse Barrier	Miyagi, Japan	3 x 42.1 x 2.30	1984	RG – air
Kurotani Dam	Okayama, Japan	1 x 35.0 x 6.00	1990s	RG – air
Nanming R. Dam	Guiyang, China	1 x 60.0 x 8.00	2015	SR – air, 6 bladders
Lake Traverse Dam	Minnesota, USA	1 x 27.0 x 1.50 1 x 5.90 x 2.20	2000	SR – air
Saylorville Lake	Iowa, USA	43 x 130.0 x 1.82	2012	SR – air, 43 bladders
Coon Rapids	Minnesota, USA	2 x 96.0 x 2.4 1½ x 45.8 x 2.40	1990s	RG – air (these gates have now been removed and replaced with hinged leaf gates)
Tempe Town Lake	Arizona, USA	4 x 67.0 by 4.80	1999	RG – air (now removed and replaced with hinged leaf gates)
Nine Mile Dam	Washington State, USA	1 x 67.0 by 3.00	2010	SR – air, 14 bladders
Adam T. Bower	Pennsylvania, USA	6 x 91.4 x 2.44 1 x 57.0 x 2.44	1966, 1988	RG – water and air, since 1988 only air
Highgate Falls	Vermont, USA	1 x 67.0 x 4.60	1994	RG – air
Palmer Dam	New York USA	105.4 x 1.83	2001	RG – air, in 2 parts

Dam Site	Location	No. of gates x L [m] x H [m]	Construction year	System – inflating (RG/SR – air/water)
Curtis Dam	New York USA	3 x 63.6 x 1.20 1 x 20.4 x 2.10	2001	RG – air
Rainbow Falls	Montana USA	2 x 76.2 x 3.60	1992, 2013	RG – air
Friant Dam	California, USA	2 x 61.0 x 5.50	1998	SR – air
Rock Falls Dam, Sinnissippi	Illinois, USA	4 x 29.1 x 3.20 3 x 14.5 x 3.20	2002	SR – air bladder length 4.88 m

13–2. Rubber gates

An RG consists of a tubular, inflatable bladder made of a single or multi-layered synthetic fiber fabric, typically rubberized on one or both sides. Multiple fabric layers increase the strength of RGs. A typical RG cross section can be 60 mils construction and up to 24 mm thick, depending on design conditions.

a. The rubber bladder is anchored to the spillway crest at the upstream edge and at the side walls. See Figure 13–3, Figure 13–4 and Figure 13–5 below. This is accomplished by a series of anchor bolts and plates clamping the folded edges and ends of the bladder together. Within limits, changing the pressure in the bladder can change its height and control the upstream water level. When deflated, the rubber bladder flattens against the crest of the spillway. When used as flood barriers, the deflated bladders can be folded in shallow recesses, which provides protection against damage from debris and from ships and other vessels. The PIANC WG 166 Report provides additional details of the anchoring systems for RGs.

b. RGs are low-pressure systems and have typically been filled with air or water. One of the first RGs was the so-called “Fabridam,” developed in 1956 by Norman Imbertson, Chief Operations Engineer in the Department of Water and Power of the City of Los Angeles, USA. The Imbertson gate, patented in 1965, was water and air filled. Early inflatable gates used water as the filling medium.

c. After the installation of the first Bridgestone gates in 1978, air-filled systems were more prevalent. In the recent decades, however, water-filled gates are being used more often, especially in Germany (see Figure 13–3). Their major advantage above the air-filled gates is a better, more stable behavior, particularly in case of pressure drop or incidental local loads. A water-filled gate does not tend to form the so-called “V-notch,” which the air-filled gate does. An advantage of the air-filled gates is their buoyancy that helps raise the gate, reducing energy consumption and the required strength of the bladder.

d. Changing the pressure in the bladder controls the depth of the upstream water pool. Roughly speaking, providing the pressure equal to the upstream water head should keep the system in equilibrium and allow damming the flow. However, if the downstream side is dry, the pressure in the bladder needs to be about 20 to 60% higher than the carried water head. This is to compensate for tensile anchoring reactions and bladder weight. The PIANC WG 166 Report and textbook “Lock Gates and Other

Closures in Hydraulic Projects” (Paulus and Daniel 2018) provides additional discussion and criteria.

e. The rubber material and its reinforcing fabric must be resilient enough to resist ice loading and debris impact. The rubber provides air and water tightness while the fabric provides tensile strength. Typically, the sheet will include several alternating layers of rubber and either woven fabric or crossed-fabric cords. Manufacturing a rubber membrane requires large-scale rubber vulcanizing equipment, usually an autoclave or heated press machine. Material handling is important since space is required to assemble the sheet and a completed membrane may weigh more than 20 tons. Time is also a consideration since a large sheet may take several weeks to produce.

Figure 13–3. Bannetze Dam water filled rubber gate in Hannover Germany

f. Each inflatable gate manufacturer has their preferred method of vulcanizing rubber sheets. Many of the gate manufacturers focus on membranes for rubber dams and use vulcanizing press machines. SR gate bladders are usually smaller and are more typically vulcanized in an autoclave. Some manufacturers employ both methods, selecting the appropriate method depending on size, application, and individual preferences. The correct arrangement of vulcanized joints is in the gate lateral direction, which does not expose them to large tensile loads.

g. RGs need to be designed with nappe breakers or flow splitters on top of the gate to prevent vacuum formation and, ultimately, vibrations of the gate. These breakers and splitters may have different forms, varying from protruding seams with toothed edges to specially designed flow-breaking corbels, vulcanized to the bladders. Examples of these details are seen in Figure 13–4.

Figure 13–4. Rubber gates with flow breakers: a) toothed seam at Highgate Falls gate, Vermont, United States; b) flow-breaking corbels at Marklendorf rubber gate, Germany

h. The Highgate Falls dam shown in Figure 13–4 is part of a 9.8-MW hydroelectric plant. Its RG, manufactured by Bridgestone, regulates pool elevation and is 4.6 m high and 67 m long (15 ft by 220 ft). The plant is owned by the village of Swanton, Vermont, on the Missisquoi River.

i. The RG at Highgate Falls is one of the tallest in the United States and is accessible for inspection and maintenance at one side. Annual inspections are conducted every August. It was one of the first RGs in the world to have a pressurized hatchway, allowing dam operators and maintenance crews to walk inside. Overall, this RG has worked well with few O&M problems. The inflatable gate experiences severe icing conditions in the winter and works well for passing ice and debris.

j. The Marklendorf Dam gates work together with a similar weir at Bannetze, and controls the navigation conditions on the Aller River, a tributary of the Wezer in Germany. Shortly after going into operation, the RGs experienced vibration problems under high flows. The installation of flow-breaking corbels in 2008 entirely removed this problem. These gates also provide evidence that water filling can be applied in the areas of relatively cold winters, as the winter temperatures at this location can drop below zero Fahrenheit.

k. The Coon Rapids Dam RGs shown in Figure 13–5 and Figure 13–6 were some of the largest RGs in the United States. Coon Rapids Dam is located on the Mississippi River within the Minnesota (United States) counties of Hennepin and Anoka. The dam divides the two counties. There were multiple O&M issues with this installation since the air-inflated RGs were first installed in 1995 by Sumitomo Electric Industries, Ltd. Eventually the RGs were completely replaced with steel hinged crest (flap gates) in 2013 and 2014. The complete case study is provided in the PIANC WG 166 Report.

Figure 13–5. Old Coon Rapids Dam rubber gates on Mississippi River

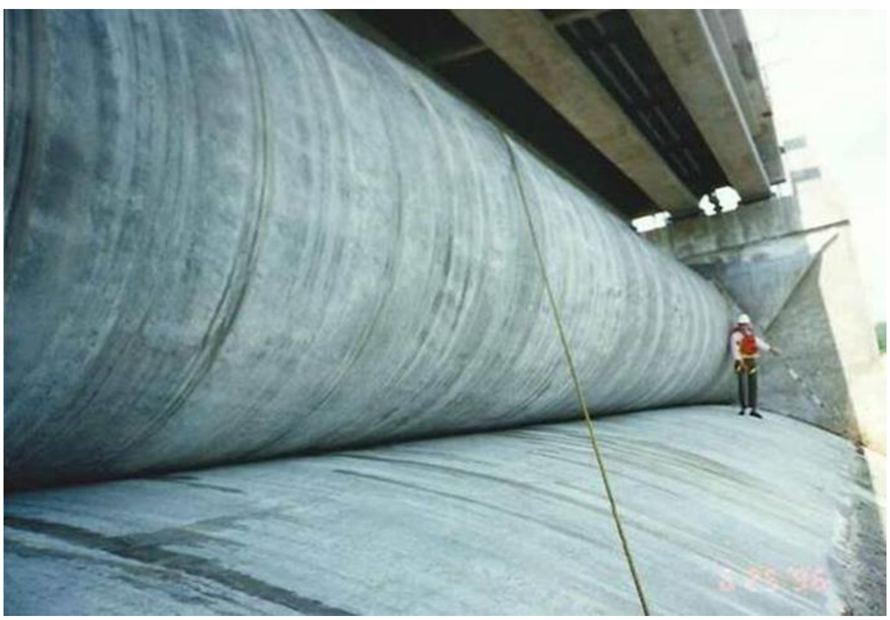


Figure 13–6. Coon Rapids rubber gate (Sumitomo) shown during an inspection of rubber bladder in 2006

l. Another major application of RGs is in flood and storm surge barriers. The most prominent example is the Netherlands' Ramspol Barrier with its three world's tallest RGs. (See Figure 13–7.)

m. The Ramspol project was thoroughly engineered using different finite element models, supported by physical model investigations. It not only proved the RG's fitness for purpose in this field, but it also delivered much expertise about the behavior of the bladder and other components under extreme conditions. These conditions included the actual operation during storm surges and the complex folding of the bladder in bottom recess. Details of the design and design process are included in the PIANC WG 166 Report.

n. The Ramspol gates are filled with water (about 2/3) and air (about 1/3). Such an arrangement increases the dam stability and gives a better control of its shape. The probability of freezing while the gates are operating is negligible.

Figure 13–7. Ramspol Storm Surge Barrier rubber gates, Netherlands, test closure photos Rijkswaterstaat

o. The RGs in the Ramspol dam are inflated by pumping a fixed volume of air; and then water is let in from the upstream side. For deflation, air is let out and the water is pumped out. This is done simultaneously to allow the rollers of dam storage system to get the rubber sheet in the right position. In the standby position, the Ramspol gates are stored in a bottom recess, and therefore, not exposed to UV light and large temperature differences.

p. The primary disadvantage with RGs is the potential for damage to the bladder itself. There is no metal or other plate to help protect the bladder. Debris in the water can potentially impact and puncture the bladder, which may cause leakage and, ultimately, the loss of stability of the entire dam. This is since RGs are usually built of one continuous bladder rather than multiple individual bladders.

13–3. Steel rubber gates

An SR gate is a newer type of gate developed in the late 1980s by Obermeyer Hydro Inc., an American company from Wellington, CO. There are few SR gate manufacturers in the world. The SR gate consists of a tubular rubber bladder supporting a straight or arced pivoting steel panel. Both the rubber bladder and steel panel are secured to the spillway crest; the first by a clamping and the second by pivot anchoring. The PIANC WG 166 Report also provides detailed design considerations for these gates.

a. The rubber bladder is located on the downstream side of the steel panel and is inflated and deflated to rotate this plate upward and downward. The bladder is inflated and deflated in a similar manner as the RGs described above. Air is primarily used as the filling medium for SR gates. Rubber restraining straps attached between the top of the steel panel and the ogee crest structure are used to prevent over-rotation of the panels. Typical installations consist of multiple steel panel leaves or sections supported by one or more bladder sections (Figure 13–8).

Figure 13–8. Typical steel rubber gate, Saylorville Lake Dam, Iowa

b. The segmenting of the SR gates has many advantages that the conventional, continuous RGs do not have. The primary advantage is that if one bladder is damaged, the other bladders will continue to operate. This segmenting also requires attention to some additional issues. One is that the gaps resulting from unequal angular positions of the panels can trap debris. This can make it difficult to bring the panels back in line.

c. To overcome unequal positioning of the panels, a unique design was incorporated into the Auxonne dam on the Saône in France, shown in Figure 13–9. The panels are designed to elastically fix all steel panels to each other with wire rope to guarantee a straight top edge under all conditions as shown in Figure 13–9b. A potential advantage of such a choice is also its lower vulnerability to pressure differences in bladders, friction differences in panel pivoting, and other irregularities. The wire rope connections between the steel panels ensure that if a rubber bladder fails, its steel panel will still be supported by the panels next to it.

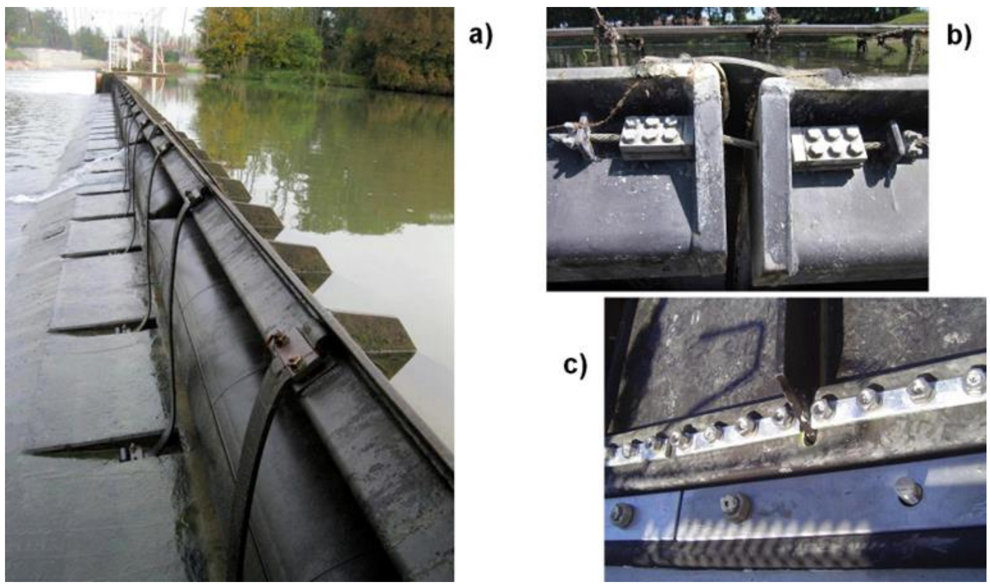


Figure 13–9. Steel rubber gate of Auxonne Weir on the Saône, France: a) view on weir in operation; b) panel fixing on the top edge; c) anchoring of the bottom edge (photo credit to Van Ness Feldman)

d. Figure 13–9c shows an anchoring detail of the bottom edge in the Auxonne dam gate during assembly. Note that the rubber sheet of the gate bladder is water and airtight, fixed to both the concrete sill (lower anchor bolts) and the gate steel panels (upper bolts). In this way, no additional seals were required to seal the panel bottom edge.

e. The filling and emptying system for SR gates and RGs is similar. Air-inflated RGs use blowers or compressors. Water-inflated gates use pumps. Piping is generally embedded in the concrete spillway, so there is a risk for air leakage (or water leakage in water-filled RGs). Correct installation should also make sure that joints do not leak air out or leak water into the system. The gate needs to be tested for leaks before burying or embedding. These systems operate generally in low pressure, and pressure in the piping can be less than the outside water pressure.

f. For SR gates, sections are normally placed side by side. There are seals between the metal panel sections to prevent leakage. Although the design of the rubber bladder is like a RG, the overall design of a SR gate is substantially different than for a RG.

g. The steel plate of the panels is typically equipped with vertical ribs for structural rigidity. Restraining straps fastened near the top of the panels and extending down to the crest or floor on the downstream side are used to prevent the panels from completely rotating. The bladders are protected by the panels. SR gates are also designed with nappe breakers or flow splitters on top of the gate to prevent vibration.

h. On a steel RG, periodically, very small differential head conditions combined with reverse prevailing winds or water chops have been known to snap the restraining cords and push the steel panels over backward. This is a point of consideration in detailed design and was an issue at Reservation Highway Dam in Minnesota. See Figure 13–10. Another point is that, in general, an SR gate does not perform in dynamic ice conditions, as would a traditional massive steel structure with massive hoist equipment. However, there are multiple RGs (without a steel panel) in operation in cold climates. This is the case in both the northern United States and northern Europe. The rubber can deflect and absorb ice impact better than a steel structure.

Figure 13–10. Reservation Highway Dam, Minnesota, steel rubber gate

i. In the range of large heights, larger than about 6.0 m, SR gates driven by single bladders may become uneconomical. Wide bladders also occupy much space in the dam crest or sill. This space is not always available. The solution is to stack the bladders on top of each other, which saves both material and space. In addition, the compressed air volume is then much lower, and raising and lowering of the gate requires less energy. Disadvantages are higher pressure and more complex arrangements of the piping and other systems, factors that usually increase the probability of failure.

j. Ice can be a concern for SR gates needed for winter operation. The steel plate can become ice covered, which can increase the loading on the rubber bladders. The gate panel also has potential for becoming frozen in ice. Again, both mixers and air bubblers can be used to limit ice formation.

k. Electric heaters can also be used on the steel panels. A recommended sizing of electric heaters is to provide 20 watts/ft minimum. The designer should evaluate the need for a higher rating under extreme cold weather conditions. The system consists of heating elements and heating cables. Heating cables should be self-regulating type. Electrical junction boxes should be used to the extent possible. It is recommended to provide multiple junction boxes with embedded conduit.

l. UHMWPE abutment plates and skin plates can also be used in freezing conditions. Ice does not adhere to the UHMWPE plates. This prevents the gate from freezing.

13–4. Mechanical and electrical design of inflatable gates

Mechanical and electrical systems are important components of inflatable gates. They provide the means for inflating, deflating, and controlling these types of gates. From a mechanical and electrical perspective, the operation of an SR gate or an RG is essentially the same. The primary difference is that RGs are typically one large air bladder whereas SR gates typically consist of multiple bladder sections (and the associated steel panels).

a. The multiple rubber bladders of an SR gate can present problems in terms of level and height control and ensuring all the bladders are inflated to the same height. See Figure 13–11. The SR gate also has more components including the steel plate, rubber bladders, restraining strap, and the seals between bladder sections and the plate.

b. The components of an air-filled system are straightforward and consist of air blowers or air compressors, control valves, and piping. Water-filled systems are generally more complicated and require pumps, as opposed to compressors or blowers. The electrical control systems are similar between air-filled and water-filled systems. New installations typically incorporate PLCs. Also, remote operation of inflatable gates is often used, especially at hydropower sites.

c. Pressure requirements are generally very low for RGs, and hence, air blowers are typically used. SR gates will generally have higher pressure requirements and will typically use compressors. Both SR gates and RGs incorporate automatic deflation systems. Safety equipment (such as a countermeasure to prevent an inflatable gate from overpressure and a mechanical deflation system) are essential.

d. The cycle times of the air blowers or compressors need to be calculated and minimized. The overall air volume of the rubber bladders needs to be considered and factored into the receiver size. If the receiver tank is properly sized, it will prevent rapid cycling of the compressor or blower. The manufacturer can provide calculations for sizing the system including blowers, compressors, receivers, and piping.

Figure 13–11. Steel rubber gate – Lawrence Dam

e. A receiver tank should be provided for each blower or compressor although a common receiver tank will also work. This will help limit the starting and stopping of the blower or compressor. Some RG applications have not used a receiver tank although this is not common. A single or common receiver tank connected to a manifold system allows more redundancy if one blower or compressor is offline or malfunctions.

f. A typical air blower or compressor should be limited to a maximum of 10 starts per hour. For sites that use multiple blowers or compressors, there needs to be equal operating time on all blowers and compressors. The control system (Figure 13–12) should be designed to do this and provide alternating sequence of operation. The operating time to fully inflate air bladders in either an SR gate or RG should be 20 to 40 minutes under normal conditions and 60 minutes maximum.

g. A faster inflation time is usually not necessary since the mechanical and electrical system will be oversized and the cycle times will be affected. The deflation time will be affected by the size of the exhaust valve. In emergency situations, an inflatable gate should be designed to deflate very quickly (under 5 minutes).

h. An example of an emergency could be a ship or vessel impacting the gate or a breech or failure of a hydropower dam. However, in practice, the overall deflation time is set the same as the inflation time. Methods to calculate inflation and deflation time should be provided from the manufacturer. The major compressor and air blower manufacturers also provide sizing calculations for their equipment. Most manufacturers will have computerized sizing calculations.

Figure 13–12. Operation Panel – Palmer Dam, Illinois

i. There are some other considerations for determining the overall pressure requirement. This includes the length of the supply and return lines. An extremely long supply and return line may add significantly to the pressure loss. An RG is normally designed with larger supply and return piping then an SR. This is because an air blower is limited in pressure and high-friction losses in the piping system will affect the selection of the air blower. As a guideline for air blowers and RGs, limit any piping friction losses to 6.8kPa (1 psig). This will typically require piping sizes at least 101 mm (4 in).

j. SR gates operated with a compressor will have much more pressure to work with and the piping friction losses are not as much of a concern. An SR gate will typically have 51-mm diameter (2-in.) supply piping (Figure 13–13). Longer pipe lengths may require large diameter piping. Again, the SR gate manufacturer will typically provide sizing calculations for the piping system.

Figure 13–13. Rubber gate air blowers, supply piping, and manifold – Curtis Dam

k. It is recommended to install all mechanical and electrical operating equipment in a heated and climate-controlled building. The heating, ventilation, and air conditioning (HVAC) system for the operating building needs to account for all the equipment operating. Both air blowers and air compressors generate heat during operation. The building space requirements will normally be less for air inflated equipment as opposed to water inflated gates.

l. Flexible connections should be provided to the air compressors or air blowers to account for vibration. For supply and return piping, stainless steel material is recommended. The designer should use ASTM Type 316 (A4) stainless steel to minimize any corrosion issues. For stainless steel, it is also important to consider any galvanic corrosion potential with any steel components.

m. Proper installation of pipe joints is critical to minimize not only air leakage but to prevent water infiltration during deflation of the rubber bladder(s). Some sites have used high-density polyethylene (HDPE) with success, and this can also be considered (Auxonne). Whether HDPE or stainless steel piping is used, the pipe system should have a minimum life expectancy of 50 years. For any piping exposed to sunlight and installed outdoors, stainless steel piping is recommended.

n. Supply pipe manifolds should be included (Figure 13–14). Check valves should be included in the design to prevent backflow into the air blower and manifold. Means to address water intrusion into rubber bladders must be accounted for in design. Piping is generally embedded in the concrete spillway. There is a potential for air leakage, and joints can leak air out or leak water into the system. The installation of the piping system must be done correctly and should be tested for leaks before burying or embedding.

o. RGs are typically very low-pressure systems and pressure inside the pipe system can be less than the pressure of the column of water on top of it. Entrained water should be periodically purged. Depending on the climate, the system may need to be winterized by adding recreational vehicle antifreeze to deal with entrained moisture. One solution is to use piping galleries. However, this greatly increases the cost of the system.

Figure 13–14. Rubber gate supply piping – note check valve

p. The designer should determine the need for emergency generator backup power and evaluate the reliability of the utility power supply. It is recommended that an emergency generator be provided for navigation and hydropower applications.

q. The electrical power requirements of inflatable gates are typically small and small generators can be used (under 100 kW). An automatic transfer switch (ATS) is recommended on all installations, so power is automatically transferred to the generator. Silencers should be provided that limit sound level of blowers and compressors to 70 dba.

13–5. Rubber gate mechanical design

Air blowers, as opposed to compressors, are typically used for low-pressure RG applications. Air blowers generally provide more volume but are limited in pressure output. Air blowers are typically limited to 82 kPa (12 psig) pressure. Thus, friction losses in the piping system have to be minimized. It is recommended to provide at least 2 air blowers for redundancy.

a. RGs are normally inflated by high-volume, low-pressure blowers and are emptied through exhaust valves. The gates can be deflated to pass flood flows, to drain the pool, or to bypass flow during hydro-turbine shutdowns (hydro plant installations). An automatic control system typically operates the blowers and exhaust valves to maintain a set pool elevation or a set air pressure inside the gate.

b. The means of limiting overpressure in an RG application is typically a relief valve near the air blower. The control system can also be designed to monitor the air pressure inside the bladder. Air blowers will also bypass air once they reach their maximum pressure capability. That is an advantage of an air blower over a compressor (Figure 13–15). The blowers and exhaust valves should also be capable of manual operation.

c. Generally, air dryers are not necessary for RGs because of the larger diameter piping and the overall larger size of the bladder (able to accommodate more water). However, the RG manufacturer should provide the final guidance. Some RG manufacturers provide a condensate drainage system.

d. The actual air pressure requirement will depend on water height. Most RG installations are less than 3 meters in height. As such, the internal air pressure is low, varying from about 7 to 55 KPa gauge. A 4-meter-high RG (Highgate Falls) operates at approximately 41kPA pressure.

e. Some RG installations allow access inside the dam (Ramspol and Highgate Falls). For these applications, it is critical that confined space requirements be followed. In the United States, OSHA governs these standards.

Figure 13–15. Air blower and receiver for rubber gate (Highgate Falls)

13–6. Steel rubber gate mechanical design

Rotary screw compressors should be used for high-pressure SR gate requirements. Rotary screw compressors are more efficient and more suited to the requirements of SR gates than a reciprocating compressor. The rotary screw compressor should have modulation control, a low sound enclosure, and be a packaged unit (Figure 13–16). This will facilitate the installation of the compressor system. Filters should be provided for general clean-up of fine and bulk contaminants that may be present in the compressor system. The filter is normally mounted after the air dryer unit, with quick disconnects on both sides and ball valves to shut off and reroute air supply for servicing.

a. Ice loading may have to be accounted for on an SR gate, since it can add to the pressure requirement. Obermeyer typically uses a 1,500 lb per lineal foot ice line load (21.8 kN/m) load condition. This is applied 152 mm (6 in.) below the top of gate panel.

b. Maintaining equal air pressure in all the rubber bladders is especially an issue with SR gates. There should be separate inflate lines and deflate lines on SR gates.

Figure 13–16. Rotary screw compressor, Auxonne Dam

c. Air dryers need to be provided for SR gates to limit moisture inside the gate. Normally these are the desiccant type. The rubber bladders on SR gates are smaller, and the supply and return piping is smaller. Also, the pressure is higher, requiring dryer air. One dryer per compressor or blower should be provided.

d. There needs to be an intake filter and another filter on the exhaust side for each air dryer. Air dryers should be sized for the full capacity of the air compressor and should have a digital control system. Dew point monitors should be included as part of the air dryer package. Purge valves should be used to purge any water in the pipe system if the air dryer malfunctions. These need to be installed at the low point of the piping system.

13–7. Water-inflated gates mechanical systems

Water-filled RGs have some advantages over air-filled RGs but also some drawbacks. Generally, in water-inflated RGs, the extraction of water is taken upstream of the weir and is then directed via piping into an intake shaft. A filling pump then draws water from the intake shaft into the control or regulating shaft.

a. The water pressure inside the bladder is created according to the principle of communicating vessels. A water column located in a regulating shaft is connected to the bladder by a pipe (inlet pipe). The height of the water column in the regulating shaft determines the inner pressure, and consequently, the height of the inflated bladder (see Figure 13–17).

b. The regulating shaft and accordingly the bladder are filled by pump(s) that are controlled by sensors located at the upper edge of the regulating shaft. The filling pump(s) are fed from a supply shaft generally connected to the upstream side by a feed pipe. The RG is inflated by filling the regulating shaft. As soon as the pressure inside the bladder exceeds the total of external forces (rubber weight, water load), the bladder starts inflating.

c. The height of the regulating shaft is set by a servo drive. The high position of the regulating shaft means maximum water pressure in the bladder, provided the filling pump has filled the shaft to the edge. Reducing the height of the water column in the regulating shaft decreases the height of the RG. To measure the discharge volume overflowing the RG with the highest possible accuracy, the sensor calculating the discharge volume must be located close to the RG on the upstream side.

d. The physical relation between upstream and downstream water level, discharge, and inner pressure is more complicated than an air-filled RG. The designer should use the PIANC WG 166 Report for specific design requirements.

e. The pump requirements are like air blowers or air compressors. It is recommended to provide multiple pumps for redundancy, and there needs to be equal operating time on pumps. Pressure requirements are typically low. Dry-mounted centrifugal pumps are often used as filling pumps.

f. Even in normal mode, the water demand of filling pumps may vary greatly. Therefore, it is recommended to provide VFDs to operate the pumps. This allows the flow rate of the pumps to vary according to the actual demand. The piping requirements are nearly the same as for air inflated RGs. Both stainless steel piping and HDPE piping have been used with success.

g. Water circulation in the inflatable structure is needed occasionally to remove the stagnant water and for operation in cold weather conditions. To ensure this function, a separate pipeline is necessary. Sometimes, it is no circulation at all, but a slight deflate of the rubber dam and a refill with “warm” water provided from the bottom of the upstream pond or lightly heated in the entrance slot.

Figure 13–17. Water inflated gate – pumps and supply piping – Marklendorf Dam, Germany

13–8. Control and automation

The control system for air-inflated structures is critical for proper operation. A computerized PLC is recommended to control the inflation and deflation of the inflatable gate. The PLC can monitor water levels and adjust the height of the inflatable gate accordingly. The control systems are similar for SR gates and RGs. For new installations, it is recommended to use touch-screen control panels.

a. The electrical control equipment and control cabinet should be installed in a heated and enclosed building. A typical control system is PLC-based and requires a heated and climate-controlled building.

b. The PLC monitors the status of the blowers, valves, sensors, inner pressure, and water level; annunciates alarms on an alarm graphic screen on the computer; and annunciates on an alarm panel in the operator control room. The operator can reset any alarms and troubleshoot the problem. For new installations, it is recommended to provide SCADA. The capability of remote control should be provided.

c. A typical system for an air-inflated dam will consist of a water level sensing pipe, a pressure sensing pipe, and an inflation/deflation pipe. There should be multiple safety devices to prevent over-pressurization of the rubber bladder. Several control valves are recommended. Pilot-operated solenoid valves should be provided on both the inflation and deflation piping (Figure 13–18).

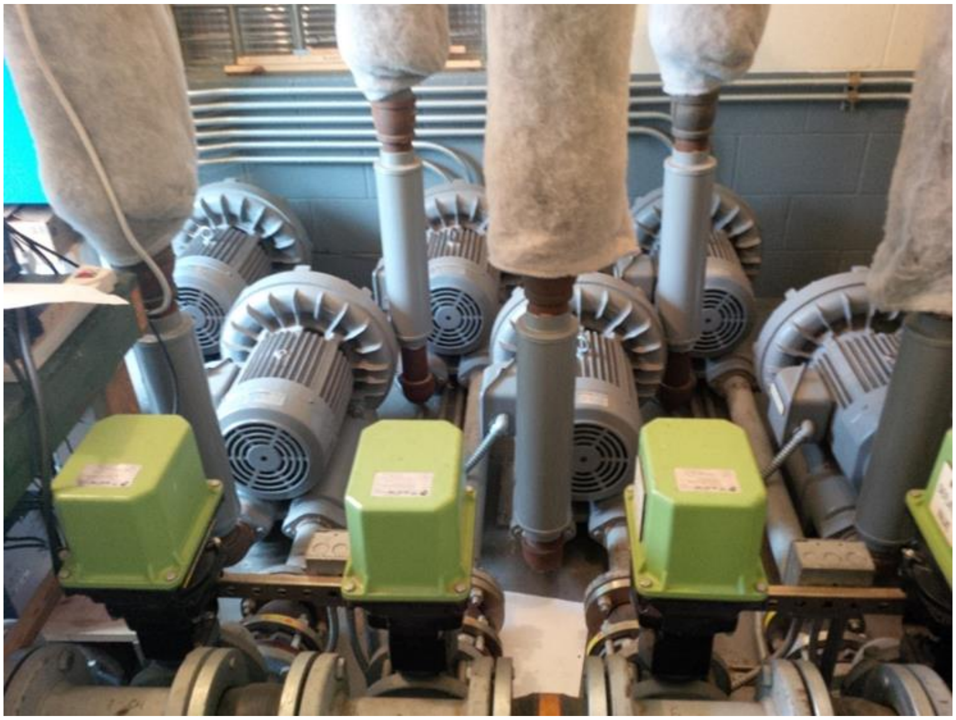


Figure 13–18. Air blowers and solenoid valves – Adam T. Boyer Dam

d. The system should be designed to accommodate flooding conditions and provide automatic deflation if necessary. The control system for an inflatable gate is typically provided by the manufacturer. This includes the computer screens, PLC system, and control wiring. Inflatable gates for hydropower applications will often have a different control system than an inflatable gate for flood control or for navigation (Figure 13–19).

e. For hydropower applications, the gate is normally kept inflated most of the time. For navigation projects, the gate could be kept in both inflated and deflated modes depending on river conditions. It is important that the proper control system be provided for the application.

Figure 13–19. Bridgestone control panel, Highgate Falls

13–9. Steel rubber gate control

SR gates can be operated manually or by a computerized PLC system. Water level sensors are often located on the upstream side of the gate. The incoming signal is then scaled by the PLC and displayed on the human machine interface (HMI) touch screen. This signal is also used by the PLC program to determine the position/elevation of the gate and regulate the position by opening/closing the inflation and deflation valves.

a. SR gates can have discharge control with an inclinometer on the gate. The idea is to measure the gate angle and then measure the discharge volume. However, the Auxonne Dam has had issues with the discharge formula. The need is to maintain equal crest elevation, which is especially an issue for multiple rubber bladders on the SR gates.

b. It is recommended to use multiple inclinometers and then have the computer system compare readings. An alarm can be provided that will signal if the inclinometer readings differ from a preset value. SR gates should be designed to maintain equal crest elevation across the dam within 50 mm (2 in.) under overtopping conditions.

c. SR gates are typically controlled pneumatically. See Figure 13–20. The pneumatic control system provides the automatic water level control. A PLC should be provided for the system. The PLC communicates directly with the pneumatic control system. The PLC should measure the upstream water level with a transducer. The PLC then operates inflate and deflate solenoid valves to raise or lower the gate sections in response to changing upstream water levels. It is recommended to provide at least two gate position indicators for measuring the position of the SR gate. This will provide redundancy. Gate position sensor should be electronic that provides a 4 to 20mA signal that is linearly proportional to the angle of the sensor.

d. For SR gates, there should be three water level sensors. This includes the upstream pool level, the downstream pool level, and a water level sensing well. Each air bladder should have a transducer and a position sensor.

e. The SR gate can maintain a constant crest elevation or maintain a fixed water depth over the dam. By controlling the air pressure, the design of an SR gate allows control of the crest elevation at virtually the whole height of the dam.

Figure 13–20. Pneumatic control system – Auxonne Dam

f. An automatic deflation system should be included in the design. A deflation float valve can act as safety measure in case the control system fails to deflate the bladders automatically. The float valve can be mounted in a stilling well.

g. A transducer or bubbler system must monitor high water conditions. If the PLC is offline or no operators are present, the system should not allow any operation of the SR gate. Alarm signals should require manual reset for the operator to verify and diagnose the problem. O&M manuals are critical for the proper functioning of the system and should be provided by the manufacturer.

h. A summary of equipment as follows:

(1) Receiver tank – from compressor.

(2) Inlet pressure transducer – reads inlet pressure to bladders.

(3) Set pressure regulator – reduces pressure from compressor.

(4) Inflate solenoid – used with PLC to control the gates – normally closed.

(5) Inflate bypass valve – used to inflate the air bladders – isolates inflate solenoid.

(6) Deflate solenoid – normally closed and pilot operated.

(7) Deflate bypass valve – used to deflate the bladders – isolates deflate solenoid.

(8) Inflate header pressure transducer – measures air pressure in the inflate header.

(9) Deflate header pressure transducer – measures air pressure in the deflate header.

(10) Solenoid operated pneumatic valve – between inflate and deflate headers – allows pressure equalization between the different air bladders.

(11) Accumulator isolation valve – used for maintenance to switch out solenoid valves.

(12) Accumulator tank – allows stable volume of air for the solenoid valves.

(13) Pressure relief valve – protects air bladders from over-pressurization.

13–10. Rubber gate control

For RGs, several modes of control are common, including: upstream water level control, pressure control, and manual. Like an SR gate, a computerized PLC can be used with HMI screens. The control system should be programmed to recognize whether V-notch or no V-notch is being used. A summary of the typical control systems as follows:

a. Manual control. Inflation/deflation of a rubber dam is accomplished by operating the pull/push buttons on the front of the control panel to either start/stop a blower or open/close a deflation valve. If a flood event occurs while the control system is operating in manual mode, the operator will monitor the water conditions closely. The operator will need to operate the deflation valve to pass additional water. It should be noted that in Japan and per the Japanese standards, manual control is not allowed.

b. Automatic (pressure) control. Once pressure control is selected, the air pressure within the rubber bladder is controlled by a PLC in the control panel.

(1) The PLC monitors the pressure within the dam and inflates or deflates the dam as required to maintain the inner pressure within a narrow band around an operator-selected pressure set point. If a flood event occurs while the control is in automatic control mode, the operator monitors the water conditions closely.

(2) The control system will deflate the rubber dam to a small degree with rising upstream water level (to maintain the pressure set point). However, the operator needs to either reduce the pressure set point or switch to another operating mode to pass additional water. For this set-up, pressure control with a limit on upstream water level should be included.

c. Automatic or self-regulating upstream water level control. Once water level control is selected, the air pressure within the rubber is controlled by a PLC in the control panel (Figure 13–21). The PLC monitors the upstream water level and inflates or deflates the dam as required to maintain an upstream water level within a narrow band around an operator-selected water level set point.

(1) The operation of the dam is controlled by computerized control system that is programmed to monitor the upstream level by inflating or deflating the dam by automatically turning on one or two inflation blowers or one or two motorized deflation valves.

(2) If a flood event occurs while the control system is operating in water level control mode, the operator monitors the water conditions to verify the proper operation of the control system. The control system will deflate the rubber dam with rising water level and thus pass the additional water.

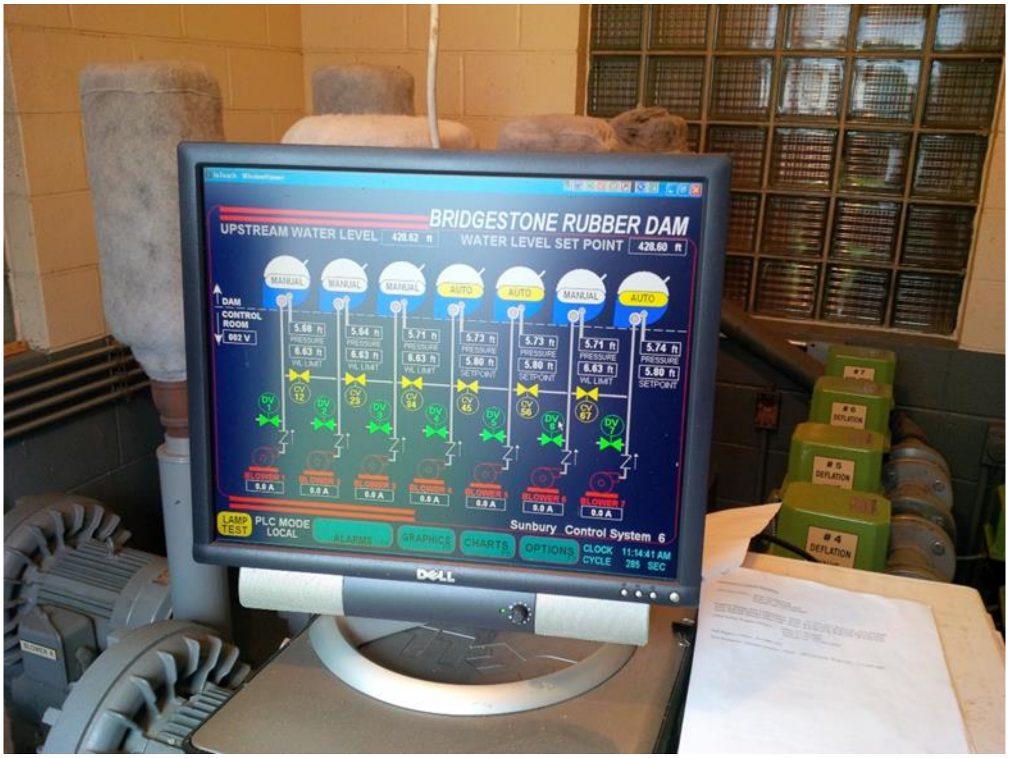


Figure 13–21. Computer control screen – Adam T. Boyer Dam

d. Application. The PLC monitors the status of the blowers, valves, sensors, inner pressure, and water level; annunciates alarms on an alarm graphic screen on the computer; and annunciates on an alarm panel in the operator control room (Figure 13–22). Like for the SR gate, the operator should be required to manually reset any alarm conditions by first verifying the problem. It is recommended that any alarm systems not be allowed to be overridden.

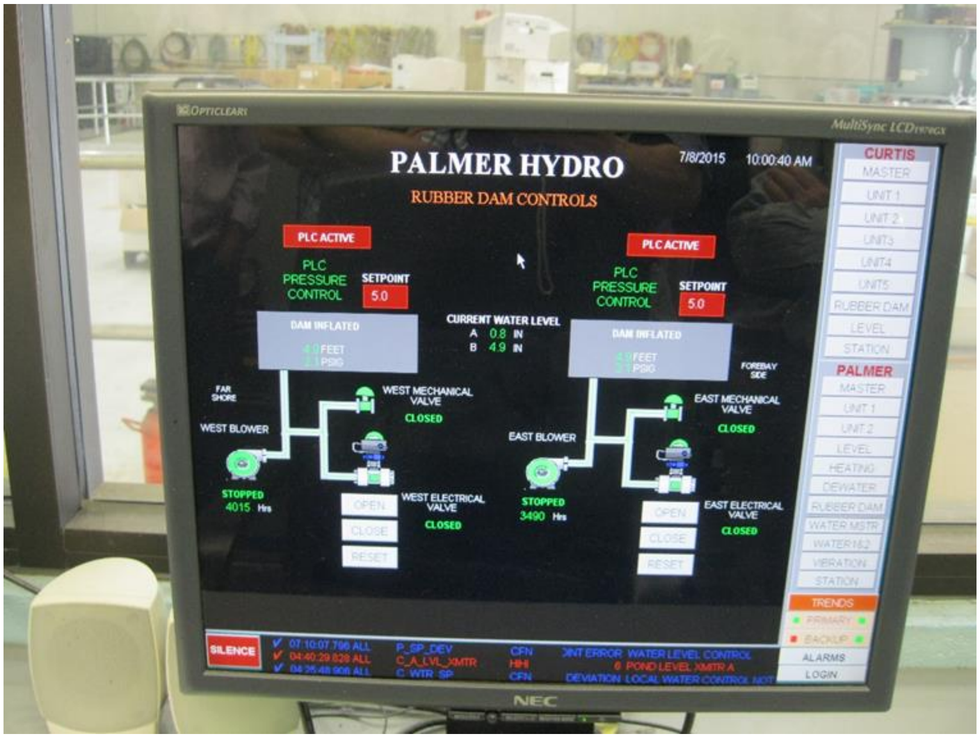


Figure 13–22. Computer control screen – Palmer Dam

Chapter 14
Ice and Debris Control

14–1. Objective and design summary

Ice and debris control at locks and dams is an important feature to minimize or eliminate delays to shipping industry. These systems are critical for keeping locks operational during the winter. This chapter focuses on ice control, but systems such as air bubbler systems are also used for debris control.

a. The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) can also provide specific design guidance on ice control systems for locks and dams. CRREL has produced many reports and technical guidance over the last 40 years concerning ice control systems. A number of these reports are referenced below. The designer should also use EM 1110-8-1 and EM 1110-2-1612.

b. Problems caused by ice formation include the following:

(1) Clogging of the lock entrance and lock chamber by broken and solid ice.

(2) Ice clinging to gates and valves so that operation becomes difficult or impossible.

(3) Freezing of floating bollards so that they become inoperable.

(4) Formation of ice on the lock wall surfaces so that lock width is restricted.

(5) Ice formation on top of lock walls, parapets, and walkways.

(6) Ice buildup clinging to the bottom of barges causing them to hang up on the lock sills.

c. The Soo Locks in northern Michigan experiences most of the problems noted above. Figure 14–1 shows a freighter passing through the Soo Locks during the winter. This lock experiences severe icing conditions since it operates into mid-January and is operational again in mid-March. Ice control systems used at the Soo Locks are discussed in more detail below.

d. Several methods are used to control ice formation on lock gates, lock structures, and dam gates described in EM 1110-2-1612. This includes the following:

(1) Air bubbler systems.

(2) Mixers.

(3) Electric heating.

(4) Steam heating.

(5) Ice booms.

(6) Ice repellent coatings for lock walls and gates.

(7) Removal of ice from lock walls with mechanical equipment.

e. Air bubbler systems are used extensively on United States inland navigation locks and are the most common means of ice control. These are used extensively at the Soo Locks, the locks on the Upper Mississippi River and Illinois Waterway, and many other locks. More discussion is provided below on these systems. Electrical heating systems and steam systems can also work well for keeping ice off gates. Steam systems are used for the miter gates at the Soo Locks.

f. On many inland waterway locks, barges and ships can push significant amounts of ice into the lock chamber as shown in Figure 14–1. Broken ice can also be carried downstream by the river current and wind and accumulate in the upper lock approach area. Barges can then push this into the lock chamber. Broken ice pushed into the lock chamber ahead of tows can limit the length and width of the lock chamber. To deal with this issue, ice lockages are sometimes used.

g. An ice lockage is simply a dedicated locking to flush ice out of the lock chamber. It also adds significantly to the vessel transit time through the lock. Ice locking is frequently conducted at the Soo Locks, sometimes into May and June.

h. Ice accumulation on hydraulic gates and its impact on gate structures are further described in EM 1110-2-1612 and EM 1110-2-2107. Moving ice also has significant force and can cause extensive damage to gate structures as further discussed in EM 1110-2-1612. Ice can also place additional load on structural components and add to the required machinery loads. Ice loads on dam gates can prevent the gate from opening due to the overloads on the machinery being exceeded.

Figure 14–1. Iron ore freighter passing through Soo Locks in winter

i. Ice accumulations in the upper lock approach area can also cause ice to become wedged between the lock gates and the recess. Ice pushed into the lock chamber ahead of ships and tows causes the same issue for the lower gates. Without air bubbler systems, lock operators sometimes have to “fan” the gates to move ice out the recesses or manually push ice out of the recess.

j. Many locks also have significant debris accumulation that can affect transit through the lock. This is especially the case during significant flood events when debris is swept into the river. Debris in the lock causes the same issue as ice, and many USACE locks conduct “debris” locking just like ice locking. Generally, water-borne debris includes large floating debris such as trees, floating logs, or ice blocks and sheets at or near the water surface. Small floating debris includes smaller ice particles, smaller woody debris, and garbage that tends to float on the water surface.

k. Dam gates are also especially vulnerable to ice accumulation. Broken ice carried downstream by the river current typically accumulates at a dam structure. Many USACE dams are operated at low flows over the winter with small gate openings. As such, much of the ice does not pass through the gate. Ice accumulations can also cause significant loads on the gates.

l. Some USACE locks and dams have tainter gates and roller gates that are submergible and designed specifically for passing ice and debris. These submersible radial gates and roller gates are typically used throughout the winter to pass ice. The lock chamber tainter gate at the USAF Lock is designed specifically to pass ice and debris and allow flood flows to pass through the lock chamber, as shown in Figure 14–2.

Figure 14–2. Upper St. Anthony Falls Lock tainter gate passing flood flows through lock chamber

14–2. Heat transfer

Heat transfer through the ice cover is a balance of the heat lost to the atmosphere, the heat conducted through the ice, and the heat transferred from the water to the bottom of the ice cover. Air bubbler systems will accelerate the heat transfer from warmer water depths to the bottom of the ice cover.

a. For the purposes of calculating heat transfer and energy requirements, the International System of Units (SI) units will be used. These calculations are also provided in EM 1110-2-1612. The rate of thickening or melting is determined by the product of the latent heat of fusion (h_f) of the ice (333 J/g) and the heat transfer rate. Pure water freezes at 0 °C under standard atmospheric pressure and when water freezes, 333 J/g of latent heat is released. Stated another way, to melt ice and affect phase change, energy of 333 J/g is required.

b. Specific heat (C_p) is a measure of the quantity of heat required to raise the temperature of one unit mass of fluid one unit degree under constant pressure. The specific heat of water is much larger than the specific heat of many other materials. As a result, relatively large amounts of heat must be added to or extracted from water to change its temperature. The specific heat of ice as a function of temperature is described by equation 14–1 in SI units from EM 1110-2-1612.

$$C_p = 2114 + 7.789\theta \qquad (14\text{–}1)$$

where

θ = temperature in degrees Celsius

C_p = specific heat in joules per kilogram per degree Celsius (J/kg ºC)

At 0 ºC, the specific heat of ice, C_p = 2114 J/kg ºC

c. For melting ice, the density also must be considered. The density of freshwater ice is 916.8 kg/m^3 at 0 °C. Ice also becomes denser with decreasing temperature. For instance, at minus 30 °C, the density of ice is about 920.6 kg/m^3.

d. For engineering calculations, the approximation of 915 to 917 kg/m^3 for the density of ice is adequate from EM 1110-2-1612. For melting ice with either steam systems or electric heaters, both the thermal conductivity of ice and the latent heat of ice are required values.

e. Thermal conductivity (k) describes the ability of ice to transmit heat under a unit temperature gradient and is typically expressed as watts per meter per degree Celsius (W/m °C). The thermal conductivity of ice is temperature dependent but typically taken as 2.25 W/m °C [2]. The value of the thermal conductivity based on temperature is derived in EM 1110-2-1612. The amount of energy in Joules required to melt ice is then given using equation 14–2.

$$E = m \times C_p \times \Delta T + m \times h_f \qquad (14\text{–}2)$$

where

E = the energy in Joules

m = mass of the ice

ΔT = the difference in the temperature of the ice and its melting point

The energy in Joules can then be converted to kilowatt hour (kWhr).

14–3. Soo locks design

The Soo Locks in the United States are located on the Great Lakes and are one of the most northern locks. There are two primary locks at this site, including the Poe Lock and the MacArthur Lock. A new lock chamber is in construction as of the writing of this manual. Once the new lock is constructed, there will then be two parallel 1,200-ft long locks. The information provided herein for the Soo Locks is intended to provide the designer a summary overview of the ice control systems installed there. The Soo Locks use a multitude of ice control systems that can be adapted to other lock sites.

a. The Soo Locks operate into January, yet at the same time experience severe ice conditions with ice built up in front of the miter gates. Several ice control systems are used at the Soo Locks to keep ice off the miter gates. CRREL also modeled ice passage through this lock and summarized it in the report “A physical model study of ice passage at the Soo Locks” (Tuthill 2000).

b. First, a steam system is used for mitigating ice formation and removing ice from the miter gates. The steam system, however, requires a dedicated on-site steam and boiler plant and requires significant amounts of energy, in this case natural gas, to operate. The steam plant was upgraded and replaced in 2020. The new miter gates for the new lock will also have steam heating systems. The boiler plant consists of three fire tube boilers, each rated at 5 million BTU (British thermal units)/hr output. A portion of the steam is also used for building heating.

c. There are also a set of 4 flushing valves through the upper miter gates at both locks used to push ice downstream (Figure 14–3).

Figure 14–3. Soo Locks MacArthur Lock ice flushing valves

d. Air bubbler curtain systems are also used to provide additional flow around the miter gate recess area (Figure 14–4). There is a point source bubbler system at the Poe Lock that is very effective for keeping ice away from the miter gate recesses.

e. The air curtains are used to move ice for setting bulkheads and to move miter gates. They also use point source bubblers (550 cubic ft per minute or 15.4 cubic meters per minute) for controlling ice at multiple other locations. They use individual control of each point source bubbler and use a central compressed-air plant with three rotary screw drive compressors (Figure 14–5). Each compressor is rated at 700 hp (521kw). Three compressors are used for redundancy. However, with the new lock coming online, there will likely be cases where multiple compressors are used at the same time.

f. An air screen has been placed across the upstream entrance to the Poe Lock that has proved to be very effective in keeping floating ice out of the lock. A 2-in. (51-mm) diameter pipe with 0.40-in. (10-mm) diameter orifices spaced 10 ft (3 m) apart was placed on the downstream vertical face of the upstream stoplog sill.

g. This manifold was connected to a 2-in. (51 mm) vertical riser pipe placed in a recess in the lock wall. The riser pipe was connected to an air compressor with a 2-in. air supply line. Air was supplied by the rotary screw compressor that has an output of 1,150 cubic ft (32.6 m^3) per minute at 110 pounds per square inch gauge pressure (758 kPA).

Figure 14–4. Poe Lock air bubbler system in operation

Figure 14–5. Soo Locks compressed air plant

14–4. Tainter gates

Tainter gates are a common type of dam gate and ice build-up can cause a multitude of operational problems. Significant ice accumulation can occur on the upstream skin plate. Spray from the operation of dam spillway gates over the winter can cause ice to form on the pier walls or on the radial gate trunnion arms. This can jam the gates or stop them from fully closing.

a. In some cases, the weight of ice formed on the gate structure is so great that the operating machinery cannot raise the gate. The side and bottom seals of radial gates can also leak, causing additional spray. As a result, there is more ice buildup on the pier walls or the gates themselves, causing additional gate loads. During severe cold, gates must be moved frequently, or they will freeze in place. Attempts to operate gates when frozen in place can result in damage to the operating machinery and hoisting mechanisms, including the chain and wire rope.

b. Electric heating systems have been installed on several tainter gates across USACE. This includes heating the side seals of radial gates. Chapter 18 in EM 1110-2-1612 provides detailed guidance on the design of electric heating systems for tainter gates. The heating system improves the ability of the side seals to reduce leakage past radial gates, and thus reduce the associated buildup of icing on the walls and the gate structures. With increased flexibility in cold weather, the seal better conforms to irregular surfaces, thereby reducing leakage to the downstream side.

c. Lock and Dam 2 on the Upper Mississippi River has several heating systems installed on 4 of the 19 tainter gates. These gates are 30 ft wide by 30 ft tall. The heating systems are described in technical reports: Lock and Dam 2 Tainter Gates, De-Icing Report, Mississippi River, Hastings, Minnesota – RCM 861608-7 (USACE 1987) and Monitoring Electrical Dam Gate Heaters (Clark 1983). The study done in 1987 by RCM determined electrical heating is the best available method to remove ice from the dam gates at Lock and Dam 2.

d. The study considered electrical heating elements, hot glycol circulation, steam, infrared heat, and air bubblers and determined that electric heat provided the most cost effective and reliable method of de-icing the gates. This includes electric heaters installed in the pier walls near the side seals, electric heaters installed on the skin plate, and electric heaters installed on the trunnion arms. The design criteria included de-icing time of 4 hours or less, a temperature of minus 28 °F (minus 33.3 °C), and a total of four gates to be de-iced (one at a time). The system is summarized in Table 14–1.

Table 14–1
Watts per gate – heating system Lock 2, Mississippi River

Heater Placement	Number of Heaters	Watts per Foot	Watts per Element	Total Watts per Area	Total Watts per Gate
Side Seal (per side)	1	275	7,350	7,350	14,700
Skin Plate	10	150	1,950	3,900	19,500
Support Channel (per side)	1	175	1,200	1,200	2,400
Trunnion Arms (per side)	2	225	3,100	6,200	12,400
Total	14	–	–	–	49,000

e. The heaters at Lock 2 use U-shaped tubular heaters made of nickel chromium wire and an outer sheath of Incoloy placed inside water-tight insulated cavities. The skin plate heaters are installed in a steel box on the upstream face of the radial gate. The side seals of the radial gate are the J-seal type. The rubber J-seal is bolted to the radial gate and is in contact with a rub plate along both sides of the gate. Side seal heaters prevent ice formation on the steel rub plate and help keep the J-seals flexible in cold weather. In this design, the heater cavity is formed by a channel welded to the back of the rub plate. Overall, the heating systems have worked well. The primary disadvantage is the extra weight added to the gate.

14–5. Air bubbler system overview

Air bubblers and air screens have been used successfully (as discussed previously for the Soo Locks) to prevent floating ice from entering lock chambers and lock approaches and to prevent floating ice from clogging gate recesses. One of the first design guidance was produced by CRREL as Technical Digest Report 83-1 (Carey 1983). The designer should use this report to understand the fundamentals of air bubbler systems.

a. Ice and debris control systems using compressed air are used on many locks and navigation structures in the United States including the Upper Mississippi River, Illinois Waterway, and the Ohio River. The Starved Rock Lock on the Illinois Waterway was one of the first sites in USACE to incorporate an air bubbler system. These systems also are used on the SLS and European navigation structures.

b. Several design references are available for air bubbler systems, including the Compressed Air and Gas Handbook (CAGI 7th edition), the Compressed Air and Gas Data from Ingersoll Rand Corporation (Gibbs 1971), CRREL Report 79-12 (Ashton 1979), EM 1110-2602 (Chapter 11), and EM 1110-2-1612. UFC 3-420-02 can also be used. The UFGS specification 22 15 26.00 20 can be used as a starting point for developing a technical specification. UFC 3-420-02 can also be utilized as design guidance.

c. Air systems provide several advantages over mixers and heaters. They are less labor intensive than a mixer system. The operational cost is generally lower when compared to electric heaters. A heat system is ineffective for moving large ice floes and for pushing debris out of the gate recess and quoin area.

d. The air system uses an air plant or compressor, supply piping with manifolds and control valves, and diffuser piping (installed on the gates, lock floor, and in the gate recess) to aerate or bubble the water in front of lock gates and across the gate sills or lock floor. Air bubbler systems transfer heat energy stored in the water up to the underside of the ice cover. The heat may melt the ice completely, creating an open-water area above the air bubblers, or it can reduce its thickness, so that ships can pass through it or so the ice breaks up earlier and more easily.

e. The system is effective for clearing ice and debris from the miter gate recess and to prevent slush ice from entering the lock. Some sites have used a central air plant, while others have used smaller systems or localized plants spread out on the lock. For existing locks, the installation of high-volume bubbler systems should be included as part of lock and dam major maintenance contracts. This allows the installation of the submerged pipe and accessories while the lock is dewatered and reduces the overall cost to install submerged high-volume bubbler piping.

f. A pipe with numerous orifices is connected to a large volume air supply and is placed across the bottom of the lock entrance. The continuous discharge of air from the orifices produces upward water currents that push the floating ice back away from the lock entrance. Also, agitation produced by circulation of subsurface water retards formation of ice. However, as cold weather continues and air temperatures become colder, the subsurface water may eventually become so cold that there will be no reduction in ice formation, but water circulation still helps to retard complete freeze-up.

g. Piping with orifices is also used on the bottom of miter gates and sector gates and in the gate recesses. Details of these systems are discussed below.

h. There are both high-volume and low-volume air bubbler systems. High-volume systems are more effective for moving ice and reducing brash ice and described further below. Low-volume systems are more effective in bringing warmer water from deeper depths to the surface. Low-volume systems typically use smaller air blowers or compressors at each gate corner, typically rated at 25 to 50 hp. The actual performance requirements of low-volume blowers and compressors will be site specific.

i. Low-volume systems are used at Locks 2 to 10 on the Mississippi River throughout the winter to keep ice off the miter gates even though the locks are not operational. The rotary screw compressor at Lock 5 is shown in Figure 14–6. Most of the locks on the Upper Mississippi River are low head and shallow draft locks. Therefore, air blowers are used primarily. High-volume systems are used at Locks 11 through 22 on the Mississippi River with a central air plant. The central plant air compressor at Lock 14 is shown in Figure 14–7.

j. Both central plant and localized plant systems have been successful. The selection of the type of plant is site specific. For sites with localized plants, it is recommended to use a compressor on each gate leaf (Figure 14–6).

Figure 14–6. Air compressor installed on lock miter gate machinery platform

Figure 14–7. Central plant air compressor at Lock 14, Mississippi River

14–6. Air bubbler system design

Air bubbler systems transfer heat to the ice cover through the circulation of water caused by a rising plume of air bubbles released from orifices or diffusers beneath the water surface. CRREL's Technical Digest Report 83-1(Carey 1983) is still the basic design guidance for these systems, along with the CRREL Report 79-12 (Ashton 1979). EM 1110-2-1612 also provides guidance. The water from this lower depth is usually warmer than that near the ice cover in the winter due to thermal stratification. This transfers heat to the ice and causes melting.

a. The amount of energy necessary is based on the heat of fusion of the ice and the thickness of the ice cover. The air itself also undergoes a temperature rise after being compressed. Thus, the air released through orifices in the diffuser piping typically has a much higher temperature than the water. Under favorable conditions, the energy from the heat transfer going into melting can be many times greater than the energy used to operate the system.

b. It is this multiplication effect that makes air bubblers so advantageous over any direct use of energy (such as electric heaters) to melt ice. Water temperature is of prime importance. The maximum density of water occurs at 4 °C or 39 °F. It cannot be assumed that the temperature at lower water depths is indeed 4 °C. A further temperature decrease below 4 °C causes the density of water to decrease. In a water body with any significant amount of flow or circulation, such as a river or a bay open to a larger water body, the temperature may be at or near 0 °C (32 °F) throughout the depth because of turbulent mixing.

c. A basic air bubbler system uses an air blower or compressor, supply piping with manifolds and control valves, and diffuser piping (installed on the gates, lock floor, and in the gate recess) to aerate or bubble the water in front of lock gates and across the gate sills or lock floor. The air bubbler system at Lock 8 on the Mississippi River is shown in Figure 14–8. This lock is 110 ft (33.5 m) wide and is considered a shallow draft lock. The air bubbler system is typical of the locks on the Upper Mississippi River and Illinois Waterway and includes air bubblers in the gate recesses, gate quoin areas, and across the sill of the lock. Two-inch air bubbler piping is installed along the bottom of each miter gate.

d. There are 12 diffusers on each miter gate leaf, 12 diffusers in each miter gate recess, and 18 diffusers across the sill of the lock. The system is installed at both the upstream and downstream ends of the lock. The system is effective for clearing ice and debris from the miter gate recess and to prevent slush ice from entering the lock. Compressors are installed in each gate corner.

e. Air blowers or air compressors can be used. However, air blowers are limited to around 89.6 kPa (13 psig) and are feasible only for low head and shallow draft locks. The advantage of an air blower is that it provides significant air volume compared to a compressor. The supply lines, however, for air blower systems need to be much larger to minimize friction losses, typically 3 or 4 in. minimum.

f. Lock sites with long supply lines and deep drafts require air compressors that can provide much more air pressure, commonly to 100 psig or 689 kPa. Rotary screw air compressors have worked well at many USACE lock sites and should be considered over reciprocating compressors. Air dryers are generally not necessary and not used at majority of lock sites but should be evaluated for specific applications.

g. Since air is compressible, it is important to understand and specify what units, pressure, and temperature are being used when sizing and designing air bubbler systems. In the United States, flow rates are often expressed as SCFM or standard cubic feet per minute. This is the air flow rate at atmospheric pressure, or 14.7 psia and at 60 °F. One SCFM is equivalent to 1.70 cubic meters per hour (m^3/h).

h. To facilitate pipe sizing and determining friction losses, pressure drops for standard lengths of piping are provided in various manuals, including “Compressed Air and Gas Data” and the “Compressed Air Handbook.” This also includes pressure drop across the orifices. CRREL also developed a sizing program in the 1980s and 1990s and is further being developed at the writing of this manual. The current design program is BUBX. The designer can reach out directly to either HQ or CRREL to obtain the latest updates on air sizing programs. It is imperative that enough pressure be provided to reach the farthest diffuser from the compressor.

i. Turbulent flow is assumed, and friction losses are based on the Darcy formula, with friction factors based on Moody. Flow rates and pressure drop tables in these manuals are typically expressed in SCFM units. It is also normally valid to assume isothermal flow or constant air temperature through the air bubbler system. The

“Compressed Air and Gas Handbook” also provides extensive discussion on the different types of compressors available in the marketplace and methodology for sizing compressors.

j. The orifices and diffusers at the bottom of the pipe are important to allow water and debris out when air is forced through and for proper air distribution. In USACE, hole diameters typically vary between 6.35 mm to 15.8 mm (1/4 in. to 5/8 in.), depending on the air flow and spacing. The spacing usually varies from about 1 to 2.5 m (3 to 9 ft) depending on the location and the desired effect.

k. Many new designs use a welded outlet over diffuser holes, and a 1/2 pipe threaded nipple to take standard rubber check valve or nozzle configurations, therefore facilitating exchange and replacement (Figure 14–9) by divers. These nozzles also prevent water from infiltrating into the bubbler supply pipe.

l. Proper attachment to the bottom of the lock is critical because ships create turbulence that might move improperly fastened piping. Installation of diffusers should be done with the diffuser pointing down as shown in Figure 14–9. This reduces the chance of the diffusers being damaged by barge tows and debris. Diffusers installed pointing down also trap the air remaining in the piping after the system is turned off. The trapped air substantially reduces the amount of water in the pipes the next time the system is used.

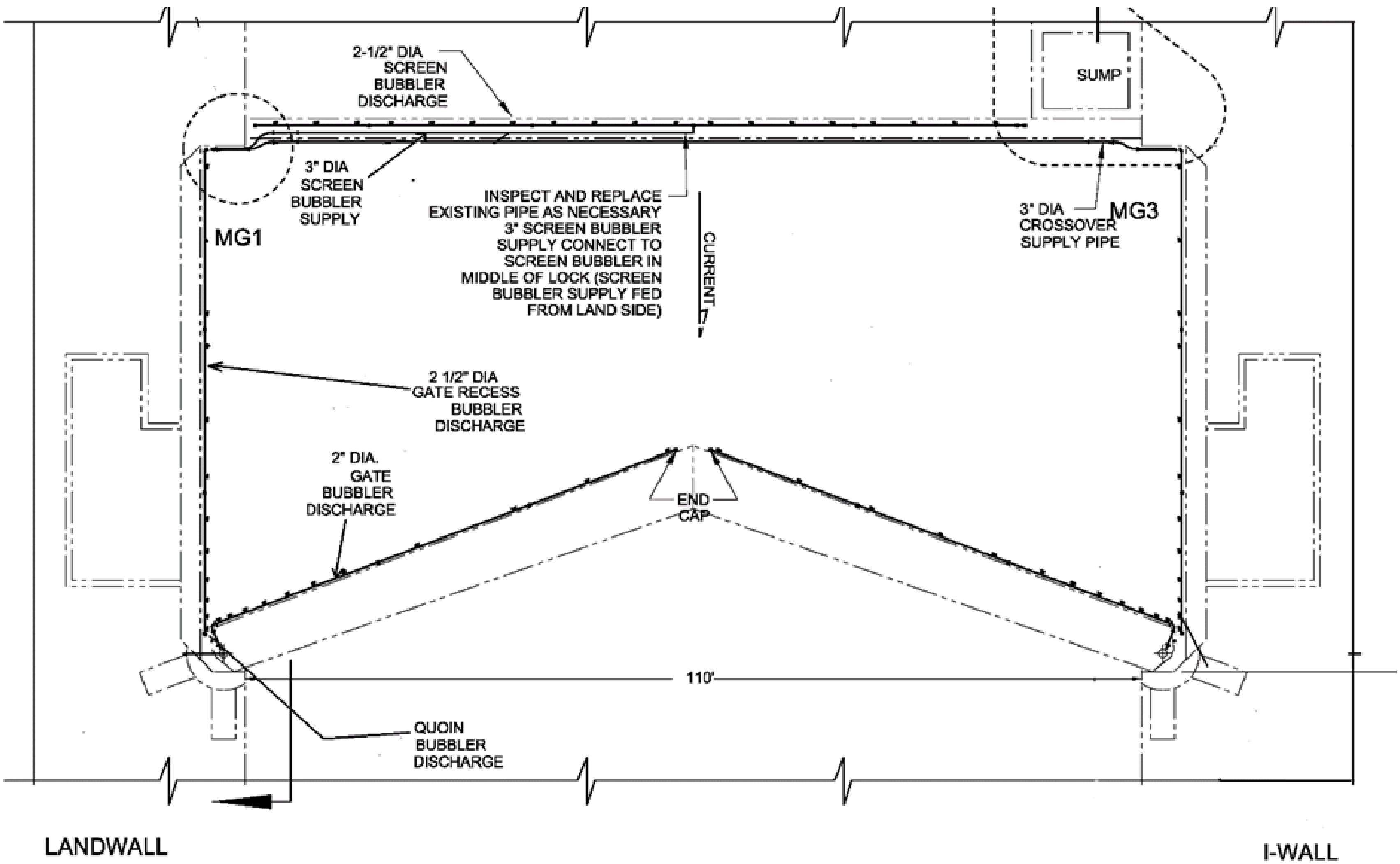


Figure 14–8. Lock 8 air bubbler system layout dimensions in United States customary units

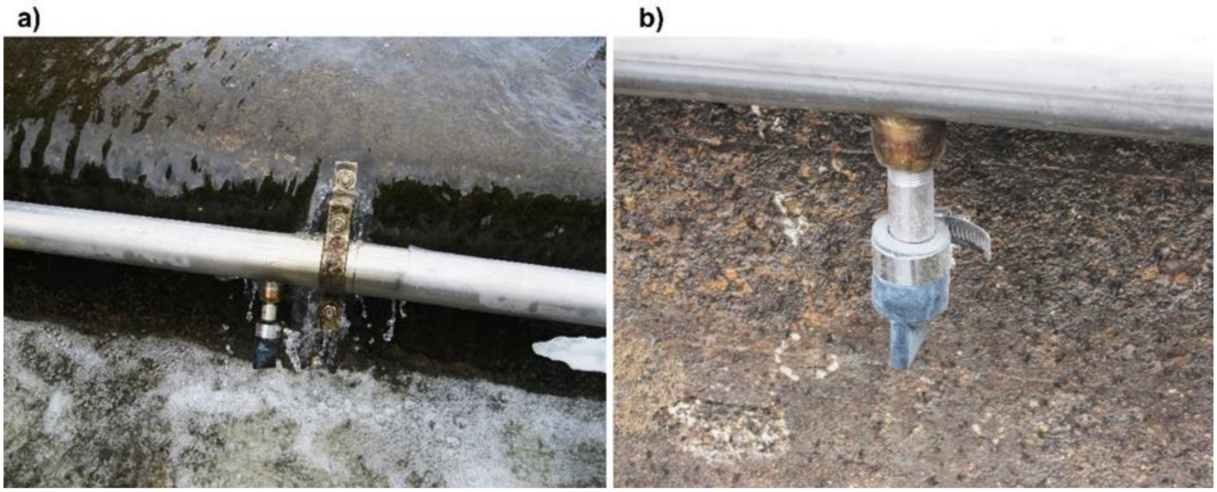


Figure 14–9. Air diffuser check valves a) showing supply pipe and attachment b) detailing check valve configuration

m. Air manifolds should be provided at each gate corner. Run the supply line from the air compressor or blower directly to the manifold and not directly into the supply piping. The manifold allows proper distribution and control of air. See Figure 14–10.

n. Use butterfly valves on all supply lines to allow closure and throttling. Electrically operated, motorized actuators may be used to actuate the air valves. Electric motor actuators should be provided with integral heaters in cold climate locks to prevent the air valves from icing up. The open/close operators may be installed on the local lock operator control console, which should allow the human operator to view the movement of debris and ice as well as the break-up of ice. Piping should then extend from each manifold down to the lock floor and lock gate diffuser piping.

o. Use crossover piping across the lock chamber floor to connect manifolds together. This allows one compressor to be used for multiple gate corners if one compressor fails. Crossover supply piping friction losses should be minimized, and piping should be at least 3 in (76 mm) or larger in size. For central plants, crossover piping allows interconnection of different manifolds. EM 1110-2-1612 states using 4-in. (101-mm) supply lines for any lengths over 500 ft (152 m).

Figure 14–10. Typical diffuser supply system and manifold

p. Pipe connections are a common place for air loss; therefore, grooved-type couplings or similar are recommended. Grooved coupling systems can be quickly assembled in the field. To minimize corrosion, stainless steel pipe and couplings should be used for any materials below the water line. Galvanized pipe and couplings have failed in multiple applications after only 5 years of service due to corrosion. The grooved coupling system and pipe should be the same stainless steel material to minimize any galvanic corrosion. Galvanized piping and couplings can be used above the water line.

q. Ideally, a cleanout port should be located on the end of air curtains that can be opened by a diver to flush out debris that forms inside the pipe (provide a larger diameter than holes). Consideration should be given to installing a smaller diameter line at the opposite end of the feed line that can be used as a backwash or purge line. The smaller line needs to be away from navigation or other contact points to prevent failure.

r. Compressor or air blower sizing is determined by an iterative analysis, which determines air discharge rates from orifices in the piping, assuming a dead-end pressure. The dead-end pressure needs to be high enough to overcome the static head at farthest diffuser.

s. CRREL previously developed sizing spreadsheets and the CRREL BUB-300 program for sizing of bubbler system components and sizing of the compressor and orifices originally in Fortran and then in an executable (EXE) file. However, this program is now outdated and not practical anymore. CRREL does have a new program (BUBX) they developed at the writing of this manual. There are commercial online compressed air programs that can be used. One such website is: https://www.tlv.com/global/TI/calculator/air-pipe-sizing-pressure-loss.htmls.

t. The required compressor air flow rate is based on the total sum of the diffuser nozzle flow rates. Use consistent units such as SCFM. The static head required for the system is based on the water level over the top of the air diffusers. The iterative analysis calculates the orifice discharge and pressure, starting from the farthest end of the system and working toward the supply point (compressor). After all the orifices are analyzed, the supply line pressure and air flow are calculated.

u. The compressor pressure and flow rate necessary to sustain the supply line pressure and air flow are then calculated. The calculated compressor output is compared to the actual compressor output. The trial dead-end pressure is then adjusted, and the analysis scheme repeated until the calculated and specified compressor outputs differ by no more than 1%.

v. For high head locks, the submergence depth and the hydrostatic pressure likely will be the controlling factor in the required compressor pressure.

w. Output pressure must be high enough to overcome hydrostatic pressure at the submergence depth and frictional losses in the supply and distribution lines, and still provide a pressure differential at the last orifice to drive the air out at the desired rate. Supply and distribution line diameters should be large enough so that frictional pressure losses along the line are small. This is especially critical for systems using air blowers.

x. A small increase in line diameters often results in significant reduction in frictional losses and more uniform discharge rates along the line. Orifice diameter and spacing should be selected to maximize air flow rates. Too large an orifice diameter can result in all the air being discharged at one end. One-quarter inch to 5/8 orifices have been effective. The larger orifices (typically 1/2 in. to 5/8 in.) are used for high-volume systems discussed next.

14–7. High-volume air systems

High-volume bubbler systems generally use a central plant providing lock personnel a means to control debris, ice formation, and ice movement. However, these high-volume systems can also be a point source system, such as in the miter gate pintle area.

a. EM 1110-2-1612 states: “From laboratory analysis, it is recommended that a design flow of 0.85 m^3/min (30 ft^3/min) be provided for each orifice. This will provide sufficient air to create the desired effect at the water surface.” The Soo Lock system was discussed above and has proven to be highly effective. High-volume systems also are installed on the locks on the Ohio, Mississippi, and Illinois rivers.

b. Designers considering installing high-volume bubbler systems should consult EM 1110-2-1612; EM 1110-8-1(FR) (Chapter 6); Repair, Evaluation, Maintenance, and Rehabilitation Research (REMR) Bulletin Vol. 12, No. 2 (1995); and CRREL’s Technical Digest Report 83-1 (Carey 1983). These documents provide valuable guidance in designing high-volume bubbler systems. Controlling the formation and movement of brash ice improves the efficiency of lockages. The benefits include:

(1) Fewer lock personnel are required to assist with the lockage.

(2) Less physical work from lock personnel is required to push ice with long pick poles.

(3) The time required to perform a lockage during winter ice conditions can be reduced.

(4) Controlling ice against the lock gates reduces gate operating machinery wear and tear. Stresses imposed on the gate's structural members are lower. Machinery life, structural component life, and time between periods of major maintenance are extended.

(5) Adhesion of ice to the lock structure and gates can be minimized by the melting action associated with the use of high-volume bubblers. Ice of varying thickness can be melted in areas contacted by the released air bubbles.

c. An air screen in cross section is shown in Figure 14–11. A gate quoin air flusher does a good job of clearing floating debris before a miter gate is opened, while consuming much less air than a gate recess screen. These flushers consist of a single orifice located near the pintle of each miter gate. Each flusher is supplied by a smaller 19-mm (0.75-in.) line and is solenoid operated from the control station.

d. A standard procedure should be to operate the quoin flushers briefly each time the gates are opened. The gate recess screens still are needed for ice and heavy debris. The St. Paul District also uses quoin bubblers with a 2-in. supply line. They have also proven effective for clearing ice and debris in the gate quoin area. A 2-in. pipe cap is used with three, 5/16-in. diameter holes drilled in the cap.

e. The Pittsburgh District also did an experiment with orifices facing up and down. Bubbler systems were installed on two identical locks with the exact same arrangement, except for the orientation of the orifices. The orifices for one system were installed pointing up, while the orifices for the other were pointed down. This was done to see if the response time of these systems could be improved. Each system had quoin flushers and flushing screens for the miter gate recesses, upper bulkhead seal, and upstream approach.

f. As expected, the system with the orifices pointing down had a significantly faster response time (time required for all orifices in a screen to begin bubbling). Orifices installed pointing up allow all of the air remaining in the screen piping after it is shut off to escape. As a result, the pipes are full of water the next time the screen is needed. It takes time for the incoming air to displace the water in the piping through the orifices.

g. The orifice closest to the supply line starts bubbling first, and each successive orifice follows until the last one in the screen begins to bubble. Orifices installed pointing down trap the air remaining in the screen piping after the screen is turned off. The trapped air substantially reduces the amount of water in the pipes the next time the screen is needed. As a result, the orifices in the screen begin bubbling sooner, with many starting about the same time. Once all the orifices in a screen were bubbling fully, there was no observable difference in the bubbling action between the two systems.

h. A high-volume system was designed and installed at Starved Rock and Peoria Lock. The major components of high-volume air systems are modeled from the research and design calculations conducted by CRREL. The findings of the research laboratory are from a prototype installation at Starved Rock and Peoria Lock. This research should form the basis of design for high-volume air systems to control ice at locks. The components of the system described below are particular to systems installed on the Mississippi River.

(1) The compressors are 150 hp, electric-motor driven, positive-displacement, rotary screw-type. Each compressor can deliver 1,275 m^3/hr (750 cfm) of free air at 690 kPa (100 psig) full flow and is designed for continuous operation.

(2) One compressor serves each bubbler system. The compressor delivers flow to the upstream and downstream gates. Compressor sizing is determined by an iterative air system analysis, which determines air discharge rates from orifices in the piping, assuming a dead-end pressure.

(3) Supply pipes traditionally have been 3-in., Schedule 40, galvanized steel piping. Galvanized steel piping is acceptable for piping installed above the water line. The piping is routed from a centrally located compressor to each end of the lock chamber. Valve manifolds are installed near the gate recesses to control the delivery of air to each submerged flushing screen. The control valves typically have been 3-in. butterfly valves with manual control. Electric control valves were installed at Starved Rock and are well liked by the operators.

(4) The submerged piping varies in size from 76 to 32 mm (3 to 1.25 in.). The varying size depends on the flushing screen being served and the proximity to the dead end of the pipe. The chamber screen is maintained at 76 mm (3 in.), due to the volume of air being delivered and the distance across the lock chamber. This screen is 29 m (96 ft) long for a 33.5-m-wide (110-ft-wide) chamber and is designed with 2.4-m (8-ft) orifice spacing.

(5) Gate recess screens are supplied with 76-mm (3-in.) piping and reduced accordingly to meet the requirements established by CRREL. The gate recess screens have varying orifice spacing to provide more air near the quoin end of the gate. The orifice spacing follows the recommendations of EM 1110-8-1(FR). Nine orifices are installed along each gate recess flushing screen.

(6) Drilled pipe plugs provide the desired quantity of air to the water. The pipe plugs are installed in vertical tee fittings along the horizontal pipe runs. Holes that are 9.5 mm (3/8 in.) in diameter have been determined to deliver the desired quantity of air

from the prototype installations. A design flow rate of 51 m^3/hr (30 cfm) per orifice is desired.

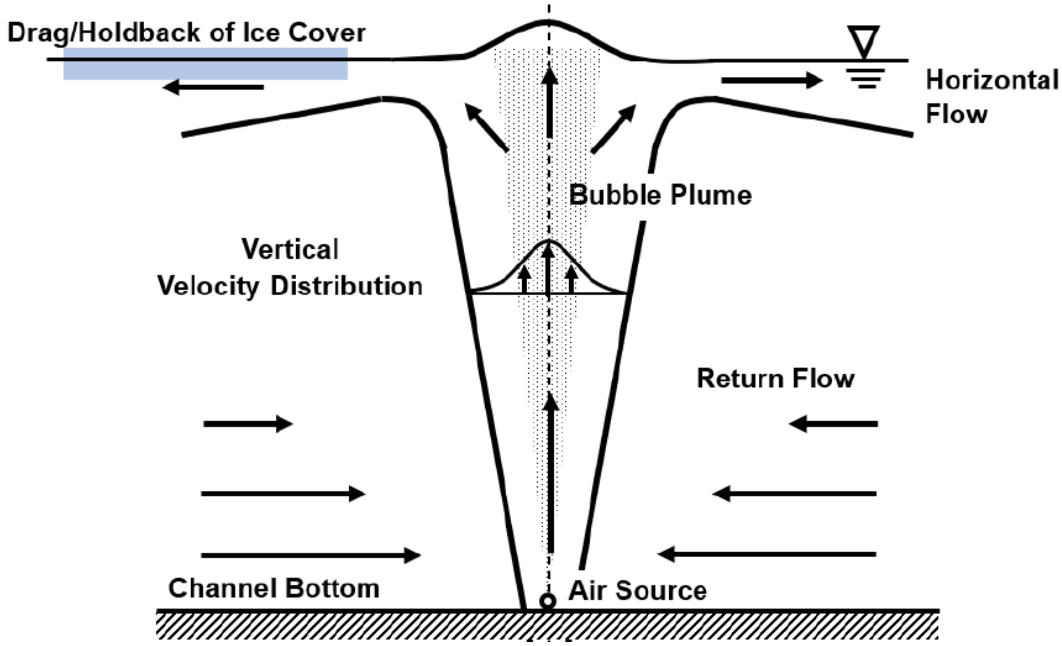


Figure 14–11. Air screen in cross section reproduced from USACE Engel et al. 2021

14–8. Lessons learned

Air bubbler systems have been in use at multiple locks for over 35 years. The following provides a summary of lessons learned.

a. Both central plant and localized plant systems have been successful. The selection of the type of plant is site specific. For sites with localized plants, use a compressor on each gate leaf. Both localized plants and central compressed air plants should provide redundancy.

b. Rotary screw-type compressors have been used successfully and are preferred. They can run for long periods with little maintenance.

c. Air blowers (Roots type) can provide substantially more air flow but are limited on pressure output. They can run for long periods with little maintenance.

d. Specify low ambient temperature compressor enclosures to permit operation at ambient air temperatures as low as -28.8 °C (-20 °F).

e. Environmentally friendly or environmentally acceptable oil has been used successfully on both the large central compressors and air blowers.

f. Size backup generators to accommodate both the electrical load from the lock and dam and the electrical load of the compressor. Central plant compressors can have a large electrical demand. Some sites (like the Soo Locks) require these compressors be operational throughout the winter.

g. High-volume systems work well for moving ice and reducing brash ice. More discussion is provided in EM 1110-2-1612.

h. Low-volume systems can be used to transfer warmer water at the bottom of the lock to top water surface. Low-volume systems can run continuously and be used during the winter in northern climates to keep ice off lock gates.

i. Rubber pinch-type check valves have worked successfully in keeping silt, debris, and zebra mussels out of the nozzles and piping system. Always provide a diffuser system that has a means for preventing backflow into the pipe.

j. Heat tape has been used successfully for air piping at the water surface to prevent ice buildup inside the supply pipes.

k. Check valves within the vertical piping have not been 100% reliable and freezing in the pipes has occurred. It might be better to install isolation valves, cross fittings, and pipe plugs to allow lock personnel to either charge the vertical piping with air or fill them with environmental antifreeze. Charging the piping with air forces the static water level below the freezing surface and is the preferred method.

l. Stand pipes with isolation valves are used successfully to allow the addition of alcohol or antifreeze to clear ice buildup.

m. Space check valves and nozzle diffusers 0.912 to 1.216 m (3 to 4 ft) apart. Install orifices and check valves pointing down. This reduces the chance of the diffusers being damaged by barge tows and debris. Orifices installed pointing down also trap the air remaining in the screen piping after the screen is turned off. The trapped air substantially reduces the amount of water in the pipes the next time the system is used. As a result, the orifices begin bubbling sooner.

n. Use all stainless steel pipe, fittings, and components for below water diffuser and supply piping. Do not use any galvanized components below water or mix and match galvanized components and stainless steel components. Provide dielectric couplings between galvanized and stainless steel components.

o. For air blower systems, minimize air supply friction losses to 6.895 kPa to 13.790 kPa (1 to 2 psig).

p. Orifices in supply piping should be 6.35 to 9.5 mm in diameter (1/4 to 3/8 in.). Higher volume systems can use up to 15.8-mm diameter orifices (5/8 in.).

q. Ball valves or positional butterfly valves with 90° full open to full close operation are best suited to deliver the air to the bubbler screens. Use manifolds.

r. Provide point source air bubblers for control of ice in multiple locations.

s. Provide PLCs and VFDs for control of air compressors. This allows modulation of air flows.

t. Ultraviolet protection is required for all exposed compressor controls to prevent deterioration.

u. Piping should be attached to the concrete wall surfaces and horizontal surfaces using stainless steel offset clamps (Figure 14–12). Also note connection to the manifold in Figure 14–12.

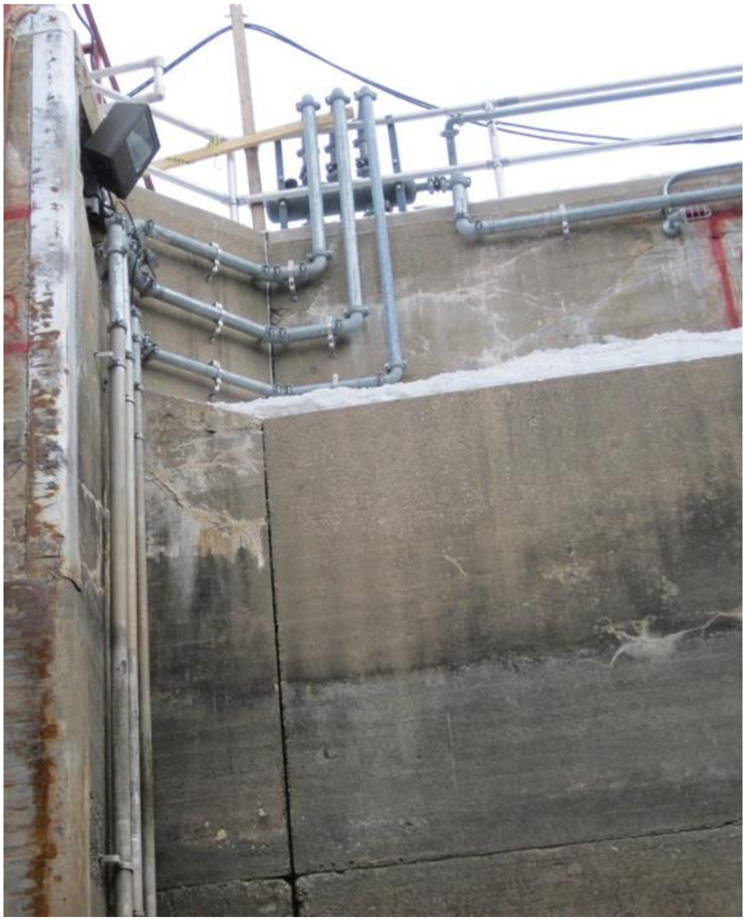


Figure 14–12. Bubbler piping attachment using offset clamps

14–9. Mixers

Mixers are another means to control to control ice formation on lock and dam structures. However, these are not used extensively on United States locks and dams. These are submersible and can be used on their own or in conjunction with air diffuser systems. All mixing applications require varying degrees of both small-scale turbulence and bulk flow. With a good bulk flow, water in the area behind the gates is put into motion which helps limit ice formation.

a. Low-speed mixers are typically used for more efficient bulk flow, lower energy consumption, and positioning flexibility. In general, however, mixers are typically effective only for smaller areas of ice control.

b. One significant disadvantage with mixers is the operational and maintenance effort involved in setting mixers.

c. Another use of mixers is in front of dam gates to limit ice formation on the gate surface.

14–10. Debris arrestors and ice booms

There are other means of moving and directing ice and debris besides air systems. A structural solution can be a debris arrestor or ice boom. The primary flexible ice control structures applicable to navigable rivers are ice booms.

a. Extensive design guidance on these structures is provided in EM 1110-8-1, EM 1110-2-1612, and the CRREL Report 95-18 (Tuthill 1995). Ice booms are essentially a line of floating logs or pontoons across a waterway or in front of dam gates that collect ice and debris and direct it away from the gate. The most common type of ice boom consists of large floating timbers held in place by a wire rope and buried anchors. To be effective, an ice boom must restrain an ice cover at the surface without restricting water flow, and it must move up and down with the ice cover.

b. Although ice booms vary in function and appearance, their wire rope structures are similar. Anchor types may vary on any one boom and from one boom to the next. They rely on the strength of the riverbed and bank materials. A structure that reaches from shore to shore will have anchors onshore and sometimes along the river bottom, depending on the expected loading. The length of the anchor lines from the river bottom to the floating parts is generally about 12 times greater than the water depth.

c. Floating trash booms are used at multiple Tennessee Valley Authority (TVA) projects. Trash racks, debris control, and ice control for USACE hydropower projects are discussed further in EM 1110-2-3006. Trash racks for pumping stations are also discussed in EM 1110-2-3105.

d. Hydropower plants located within lock chambers also use ice booms and debris arrestors. The LSAF Lock (Figure 14–13) on the Mississippi River is an example and uses a small hydropower plant in the auxiliary lock chamber. Since commercial operation in December 2011, there have been numerous debris- and ice-induced shutdown incidents with the hydropower generating units.

e. The turbine-generator complex consists of 16 matrix units in a stacked arrangement. Since the LSAF hydropower project came online, both ice booms and trash booms have been added. The trash boom is new and now operational. The LSAF hydroelectric project has the following features that assist in debris and ice management:

(1) *Floating boom*: Located upstream of the auxiliary lock for boater safety. While not the primary purpose, the boom likely deflects a portion of floating trash and ice away from the auxiliary lock during low-flow and low-velocity conditions.

(2) *Ice breaker*: Located at the entrance to the auxiliary lock chamber. Keeps larger floating ice blocks from entering the auxiliary lock and breaks the large blocks into smaller pieces that then pass into the auxiliary lock.

(3) *Matrix unit trash screens*: Trash screens mounted to front of the matrix units. Keeps debris entrained in flow from entering the matrix units.

(4) *Trash boom*: Provides a barrier to floating debris at the LSAF auxiliary lock chamber. This new trash boom would replace the current boat safety boom that is located upstream of the auxiliary lock bay.

f. Water-borne debris and ice periodically get caught on the trash screens, interrupting operation of the hydropower units. These shutdowns reduce generating time and increase maintenance costs. The LSAF hydroelectric project includes a run-of-river 9-MW generating system, a control building, substation, a transmission line, and ancillary facilities.

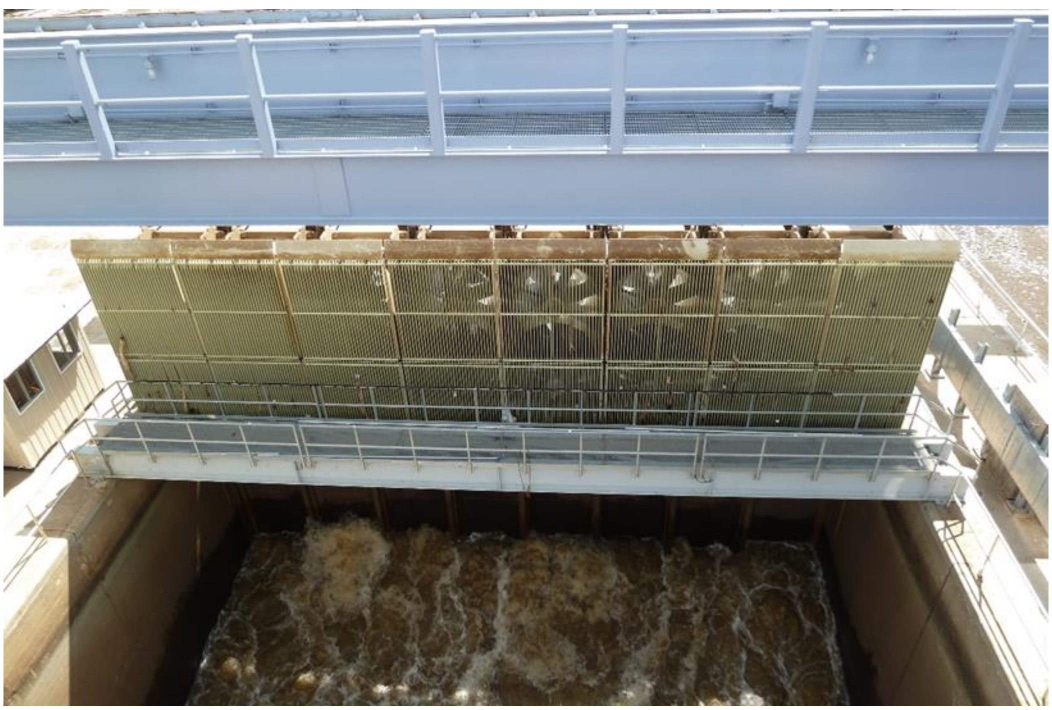


Figure 14–13. LSAF hydro plant

14–11. Ice removal

Removal of ice from lock walls can also be accomplished by manual use of jets of steam, heated water, or even saws. Steam systems have proven to be effective. Reference EM 1110-2-1612 for detailed discussion of ice removal at locks and dams.

a. EM 1110-2-1612 provides discussion on mechanical removal of ice from the lock walls and surface treatments to reduce ice accumulation.

b. Portable steam systems are available also to remove ice accumulation. These are available from several manufacturers.

Chapter 15
Power Distribution

15–1. Power system design philosophy

a. General. Comply with National Fire Protection Association (NFPA) 70. The Institute of Electrical and Electronics Engineers (IEEE) Standard 141 gives additional information about planning, voltage considerations, fault calculations, grounding, cable systems, harmonics, and more. Utilize ANSI/IEEE C2 for safe installation, operation, and maintenance of electric power and communication utility systems.

b. Risk. The level of investment in a power distribution system should match the level of risk, where $Risk = Likelihood \times Consequence$. In addition to life safety risks, the designer should consider the economic and operational impact of power system outages. Higher risk may justify more redundancy or durability.

(1) For navigation locks, USACE Asset Management uses operational condition assessment (OCA) ratings, shipper carrier costs, and baseline recovery durations to estimate economic consequences. See EC 11-2-218 for more details.

(2) The USACE Special Missions Office collects and publishes reliability statistics for various types of equipment, including power system components. More information can be found in ANSI/IEEE 3006.8. ANSI/IEEE 493 should be utilized for further guidance on reliability of power systems.

15–2. Power system arrangement

Lock and dam power supply systems are commonly arranged as either a simple radial, primary selective, or secondary selective distribution system. See Plates 78, 79, and 80 in Appendix B for example arrangements.

a. Radial power distribution system. A radial power distribution system has one path from the power source to each downstream load (see Figure 15–1). With fewer paths than a secondary selective power distribution system, a radial system has a lower cost and a lower reliability. A single-point failure can interrupt electrical power to the facility. Use a radial system where either the economics or the characteristics of the property do not justify the higher cost of a primary selective or secondary selective system.

b. Primary selective power distribution system. A primary selective system improves operational availability by reducing the consequence of losing a power source (see Figure 15–2). An automatic or manual transfer switch (MTS) disconnects from the primary source feeder and connects to the alternate source feeder. The process reverses when the primary source returns. Each primary transformer is sized to carry the full load.

(1) For a navigation lock, a typical radial system has either a main switchboard, a main panelboard, or a main motor control center (MCC) in a central control building.

Feeders extend from the central control building to a panelboard, MCC, or load at the four operating corners of the lock. See Plates 79 and 81 for example one-line diagrams.

(2) For a dam, a typical radial system has either single or redundant power feeders from a commercial utility service or from redundant power feeders supplied from the adjacent facility. The dam power source has a main disconnect switch, panelboard, switchboard, or MCC. From there, power is routed laterally along the dam to feed the loads. If provided, the redundant feeders may extend either partially or the full length across the dam, using MTSs or load-break receptacles to provide redundant power to the gates. See Plate 80 for an example one-line diagram.

(3) For smaller facilities, a typical radial system has either single or redundant power feeders from a commercial utility service. The facility power source is within a central control building on or near the structure and houses a main disconnect switch, panelboard, switchboard, or MCC. From there, power is routed laterally along the structure to feed the loads. Gate controllers may be either in the control building or in cabinets near the operating machinery.

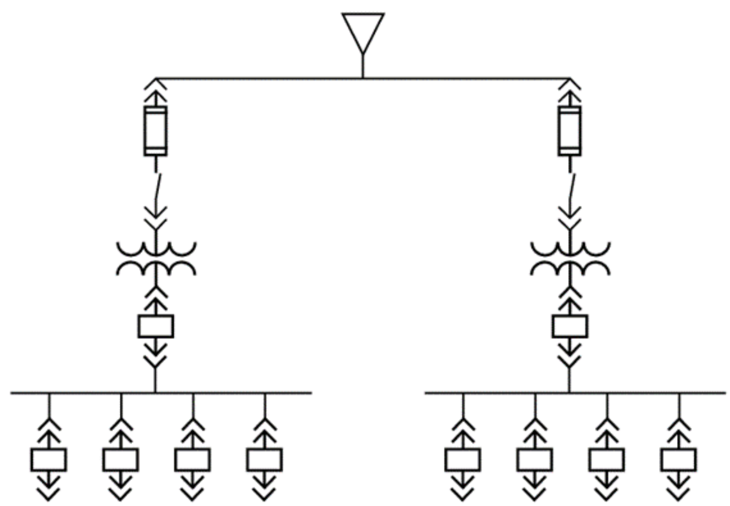


Figure 15–1. Example of a radial power distribution system

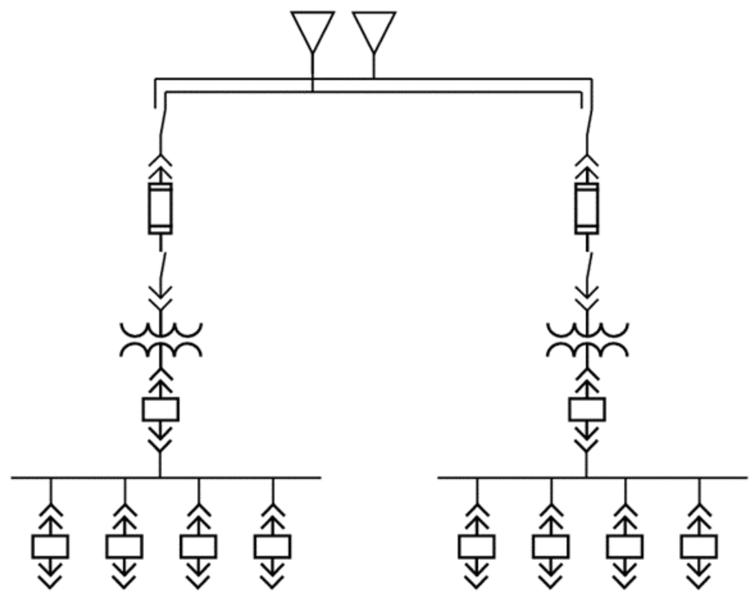


Figure 15–2. Example of a primary selective power distribution system

c. Secondary selective power distribution system. A secondary selective system improves operational availability by reducing the consequence of a feeder failure. This is done by providing more than one path from the power source(s) to critical equipment. Secondary-side feeders connect load centers through tie circuit breakers. The additional paths and equipment will be more expensive than a radial system. A secondary selective system is more complicated to operate than a radial system because the switching configurations are more complicated. See Figure 15–3.

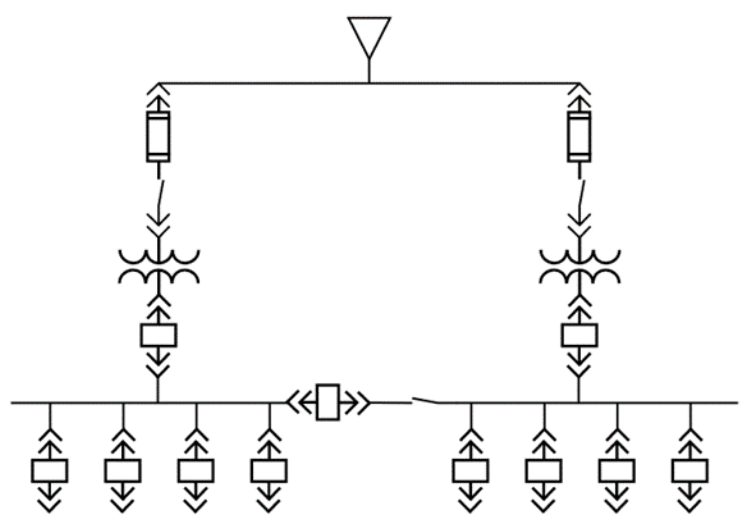


Figure 15–3. Example of a secondary selective power distribution system

(1) A typical secondary selective system for a navigation lock is provided with a main switchboard, panelboard, or MCC located in a central control building. Feeders extend from the central control building to the four operating corners of the lock to the local panelboards or machinery. The feeders form a loop around the lock. See Figure 15–4.

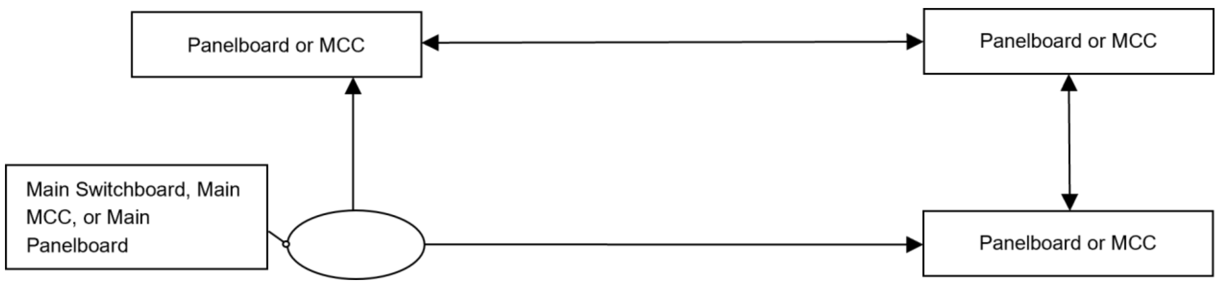


Figure 15–4. Example of a secondary selective system at a lock

(2) Use a secondary selective power distribution system when it is necessary and economically reasonable to provide redundant power paths per the risk assessment.

(3) A combined primary and secondary selective system—with two independent power sources, two full-capacity transformers, two secondary busses, and a tiebreaker between the busses—offers more operational availability. The distribution system should be configured for normal operation with half the load on each bus to prolong the transformer's life. If one transformer fails, automatic operation of the tiebreaker will quickly restore the affected bus. If a standby generator is the alternate source, normal operation should supply the full load from the primary power source. See Figure 15–5.

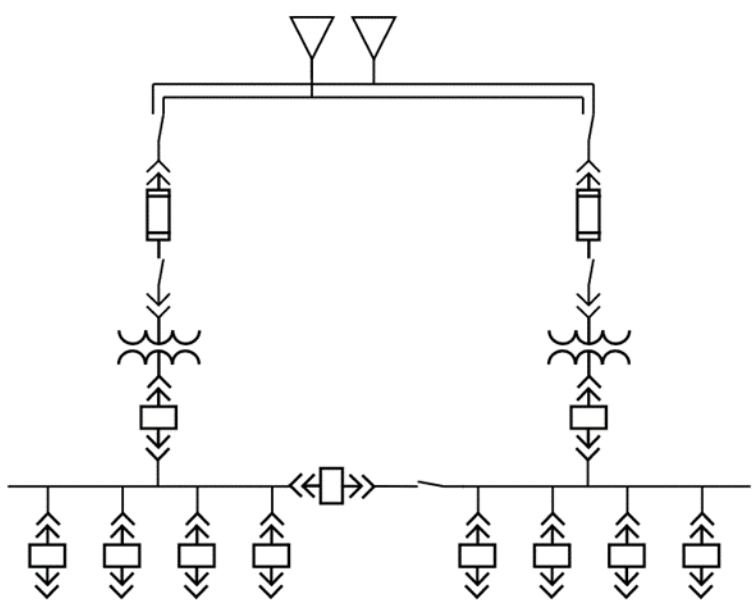


Figure 15–5. Example of a combined primary and secondary selective power distribution system

15–3. Power sources

The designer should assess the operational risk to the lock, dam, or water control structure caused by loss of power. The risk assessment should consider the consequence of the power outage and the acceptable duration of any power outage that might be experienced. The likelihood of an outage can be estimated from operational availability data published in IEEE 3006.8.

a. A primary selective topology will improve operational availability, but a second independent power service may be required as backup. The second service may be another commercial utility, a standby generator, or one of the facility's hydropower turbines. If a second commercial utility feeder provides the required backup power, it must originate from a different utility substation transformer than the primary feeder.

b. The quality of the service will affect the facility's reliability and efficiency. The electrical power supply to operating machinery is typically rated 480 V, three phase, 60 Hz.

c. Provide an optional standby power source when operating with local control or remote control. The optional standby source may be permanent or portable, and the transfer may be manual or automatic. At a minimum, provide NFPA 110 Class 6 for a 6-hour operating duration.

d. Provide a legally required standby power source when operating remotely or automatically. The legally required standby source must be permanently installed with an ATS, and it must comply with NFPA 110 requirements for Level 2 systems. At a minimum, provide NFPA 110 Class 48 for a 48-hour operating duration.

e. See the discussion of grounding options below, which includes solidly grounded wye, ungrounded delta, and high-resistance ground.

f. Each power component must be properly rated to withstand the maximum fault current rating, as determined by the fault current study.

g. The service main disconnecting means must be a circuit breaker, a switch, or a fused switch, and its size should be based on the service size.

(1) Develop the load size from the expected maximum demand. Evaluate coincident loads in each of the major facility operating scenarios to derive the maximum demand. Major operating scenarios must include normal operation, seasonal loads, and maintenance activities. The utility company usually determines the size of the service transformer based on this load information.

(2) Consider treating welding receptacles as heating loads because these circuits can be reused with space heaters for moisture control.

(3) Shore power receptacles can be installed to connect floating plants and USACE marine vessels to the facility's power system. The shore power receptacle

circuits must have sufficient capacity to start and run general machinery and tool loads, as well as critical power loads such as HVAC and refrigeration loads. Use the demand factors of NFPA 70 Table 555.12 and provide ground fault protection. Consider providing an alternate power source. See Figure 15–6.

Figure 15–6. Shore power receptacles

h. Design the power supply to ensure maximum continuity of operation, especially for primary mission requirements. Analyze reliability, availability, and cost requirements of the power system to determine the optimum equipment configuration.

(1) Normally, the source of electrical power will be the commercial power utility company. The purchasing, metering, and characteristics of the electrical supply will be coordinated with the power company. Capacity of the power source should be sized for 100% of the demand load but must be coordinated with the power utility company. Spare capacity should be coordinated with the power company as required.

(2) Under unusual circumstances, such as lack of a commercial power source, national security requirements, or where justified by cost analysis, prime power may be supplied by an alternative power source.

(3) Renewable energy sources should be considered as supplemental energy sources at navigation locks, navigation dams, and water control structures. Wind turbines, photovoltaic solar panels, and hydroelectric turbines should be considered. This equipment can be incorporated into a facility's power distribution system to provide supplemental power to reduce the total power consumption of the facility.

(4) Other energy efficiency measures are using efficient light sources, such as light-emitting diode (LED) light fixtures, and using light fixture controls to use lights only

when needed. Refer to the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) website for more information (https://www.energy.gov/eere/office-energy-efficiency-renewable-energy).

i. Electrical utility companies might offer primary metering, which means a lower cost rate per kilowatt-hour if the power is provided to the owner at distribution medium-voltage levels instead of at lower utilization voltages. Primary metering is beneficial if the facility has a large load, if it is in a remote area, and if the facility has electricians who can maintain medium-voltage system equipment. Most metering is applied at the utilization low-voltage level and includes the service transformer losses. The utility passes these costs to the customer.

(1) If the facility owns the service transformer, the facility will be responsible for maintenance of the service transformer. Maintenance and repair for medium-voltage equipment will require specialized tools, materials, electrician knowledge, training, and skills that otherwise might not be required at the facility. The commercial utility company is prepared to perform these maintenance activities. Some facilities operate and maintain medium-voltage distribution systems and have the resources to support facility-owned service transformers.

(2) A primary selective topology with two commercial electrical utility service entrances from different geographical locations might be necessary to achieve satisfactory operational availability. If one area of the electrical power grid fails, the second service entrance fed from the second geographical direction can still be used. Both service entrances might be supplied from the same commercial power utility. If considering multiple service entrances, consider coordinating with the utility company to perform a power reliability study.

(3) Two commercial utility service entrances should be considered only for large critical loads. Normally, one utility feed with a correctly sized standby generator is sufficient for a lock and dam.

(4) Consider metal-enclosed, low-voltage switchgear with 600-V draw-out vacuum circuit breakers for each supply and bus tie breaker for high-current services. The switchgear should be located near the service transformers.

(5) Each supply circuit breaker and the bus tie breaker should be remotely operated to increase personnel safety. Interlock the supply breakers with the bus tie breaker so that only two breakers can be closed at any one time. Interlocking prevents parallel operation of two sources. Include a manual disconnect switch with the tie breaker to fully isolate the tie breaker during maintenance.

(6) As a minimum, remote indication of bus voltage for each bus section should be provided with remote operation. Transfer between the two normal sources should be automatic. Transfer to the emergency power sources also should be automatic when both normal power sources fail.

(7) Redundant feeders (one feeder from each supply bus) should be provided to feed important distribution centers. Appropriate controls and interlocking should be incorporated in the design to ensure critical load sources are not supplied from the same bus. Feeder interlock arrangements and source transfer should be made at the feeder source, not at the distribution centers.

(8) Feeders should be sized based on maximum expected load with allowance for voltage drop and motor starting inrush. Feeders that terminate in exposed locations subject to lightning should be equipped with surge arresters outside the building.

(9) Normally, the auxiliary equipment for a piece of operating machinery is fed from the distribution center reserved for that machinery. The distribution system control must be evaluated thoroughly to ensure that foreseeable contingencies are covered. When providing dedicated equipment space per NFPA 70, consider future load expansions when planning egress from the space.

(10) A differential protection zone should be provided around distribution transformers owned by the facility. In switchgear and MCCs, overcurrent protective relays should trip the main breaker and the bus tie breaker to protect the bus. Ground over-current relays should be provided for solidly grounded, wye-connected systems. The adjustable tripping device built into the feeder breaker is usually adequate for feeder protection on systems using 480-V switchgear.

j. Additional power sources include standby generators, hydro-turbine power, batteries, and supplemental renewable energy sources. The type of source selected should be based on the economics, feasibility, and requirements of the application. Loads served by alternate power sources should be limited to those required to directly support essential or mission-critical equipment, lighting, environmental control, personnel and equipment safety, alarm systems, and shutdown and startup equipment necessary for mission accomplishment.

k. Some facilities have hydropower generation capability, which is a sustainable power source. When installed, hydropower is typically connected to provide power for the facility. Excess power not used by the facility is provided to the electrical power grid and measured for revenue. Synchronizing or paralleling switchgear and controls are required to connect the hydropower turbine generator to the power grid.

l. A standby engine-driven generator set may be provided when backup power is deemed necessary. See Figure 15–7.

m. Navigation locks and dams and water control structures should be equipped with a backup power source with enough capacity to operate the navigation lock, the spillway gate motors, the navigation lock bubbler air compressors, shore power receptacles, and all essential auxiliary loads on the structure.

Figure 15–7. Standby diesel generator supplied by external fuel tank at a lock

15–4. Generators

Configure the generator as a separately derived system with a four-pole transfer switch if the generator has a grounding electrode. If the generator does not have a grounding electrode, configure the generator as non-separately derived with a three-pole transfer switch and with no bond between neutral and ground at the generator. Comply with NFPA 110 and UFC 3-540-01 as applicable.

a. Considerations. It is also important to provide local control at the standby generator for testing and exercising the generator system. Generator system operation might require a load-shedding plan if the generator capacity is limited. For example, lock dewatering pumps may be powered by temporary generators instead of providing permanent capacity as part of the standby generator. Provide a load bank if generator tests cannot be performed with normal loads per NFPA 110.

b. Configuration. Standby diesel generator sets consist of an internal combustion engine directly coupled with an electrical alternator (synchronous or asynchronous). The 60-Hz frequency of the electrical generator is regulated by the driving speed of the combustion engine and electronic controls. The diesel engine and generator are mounted on a common frame. Smaller units (up to 5 kW) are portable and able to be moved by hand. Larger units (up to approximately 150 kW) are towable.

c. Location. Permanent generator sets can be installed in a structure, or they can be provided integrally enclosed, such as housed inside a prefabricated enclosure. These enclosures integrate the engine-generator set and fuel tank into the enclosure design. Otherwise, the generator must be installed in a suitable room that has the capacity to provide fresh air, duct-heated air from the radiator end of the generator set, suitable combustion exhaust pipes, a critical silence exhaust muffler, and a fuel-piping system or tank.

d. Engine cooling system. The cooling system is normally a fan-operated, water-cooling system that uses a radiator. For small units, the cooling system is mounted with the motor generator unit on the same frame. Bigger units need separate cooling systems and, sometimes, separately mounted radiators.

e. Electrical control. The electrical start and stop controls are mounted either directly on the generator or in a separate control cubicle. The controls might be manual, or the generator might automatically start after a power failure. The generator can be programmed to automatically switch back to the normal power supply after it is restored. A re-synchronizing switching feature provides an uninterrupted transfer of the power supply to the public grid after power return.

f. Sub-base tank. The diesel fuel tank is usually mounted within the frame of the generator set unit or under the integral housing enclosure. This sub-base type of fuel tank resides between the frame skid beams or between the structural members of the generator's integral housing. The capacity of this tank can be custom sized to range from a 1-hr capacity to a 24-hr operation capacity or more, depending on the operational requirement. See Figure 15–8.

Figure 15–8. Standby diesel generator on sub-base fuel tank

g. Separate and bulk tanks. To operate the generator for longer periods, separate indoor fuel tanks or bulk outdoor tanks are needed. Bulk tanks can be buried or above ground. To protect the environment from leaked fuel, the entire fuel system must be installed according to codes. The Environmental Protection Agency (EPA) regulates fuel tank installation, and NFPA and Underwriters Laboratories (UL) regulate fuel system design. Typically, double-walled tanks, double-walled piping, and containment design are required.

h. Engine exhaust system. The engine exhaust system must be designed according to environmental requirements for noise and exhaust regulations. Also, the ventilation system must be designed according to environmental requirements. Generators installed indoors will require a ventilation system capable of both exhausting air and drawing air into the room (make-up air). Larger generators will exhaust large amounts of air through the cooling system radiator. This air must be replaced, or else negative pressures will result in the room.

i. Starting. Starters are normally battery operated by either 12-V or 24-V DC. Batteries typically are provided with a 2-A trickle charger for regulated charging and continuous readiness. For large engine-generator systems, starters using compressed air are possible. Genset enclosure heaters or jacket water heaters can be used in cold environments to help engine starting.

j. Sequencing. The diesel generator is started after a power cutoff with a time delay of a few seconds up to some minutes. ATSs transfer power from the utility grid to the generator system. A generator needs time to cool down before the engine can be stopped, even after the normal power is restored and the loads have switched back to it.

k. Advantages. Diesel generators are available in sizes starting from a few kilowatts up to more than a megawatt and, therefore, can be used to feed nearly all kinds of machinery. In areas or regions where no commercial utility power supply is available, it is also possible to use this equipment for a permanent power supply.

l. Disadvantages. Generators might not be efficient or usable for systems that can endure short interruptions in power supply without significant consequences. The time delay setting, which allows the generator set engine to reach steady state before transferring, might be a longer delay than the duration of the power outage. A generator should be used only in combination with an uninterruptible power supply (UPS) system for the power supply of computer systems.

m. Maintenance.

(1) Diesel generators need frequent maintenance, and it is necessary to operate them at least once a month, to exercise them, to assure that they are maintained in an operable condition. The generator should be exercised monthly for 30 minutes according to Chapter 8 of NFPA 110. The generator must have enough load to maintain minimum exhaust temperature, which can be 30% of the standby nameplate kilowatt rating. The load can be operating machinery or a load bank.

(2) It is possible with permanent diesel generators to program the system to exercise itself automatically. Multiple generator manufacturers offer this capability as a control feature.

n. Protection systems. Generators are not able to deliver high short-circuit currents. Circuit breakers and other overcurrent protection systems must be selected per the short-circuit capacity of the generator to provide safe operation.

o. Sizing. When sizing a generator, consider motor starting currents, nonlinear loads, transformer inrush, and UPS systems to ensure the generator will start and run all critical loads connected to it. Use commercially available generator sizing software provided by a generator manufacturer to determine the required rating.

15–5. Uninterruptible power supply

A UPS is important for navigation locks, navigation dams, and water control structures that use PC systems or PLC system equipment. The UPS provides clean sinusoidal power with battery backup. Clean, reliable power is an important factor in assuring long life of a computer system. UPS systems should be used to supply power for computerized systems during controlled shutdown or when bridging the transfer to another power source.

a. Large, harmonic currents caused by nonlinear loads should be reduced as applicable with larger, grounded (neutral) conductors and with K-rated transformers suitable for nonlinear electronic loads. A UPS does not eliminate harmonics, and multiple harmonic-generating devices supplied by a UPS could affect each other. The power system design should consider the harmonic distortion caused by the UPS on its line side. UPS should be separately circuited.

b. For PLCs or computers in a central location, a large floor-mount UPS might be suitable for providing backup power and surge protection. Several smaller floor-mounted UPSs also can be used.

c. For remote standalone PLCs and computers, a small UPS should be provided. Units should be sized for all the computer components, including the PLC chassis and all internal devices and the video display monitor. Peripheral components such as printers, modems, and network hubs might or might not need continuous power. Consider connecting these devices to the UPS, however, to provide them with lightning and surge protection.

d. A rack-mounted UPS can be used for rack-mounted computer equipment. Depending on the application, several rack-mounted units might be required because of their limited power capacity. It might be beneficial to use a UPS that includes communications capabilities so the UPS can be monitored and controlled with software through a communication link to the PLC or another PC.

15–6. Automatic and manual transfer switches

An ATS is used to automatically transfer a facility's critical loads from the normal power source to the standby power source whenever the normal source fails. Most navigation locks, navigation dams, and water control structures have diesel-driven standby generators. The generator is usually tied to the facility's main distribution bus with a transfer switch or with manual, trapped-key interlocks on the main circuit breakers (Figure 15–9).

a. ATSs are commonly used for transferring power from the normal source to the standby generator unit and back again because they are convenient, smart, reliable, and fast. ATSs can be furnished as open-type construction for installation into an MCC or switchboard-type construction with digital communication to a control system for status information. ATSs also can be provided in a separate enclosure with control and instrumentation provided on the door of the ATS enclosure.

b. An ATS can be susceptible to lightning. A surge protection device (SPD) might be necessary. The SPD might be offered by the manufacturer either as an option integral to the ATS or installed upstream of the ATS in the power distribution system.

c. A PLC can control the ATS to prevent it from switching back to the normal source until operationally convenient. For example, the navigation lock operator might need to complete a lockage before the power is interrupted again. This can save unnecessary wear and strain on the machinery. Also, a PLC can perform orderly shutdowns of facility equipment before the ATS transfers power back to the utility.

d. Standby generators are usually smaller than the normal power supply. A PLC can be programmed to stagger start motors, turn off non-critical lights, limit the use of air compressors, and perform other load-shedding procedures, as appropriate. These actions avoid overloading the standby generator.

e. Remotely located operators for locks and dams might not know that power has been interrupted or that the facility is operating from a standby generator. Such information, available from ATS communication to a PLC or an alarm annunciator panel, is useful for identifying the power outage and for coordinating corrective actions necessary for repair and restoration of the incoming electrical power service.

f. An MTS may be used for facilities when its operating personnel are available, and it is either not required or not desired to immediately transfer loads to the standby power source. An MTS can be a separately enclosed stand-alone unit or integrated into a switchboard or MCC. An MTS can provide auxiliary output dry contacts for signal or control. Also, an MTS can provide optional digital communication modules for remote monitoring.

Figure 15–9. Low-voltage motor control center with programmable logic controller cabinet

15–7. Power distribution equipment

Select the power distribution equipment, such as a main switchboard, main MCC, or main panelboard, based on the specific design application for each facility. Follow requirements in NEMA 250, NEMA Industrial Control and Systems (ICS) 1, NEMA ICS 2 and NEMA ICS 6 as applicable. Follow UFC 3-550-01 as applicable. Redundancy and spare capacity in electrical power distribution equipment comes with a higher cost; however, the addition of spare vertical structures and/or spare empty buckets allows for future expansion if the electrical loads increase. See Figure 15–9 above.

a. Arrangement. A radial four-corner MCC arrangement supplied from a centralized location is typical for large navigation locks with 1,200 x 110-ft (366 x 33.5-m) chambers. This arrangement reduces the quantity of long power cables. Medium locks with 600 x 110-ft (183 x 33.5-m) chambers might consider using a four-corner radial arrangement. Smaller navigation locks and most dams need only one centrally located MCC or switchboard to distribute power and provide controls for the facility unless a higher operational availability is required.

b. Electrical loads. Group all electrical loads according to their distribution center (for example, switchboard, MCC, or panelboard). Determine the ampacity, duty cycle, and diversity factor. Perform connected and demand load calculations to determine the rating of the main circuit breaker and horizontal bus at each distribution center. Consider future expansion when selecting the ampacity ratings. Perform short-circuit, motor-start, and coordination calculations to determine current interrupting ratings (ampere interrupting current [AIC]), circuit breaker types, and circuit breaker short-circuit trip settings.

c. Voltages. To the extent practical, designers should use voltages under 1,000V for supply to facilities. Higher voltages, greater than 1,000,V, present higher dangers and safety concerns, require specialized training and staff ,and present challenges to maintenance staff for O&M of facilities. NEMA ICS 3.1 provides requirements for medium voltage systems.

d. Voltage drop. Calculate the voltage drop to determine the size of electrical wires and cables that have long lengths. Voltage drop must not be greater than recommended by NFPA 70.

e. Distribution equipment locations. Provide a sheltered, protected electrical room or other suitably protected area for the electrical distribution equipment. These areas should have easy access and must have clearances per NFPA 70, National Electrical Code (NEC). The areas should have efficient means to route cables to electrical raceways, such as gallery cable tray systems, lock wall manhole and conduit duct banks, surface conduits, bus ducts, or surface cable trenches.

f. Flood protection. Install distribution equipment either above the design flood elevation or provide other protection during a flood. Consider providing at least 18 in. of additional freeboard above the flood design elevation to protect from floodwater wave activity when installing electrical equipment inside or on top of elevated structures. If the existing switchboard, MCC, or power panelboard is located in a central structure, consider locating the new main electrical power and control equipment in the same protected areas when rehabilitating a facility.

g. Utility metering. The designer should consider required and supplemental power measurement and meters. The utility revenue meter for new or changing facilities must be coordinated with the local power utility company. Typically, the facility provides the meter socket and the power company provides the revenue meter and meter instrumentation transformers.

h. Power monitoring. In addition to the utility revenue meter, the designer should consider incorporating a separate, facility-owned digital power panel meter to measure the power characteristics in the main switchboard, main MCC, or main panelboard. Identification of major changes in power use, current, and voltage can support monitoring and troubleshooting. Digital power panel meters can be surface mounted, mounted flush through cabinet doors, or separately housed in their own enclosure. Smart power meters can be connected to a power-monitoring system.

i. Switchboard.

(1) A switchboard combines and centralizes several electrical features within a single assembly. See Figure 15–10. A main switchboard used as the facility’s central electrical hub may be configured with either standard, factory-assembled, or custom-fabricated sections. The custom-fabricated sections can be assembled to include combinations of the following electrical features:

(a) A utility service entrance and metering section,

(b) A main service disconnect circuit breaker section,

(c) A transfer switch section,

(d) A circuit breaker distribution or panelboard section,

(e) A motor combination starter and controller section,

(f) A lighting transformer and lighting and receptacle panelboard section,

(g) A general controls section (either PLC or relay-based controls), and

(h) Other special sections if required.

(2) The main switchboard typically is installed in the central control building on a concrete housekeeping pad with the electrical cables entering through the open bottom of the enclosure.

(3) The switchboard fault current rating must exceed the calculated results of the short-circuit analysis, and the switchboard must include a grounding bus.

j. Switchgear.

(1) Switchgear is like a switchboard, but switchgear is easier to maintain and modify. It uses only power circuit breakers, and working space is required on front and rear. The testing requirements are generally more rigorous.

(2) Double-ended switchgear has a transformer and a bus on each end to improve availability. A tie-breaker interlocks with the feeder breakers to allow one transformer to supply both busses. Include a manual disconnect switch with the tie breaker to fully isolate the tie breaker during maintenance. See Figure 15–10.

Figure 15–10. Low-voltage double-ended switchgear with power circuit breakers

k. Medium-voltage circuit breaker.

(1) Medium-voltage circuit breakers can provide power to larger loads such as dewatering pumps. These breakers typically fall within the 5-kV range, and vacuum interruption is preferred for indoor installations. Protective relays use current transducers and potential transformers to detect abnormalities and command the breaker to trip. See Figure 15–11. Utilize NEMA ICS 3 and NEMA ICS 3.1 as applicable.

Figure 15–11. 5-kV 1,200-amp vacuum circuit breaker

(2) Set the circuit breaker trip settings to selectively coordinate the short-circuit protection system. Size the AIC rating to exceed the calculated symmetrical fault current.

(3) If a vacuum circuit breaker feeds a nearby dry-type transformer with low basic impulse insulation level (BIL) and the circuit length is under 200 ft, certain switching events can cause the transformer's insulation to fail. If these conditions apply, the designer must consult the manufacturer to determine if a switching transient study and mitigations are necessary. See the IEEE whitepaper titled "Transformer Failure Due to Circuit-Breaker-Induced Switching Transients" (Shipp et al. 2010) and IEEE C57.142.

l. Transformer.

(1) When installing distribution transformers indoors, account for the added heat in the room to avoid premature insulation failure.

(2) If nonlinear loads on the transformer are significant, select a transformer with an appropriate K-factor to reduce harmonic distortion. At a minimum, K-factor

transformers typically include a 200%-ampacity neutral conductor and electrostatic shielding between the primary and secondary windings. For a typical 6-pulse adjustable speed drive (ASD) without a phase-shifting transformer on the primary side, the K-factor is 6. See IEEE C57.110.

m. Motor control center.

(1) An MCC combines and centralizes several electrical features within a single, multi-section, multi-compartment assembly. See Figure 15–9. Follow requirements of NEMA ICS 2.3 as applicable. Standard off-the-shelf MCC construction makes expansion and modification easy. Combination motor-starting compartments (also called buckets) distinguish MCCs from switchboards. An MCC can include the following features:

(a) Bus connection to switchgear or switchboard,

(b) Circuit breaker distribution section,

(c) Combination motor starter and controller buckets,

(d) Lighting transformer section,

(e) Panelboard section,

(f) General controls section (either PLC or relay-based controls), and

(g) Other control system and special compartments if required.

(2) A smart MCC allows monitoring and control of the power distribution equipment within it. PLCs, intelligent circuit breakers, network lighting panels, ATSs, variable speed drives, relays, and motor starters are available with standard MCC construction.

(3) The MCC fault current rating must exceed the calculated results of the short-circuit analysis, and the MCC must include a grounding bus. Motor controllers that are out of sight of the motor must include a provision to be locked in the open position.

(4) When designing MCC systems for new lock construction, consider a four-corner, secondary-selective arrangement. Most new facilities can afford a four-corner secondary-selective arrangement. One of the four corners can feed most loads without significant over-sizing of conductors to account for voltage drop. It is preferable to install each of the distributed MCCs inside control buildings that can shelter the equipment from the environment.

(5) When designing MCC systems for a new dam, consider tapping the main feeder to supply a fused disconnect for the gate controllers. The tap rule of NFPA 70 Article 240.21(B)(5) would apply. Transfer switches or switch-rated receptacles on the load side of the overcurrent protective device can transfer load to the redundant feeder. Otherwise, supply gate controllers from a central location.

n. Load verification. Facility loads often change over time; therefore, the facility's loads must be verified for upgrades, modifications, or rehabilitations.

o. Construction considerations. Consider installing equipment in the same space as the existing equipment to take advantage of existing raceways or other features of the project. Temporary distribution equipment and cables may be installed to maintain operation while the existing equipment is removed, and the new equipment is installed. Alternatively, consider installing equipment in a new space to allow more construction to occur before the outage. Existing equipment would provide power for operation during construction until loads are changed over.

15–8. Power utilization equipment

a. Panelboard. A panelboard can be used as the power distribution center for a facility. Metering, motor, lighting, or other equipment controls cannot be integral to the equipment and must be provided separately. The panelboard can be the service entrance equipment, if so rated, and the main circuit breaker can act as the main service disconnecting means. The power distribution panelboard can be fed by or can feed redundant feeders by using trapped-key interlocked circuit breakers in an MTS arrangement.

(1) The use of panelboards as the main power distribution equipment should be avoided where practical, with their usage more focused as sub-panels. Panelboards require more work to access the equipment, which means increased potential for equipment failure and increased safety issues due to having to remove the front panel for access, tighter spaces for pulling cable, entrances conduit in lieu of being mounted over a riser for cable entrance, they are wall mounted in lieu of free standing and panelboards limits mounting capability.

(2) Voltage drop at the load might require oversizing the feeder and branch cables. Verify the size of conductor termination lugs in the panelboard to ensure they accept oversized cables. Provide properly sized terminal blocks to facilitate connection of oversized field conductors, if necessary.

(3) The fault current rating and circuit breaker's fault current rating must exceed the calculated results of the power system short-circuit fault current analysis. The panelboard must include a grounding bus.

b. Low-voltage circuit breaker. Standard low-voltage (0 to 600 V) molded-case circuit breakers typically provide feeder and equipment short-circuit protection. Consider installing bolt-on type circuit breakers to reduce the risk of circuit breakers loosening from the bus over time. Provide cable terminals sized to accept the intended conductor, which might be to offset voltage drop. Auxiliary contacts, under-voltage trip, shunt trip coil, motorized reset mechanism, and other accessories are available.

c. Power receptacle.

(1) Coordinate with facility O&M personnel to determine where 480-V power receptacles are needed. For example, a 480-V receptacle might be installed next to a crossover manhole to feed dewatering pumps. Similarly, 480-V receptacles with an integral interlocked safety switch might be provide shore power to USACE marine vessels. See Figure 15–12 and Figure 15–13.

(2) All power receptacles must be grounded and rated for the application in which they will be installed. Consider voltage drop when sizing these receptacle feeder circuits. As needed, install ground fault circuit interrupter (GFCI), weatherproof (while in use), 120-V convenience receptacles around the facility.

Figure 15–12. Example 1 – Shore power receptacles

Figure 15–13. Example 2 – Shore power receptacles

d. Adjustable speed drives.

(1) NEMA ICS 7.2 discusses ASD applications. VFDs are the most common type of ASD, and they can be configured for different types of loads. Gate loads require constant-torque while centrifugal fan and pump loads require variable-torque. See Chapter 15 for control system considerations.

(2) Ensure the ASD has proper overload settings to protect the motor. If the motor will operate at very low speeds for significant amounts of time, consider totally enclosed non-ventilated (TENV) or totally closed blower-cooled (TEBC) construction for motor cooling. Totally enclosed fan-cooled (TEFC) construction might not provide adequate cooling when operating the motor in reverse.

(3) The motor should be inverter-rated to avoid insulation failure caused by voltage spikes from the pulse-width modulated (PWM) drive output. Consult the manufacturer of the ASD for recommended motor lead restrictions. Specialized ASD cables are discussed below.

(4) If the load can drive the motor to generate power, consider including an external braking resistor with thermal protection. The ASD should have the ability to skip motor speeds that resonate with the load and increase vibration.

(5) If the power source has high-resistance grounding (HRG), the ground fault current might be too low for the ASD to detect. Consider adding a ground fault relay and current transformer. Since HRG allows the ASD to operate with one phase essentially grounded, ensure the internal insulation of the ASD can tolerate corner grounding with elevated voltage to ground from the other phases.

(6) When attempting to reduce harmonic distortion, the point of common coupling (PCC) for application of IEEE 519 is typically the line-side of the VFD where it connects to other loads. The VFD's load conditions will change the harmonic distortion, and it might be necessary to take measurements on the line-side of the VFD after installation to optimize the harmonic mitigation.

e. Low-voltage electrical power cable – cable ratings and types.

(1) Low-voltage cables are suitable for applications rated 600V or less. Low-voltage, single-conductor, and multi-conductor cables applied to navigation locks, navigation dams, and water control structures will be rated 90 °C, 600 V, either solid copper wire or stranded copper wire for circuit voltages of 120V through 480V.

(2) Low-voltage electrical wire and cable must comply with NEMA WC 70.

(3) Cables must be rated for the application in which they are intended to be used. The manufacturer will mark the size and ratings on the jacket of the cable. Electrical cables exposed to sunlight should be rated UV light resistant.

(4) Minimize splices because their long-term reliability is relatively low. Do not splice cables in normally submerged locations. Splices prone to occasional submersion must be non-re-enterable. Otherwise, splice in junction boxes elevated above the expected water level. Splices must be performed by qualified personnel and inspected before energizing.

(5) Electrical cables originally installed at 1930s-era navigation locks were lead-covered type cables, which provided integral waterproofing and armoring and thus did not rely solely on the cable raceway system for physical protection. Modern electrical cables available as continuously welded, corrugated aluminum armor Type MC (metal clad), Type AC (armor clad), and bonded-shielded cables (adhered aluminum foil with overall jacket) can provide a level of waterproof and mechanical physical protection for raceways that expose the cables or allow the cables to be submersed in water.

(6) Electrical cables installed in a raceway system receive mechanical and environmental protection and do not require integral armor or cladding. Instead, the cables can be provided with standard jacket material suitable for any moisture inside the raceway. Conduit installations outdoors above grade or exposed to impact from mechanized equipment must be rigid metal conduit.

(7) Select jacket and insulation material suitable for the environmental operating temperature, extreme temperatures, and the temperature range. Cables expand and contract longitudinally, and they must be installed with adequate slack length to allow expansion and contraction inside the raceway. Slack is also important when cables cross structural expansion, contraction, or deflection joints.

(8) Rubber, synthetic rubber, and cross-linked polyethylene (XHHW-2) cable jacket and insulation materials perform better in hot-cold ambient temperature cycles and are the preferred choice for outdoor installation. Thermoplastic-type jacket and insulation

materials (THHN and THWN) might crack when exposed to extreme temperature cycles. Solid conductors are easier to terminate, while stranded conductors are more flexible.

(9) Wire and cable insulation must pass the vertical cable tray flame propagation test of NEMA WC 57 for control and instrumentation cables and the test of UL 1685 or IEEE 1202 for power cables. Use UFGS 26 05 19.00 10.

(10) For ASDs, selection of a power cable has a modest impact of voltage transients with typical magnitudes reduced by 15%. Conversely, voltage transients can also damage the insulation of the power cable, and for this reason NEMA ICS 7.2 says polyvinyl chloride (PVC) (type THHN or THWN) less than 30 mils thick is not suitable for drive cables in wet locations. XPLE (type XHHW-2) insulation will perform adequately, and load filters will further reduce the voltage transients.

(11) Asymmetrical cable construction increases the common mode current in ASD circuits. Symmetrical cable design and a low-impedance path to the drive will reduce damage to equipment. Oxidation and corrosion will degrade the impedance of overlapping and interlocking shields, so the best drive cable uses continuously welded aluminum armor with three ground wires in a symmetrical arrangement. In Figure 15–14, the cable on the left has an overlapping tape shield, while the cable on the right has corrugated aluminum armor.

Figure 15–14. Adjustable speed drive cables with shielding and symmetrical ground wires

15–9. Grounding and lightning protection

a. Grounding system. A grounding system must be installed in compliance with NFPA 70. Bond all metal equipment and significant metal structures to the facility's equipment grounding system. Although inactive, ANSI/IEEE 142 also provides guidance for grounding systems.

b. Lightning protection. Assess the need for lightning protection using Appendix L in NFPA 780. The design and installation of necessary lightning protection system features must be provided according to NFPA 780 and UL 96A and UFC 3-575-01. Grounding electrodes for all systems must be bonded together. If a facility has operated without incident for decades and the facility's mission has not changed, it probably does not need a lightning protection system.

c. Grounding system types. Solidly ground Wye, ungrounded delta, and HRG systems are permitted. Ungrounded delta grounding systems were common in the early 20th century when many of the locks and dams were built, but modern industrial installations with continuous processes tend to use HRG schemes. Table 15–1 gives a summary comparison of common grounding schemes. Implications for arc flash reduction are discussed below, and implications for ASD are discussed above.

Table 15–1
Comparison of common industrial grounding schemes

	Ungrounded Delta	**Solidly Grounded Wye**	**High-Resistance Ground (Delta or Wye)**
Ground fault overvoltage	High	Low	Low
Ground fault overcurrent	Low	High	Low
Ground faults tolerated	First	None	First
Ground fault tracing	No	No	Yes, with pulser
Line-to-neutral loads	No	Yes	No

15–10. Power quality and surge suppression equipment

a. Surge protection equipment. Provide surge protection for power distribution and computer-based control systems of locks and dams. Follow the requirements of UFC 3-520-01 for surge protective devices.

b. Power monitoring equipment. Provide advanced metering systems with monitoring capability for any vertical construction projects over 5,000 gross square feet and greater than $3 million to comply with ER 1110-2-8173. Otherwise, consider providing advanced metering systems for local indication, control, and monitoring of the facility's energy use. Switchboards and MCCs can include smart meters. Any changes or imbalances in measured electrical parameters might identify problems and assist in troubleshooting.

15–11. Arc flash

a. The designer must use the detailed incident energy method to analyze arc flash hazards before installation. Utilize EP 385-1-100 and ER 385-1-100. Unless otherwise arranged, the designer must also provide coordinated protective device settings for use in new or modified equipment. Lowering the arc flash hazard to an acceptable level of risk will usually be prioritized over perfectly coordinated protection and maximum uptime.

b. The power distribution system can change significantly between arc flash label updates, and record drawings are not always correct or complete. For this reason, field verification of protective devices and other equipment is strongly recommended before updating arc flash labels.

c. Removing or reducing arc flash hazards during the design phase is more effective and efficient than using warnings, administrative controls, and personal protective equipment (PPE) after installation. None of the arc flash reduction methods listed below will apply for all installations. Some methods reduce available fault current, others decrease duration of the arc, and others increase distance to personnel. A combination of methods will yield improved risk reduction. See NFPA 70E, Annex O.2.3 for more details.

(1) Remote racking devices allow an operator to stand outside the arc flash boundary while opening, closing, connecting, or disconnecting power circuit breakers or when opening or closing isolation switches. The likelihood of causing an arc flash is higher during these tasks. When installing new switchgear, consider including any necessary mounting provisions for external remote racking devices.

(2) For control systems, reducing the operating voltage below 50 volts will eliminate the need for energized work permits or arc flash analysis per NFPA 70E, particularly if the power supply is small.

(3) NFPA 70E, Annex O.2.3 says, "a great majority of electrical faults are of the phase-to-ground type." HRG reduces the current of the first ground fault by adding a resistor between the grounding electrode conductor and the system neutral point. Usually 10A or less, the ground fault current is unlikely to escalate into a line-to-line fault or to cause an arc flash. HRG will not reduce the calculated incident energy of an assumed three-phase fault, however, it will reduce the likelihood of an arc flash. See the grounding and ASD discussions for more details.

(4) Zone-selective interlocking (ZSI) between coordinated circuit breakers can reduce the incident energy of an arc flash. When a fault occurs between two breakers, the upstream breaker will trip without the intentional delay for coordination. ZSI requires an extra communication cable between the breakers. A twisted-pair copper cable between low-voltage breakers will limit the ZSI signal to about 250 ft. for guaranteed operation, while fiber optic cables between protective relays have no effective limit.

(5) Maintenance mode switches on a circuit breaker have a similar effect. Activating the switch will change the breaker's trip settings to provide faster protection at the expense of coordination. Maintenance mode switches can reduce the arc flash hazard when testing for absence of voltage on a feeder or bus.

(6) Optical sensors detect light from an arc flash that occurs within an enclosure and cause the upstream breaker to trip without delay. A protective relay monitors the sensors and issues the trip signal, and the faster response time reduces the incident energy. Figure 15–15 shows an optical point sensor in a circuit breaker compartment.

Figure 15–15. Arc flash optical point sensor in 15-kV breaker enclosure

(7) Enclosure cooling systems can reduce the likelihood of an arc flash. When the heat in a cabinet exceeds the wire insulation’s rating, the failed insulation can expose the conductor to ground faults. The designer should estimate the heat load in control cabinets to determine if cooling will improve reliability. Free calculating tools are available online.

(8) The secondary bus of a substation transformer is notorious for high arc-flash hazards. Differential protection of the transformer can include the secondary bus by relocating the current transformers. Differential protection compares the amount of power entering and exiting the zone of protection, and if the difference is significant, the protective relay trips circuit breakers on both sides of the zone. Since differential protection is sensitive and does not include intentional delay, it can be faster than coordinated overcurrent protection.

(9) Current-limiting reactors reduce the magnitude of a fault by adding inductive reactance to the circuit. The large inductor only adds impedance during fault conditions, and the passive design requires little maintenance. Consider using reactors when the available fault current from the utility or other large power source exceeds reasonable equipment ratings. Figure 15–16 shows an outdoor current-limiting reactor.

(10) Cable limiters are fusible cable connections that can reduce the duration and magnitude of a fault that would otherwise damage the cable. Cable retrofits of parallel service entrance conductors can easily incorporate the devices. Since the cable is crimped onto the limiter, the cable must be re-terminated and shortened after the fuse blows. An arcing fault might not be sufficient to operate the fuse.

(11) Arc-resistant switchgear increases the distance between personnel and an arc flash by redirecting the incident energy through plenums to a safer location. Retrofit designs have difficulty finding extra space for the plenums, and only the Soo Locks are known to have arc-resistant gear.

Figure 15–16. 480-volt current limiting reactor for 2-megavolt ampere service transformer

(12) Arc-quenching switchgear reduces the arc duration and increases the distance to personnel by sending the arcing energy to a controlled location within the gear. A protective relay uses optical sensors to trip the upstream device and create a low-impedance path for controlling the arcing energy. The breaker-sized quenching device must be replaced after each event.

(13) Gas-insulated medium-voltage switchgear (GIS) is arc-resistant, requires less space, is more reliable, and requires less maintenance than typical air-insulated gear. The SF6 (sulfur hexaflouride) gas is non-toxic because it is not used to extinguish the arc in the vacuum breakers. GIS typically sits on a platform to accommodate cables entering from beneath. The initial cost is higher, but the life cycle cost might be lower.

(14) Inspection windows allow condition assessment of bolted electrical connections and other equipment without exposing the personnel to energized conductors. Figure 15–17 shows an example installation. Rather than open the enclosure, personnel use infrared cameras to measure the temperature through the inspection window. With the doors closed, the enclosure provides some protection from arc flash hazards and reduces the likelihood of human error causing a fault.

Figure 15–17. Inspection window in 15-kV disconnect switch

Chapter 16
Motors

16–1. General

Electric motors are required for both hydraulic drive systems and electromechanical drive systems. Pump motors are also common. The designer should reference EM 1110-2-3105 for more discussion on motors specific to pumping applications. Constant-speed motors of either the squirrel-cage induction or synchronous type are preferred. Both squirrel cage and synchronous motors are available in speed ranges and sizes that cover most requirements. An electric motor for a miter gate drive is shown in Figure 16–1.

a. Full voltage starting. All motors should be designed for full-voltage starting, even if incoming power limitations indicate that some form of reduced-voltage starting is required and applied.

b. Contractual requirements and UFGS specification sections. The contractual requirements for most of the induction and synchronous motors are described in UFGS 26 29 01.00 10 and UFGS 26 29 02.00 10. These references provide detailed requirements for common motor features such as frames, enclosure type, winding insulation, winding heaters, thermal protection devices, moisture sensing devices, overspeed design, anti-reversing device, and core construction.

c. Shaft type. Motors can be furnished with either a hollow shaft or a solid shaft. Hollow shaft motors are usually available only up to about 750 kW (1,000 hp). The hollow shaft motor provides a convenient means to adjust the impeller height.

Figure 16–1. Miter gate drive motor, Lock 5, Mississippi River

d. Motor nameplate. Motor nameplate ratings are typically listed at "full load." Since voltage and current are inversely proportional, if a motor is trying to produce the same horsepower regardless of the voltage (within "normal" operating voltage variance), then as the voltage dips, the current will proportionately increase. This becomes a concern for overheating (I^2R losses), because as current goes up (when voltage dips too far), heating goes up exponentially. For example, a "480V" motor typically will have a nameplate rating of 460V, for typical operational heating characteristics. Similarly, a "208V" motor would have a nameplate rating of 200V. Or a "240V" motor would have a nameplate rating of 230V.

e. Motor moisture drains. Totally enclosed fan-cooled electric motors often have a NEMA 4-type moisture drain installed on the bottom side of each end bell (2 total). These drains need to be periodically removed and cleaned. If these drains are not periodically cleaned, it can lead to long-term damage to the motor.

16–2. Induction motors

The squirrel-cage induction motor has a stator winding that produces a rotating magnetic field that induces currents in a squirrel-cage rotor. The squirrel cage consists of several metal bars connected at each end to supporting metal rings. Current flow within the squirrel cage winding produces the torque necessary for rotor rotation.

a. Squirrel cage induction motors have very simple construction, with no electrical connections to the rotor, and hence they possess a very high degree of reliability and generally high values of pull-out torque (only at speeds near synchronous speed). However, the squirrel-cage rotor does not rotate as fast as the revolving magnetic field set up by the stator winding. This difference in speed is called “slip.” Due to this inherent feature, squirrel-cage motors are not as efficient as synchronous motors, whose rotors rotate in synchronization with the magnetic field. There are three basic variables that classify motor performance types. These are:

(1) Starting torque.

(2) Starting current.

(3) Slip.

b. Motors can have high or low starting torques, starting currents, and slip. However, these variables are not produced in every combination. For example, high-resistance rotors (such as wound-rotor applications) produce higher values of starting torque than low-resistance rotors. But high resistance in the rotor also produces a “high-slip” motor. A high-slip motor, by definition, has higher slip losses, hence lower efficiency, than an equivalent low-slip motor.

16–3. Submersible motors

Submersible motors are sometimes considered for lock and dam applications. Submersible motors have been used effectively in pump stations where economy of design is paramount

a. Where the possibility exists that combustible gases or flammable liquids may be present, the installation location should be deemed to be classified with the appropriate NFPA 820 and NFPA 70 hazardous location rating. All electrical equipment designed to be located inside the classified location area must be properly rated for use in the appropriate hazardous location.

b. Thermal sensors should be provided in submersible pump motors to monitor the winding temperature for each stator phase winding. A water leakage sensor should be provided to detect the presence of water in the stator chamber. If the possibility exists that rodents may enter the sump, special protection should be provided to protect the pump cable(s). For example, split-type stainless steel wire mesh can be installed along the length of the submersible pump motor cable to provide physical protection.

16–4. Starting current limitations

The electric power utility must be contacted to determine starting restrictions, maximum inrush currents, or voltage dip limits. This is especially critical for motors over 75kW (100 hp).

a. The designer should perform a motor torque and accelerating time study to evaluate the motor starting torque and voltage dip requirement. The selection of a reduced voltage starter must then be based on the electric utility requirements and the motor pump arrangement.

b. UFGS 26 29 01.00 10 and UFGS 26 29 02.00 10 state the manufacturer's standard is to limit the locked rotor current to 600% of rated (full-load) current. However, when utility requirements necessitate, lower inrush current induction motors may be specified not to exceed 500% of the rated full-load current. Note that starting inrush current varies with efficiency; therefore, specifying reduced inrush will result in a somewhat lower efficiency.

c. The motor manufacturer should be contacted before specifying a reduction of inrush current for a synchronous motor. The designer should consider and compare full voltage starters, reduced voltage starting by autotransformer, reduced voltage starting by soft starter, and use of VFDs when selecting starting methods for pump motors.

d. If 500% is not acceptable, reduced-voltage starting of the closed-transition autotransformer type may be considered for use, but generally this is not the current method and solid-state starters are more common.

e. Autotransformer starters provide three taps giving 50, 65, and 80% of full-line voltage. Caution must be exercised in the application of reduced voltage starting, however, since the motor torque is reduced as the square of the impressed voltage (the 50% tap will provide 25% starting torque. Connections should be made at the lowest tap that will give the required starting torque. Reactor-type starters should also be given consideration for medium voltage motors.

f. Another method to limit the starting current is to use a soft starter, which is a solid-state drive that alters the applied voltage during the starting of the pump motor. The starting characteristic can be programmed specifically for the pump motor it is starting. The reliability, price, availability of qualified maintenance personnel, and space considerations should all be considered carefully before electing to use soft starters.

g. VFDs may also be referred to as adjustable speed drives (ASD) or AC drives and the terms are used interchangeably. VFDs are also a common method to reduce inrush currents for 460V low-voltage applications and for medium-voltage motor applications. VFDs are also commonly used for speed control, which can be a consideration for FRM pumps. The reliability, price, availability of qualified maintenance personnel, and space considerations should all be considered carefully before electing to use VFDs.

16–5. Duty, duty cycle, service factor

a. This block on the motor nameplate defines the length of time during which the motor can carry its nameplate rating safely. Most often, this is continuous, often labeled "Cont." Some applications have only intermittent use and do not need motor full load continuously. Examples are crane, hoist, and valve actuator applications. The duty on such motors is usually expressed in minutes.

b. The service factor (SF) is required on a nameplate only if it is higher than 1.0. Industry standard service factor includes 1.15 for open-type motors and 1.0 for totally enclosed-type motors. However, service factors of 1.25, 1.4, and higher exist. It is not considered good design practice to use the rating afforded by SF continuously. Operating characteristics such as efficiency, power factor, and temperature rise will be affected adversely.

c. Motor SF is defined by NEMA as the percentage of overloading the motor can handle for short periods when operating normally within the correct voltage tolerances. This is practical as it provides some safety factor in estimating horsepower needs and actual running horsepower requirements. It also allows for cooler winding temperatures at rated load, protects against intermittent heat rises, and helps to offset low or unbalanced line voltages.

(1) For example, the standard SF for open drip-proof (ODP) motors is 1.15. This means that a 10-hp motor with a 1.15 SF could provide 11.5 hp when required for short-term use. Some fractional horsepower motors have higher service factors, such as 1.25, 1.35, and even 1.50.

(2) Traditionally, TEFC motors had an SF of 1.0, but most manufacturers now offer TEFC motors with service factors of 1.15, the same as on ODP motors.

d. NEMA defines service factor as a multiplier that when applied to the rated horsepower, indicates a permissible horsepower loading, which may be carried under the conditions specified for the service factor at rated voltage and frequency. This service factor can be used for the following:

(1) To accommodate inaccuracy in predicting intermittent system horsepower needs.

(2) To lengthen insulation life by lowering the winding temperature at rated load.

(3) To handle intermittent or occasional overloads.

(4) To allow occasionally for ambient above 104 °F (40 °C).

(5) To compensate for low or unbalanced supply voltages.

e. The term “duty” defines the load cycle to which the machine is subjected, including (if applicable) starting, electric braking, no-load, and rest de-energized periods, and including their durations and sequence in time. Duty means loading the motor with one or more loads and that the loads will remain constant for specified periods (and sometimes different loads) in which speed varies. International ElectroTechnical Commission (IEC) 60034-1 defines duty cycles as shown in Table 16–1. The cyclic duration factor is defined in equation 16–1 as:

$$Cyclic\ duration\ factor\ =\ the\ total\ time\ contributes\ to\ electric\ heating * \frac{100}{total}\, cyclic\ time \tag{16–1}$$

(1) Duty specifies the length of time the motor can operate at its rated load safely and indicates whether the motor is rated for continuous duty.

(2) Care should be taken in the selection to avoid excessive duty cycles. Mechanical stresses to the motor bracing and rotor configuration as well as rotor heating are problems with frequently started motors.

(3) The number of starts permissible for a Design A and Design B squirrel-cage induction motor should conform to the limitations given in NEMA Motors and Generators (MG) 1 (look for details regarding small and medium machines).

(4) The number of starts permissible for large squirrel-cage induction motors should conform to the limitations given in NEMA MG 1. The definitions for small, medium, and large machines can be found in NEMA MG 1.

(5) Starting limitations for synchronous motors should conform to NEMA MG 1. The motor manufacturer should be consulted concerning the frequency of starting requirements if other than those prescribed above. Economic comparisons of different pumping configurations should include the reduction in motor life as a function of increased motor starting frequency.

Table 16–1
Motor duty classifications (from IEC 60034-1)

No.	Ref	Duty Cycle Type	Description
1	S1	Continuous running	Operation at constant load of sufficient duration to reach the thermal equilibrium.
2	S2	Short-time duty	Operation at constant load during a given time, less than required to reach the thermal equilibrium, followed by a ret enabling the machine to reach a temperature similar to that of the coolant (2 Kelvin tolerance).
3	S3	Intermittent periodic duty	A sequence of identical duty cycles, each including a period of operation at constant load and a rest (without connection to the mains). For this type of duty, the starting current does not significantly affect the temperature rise.
4	S4	Intermittent periodic duty with starting	A sequence of identical duty cycles, each consisting of a significant period of starting, a period under constant load, and a rest period.
5	S5	Intermittent periodic duty with electric braking	A sequency of identical cycles, each consisting of a period of starting, a period of operation at constant load, followed by rapid electric braking and a rest period.
6	S6	Continuous operation periodic duty	A sequence of identical duty cycles, each consisting of a period of operation at constant load and a period of operation at no-load. There is no rest period.
7	S7	Continuous operation periodic duty with electric braking	A sequence of identical duty cycles, each consisting of a period of starting, a period of operation at constant load, followed by an electric braking. There is no rest period.

No.	Ref	Duty Cycle Type	Description
8	S8	Continuous operation periodic duty with related load and speed changes	A sequence of identical duty cycles, each consisting of a period of operation at constant load corresponding to a predetermined speed of rotation, followed by one or more periods of operation at another constant load corresponding to the different speeds of rotation (duty). There is no rest period. The period of duty is too short to reach the thermal equilibrium.
9	S9	Duty with non-periodic load and speed variations	Duty in which, generally, the load and the speed vary non-periodically withing the permissible range. This duty includes frequent overloads that may exceed the full loads.

16–6. Starting torque

The motor must be designed with sufficient torque to start the machinery to which it is connected under the maximum conditions specified, but in no case should the starting torque of the motor be less than 60% of full load. Squirrel-cage induction motors are common drivers for spillway tainter gate hoist motors, lock tainter valve hoist motors, and miter gate machinery drive motors. The miter gate motors are sometimes designed with a high starting torque (NEMA Design D) to enable the motor to start the high-inertia miter gate leaf load in motion through the water where the gate leaf essentially "plows" water. For a more detailed discussion of torque values, see the motor type below.

a. Squirrel-cage induction motors. Normally, motors specified in UFGS 26 29 01.00 10 will have normal or low starting torque, low starting current. Each application should be checked to ensure that the motor has sufficient starting torque to accelerate the load over the complete starting cycle. UFGS 26 29 01.00 10 specifies that the pump motor have a minimum starting torque of 60% of full load. Breakdown torque should not be less than 200% of full load unless inrush current is reduced to 500% of full load current. If 500% is specified, the breakdown torque must be reduced to 150% of full load.

b. Wound-rotor ("slip-ring") induction motors. Wound-rotor induction motors are common in USACE for use on roller gate hoist machinery where the motor encounters large inertia starting loads. Wound-rotor motors are sometimes used for skew control of vertical lift gates.

(1) This type of motor is not used as frequently as squirrel-cage motors due to lower efficiency and higher initial and general maintenance cost. However, higher starting torque and speed control can be used by varying wye-connected, three-phase resistors to the rotor connected via slip rings and brushes.

(2) In the case where a lift gate may be using a wound rotor on each side, a PLC PID loop comparator may be used to adjust the speed of one side of the gate to maintain minimal skew using master-slave topology.

c. Synchronous motors. Synchronous motors must usually be specially designed for pumping applications. The load torques and Wk^2, so-called "normal" values on which NEMA MG 1 requirements are based, are generally for unloaded starts and are therefore relatively low. Starting and accelerating torque must be sufficient to start the pump and accelerate it against all torque experienced in passing to the pull-in speed under maximum head conditions and with a terminal voltage equal to 90% of nameplate rating.

d. Amortisseur windings. Double-cage amortisseur windings may be required to facilitate starting for and stabilize operation of a synchronous type motor by generating the uniformly high torque from starting to pull-in that is required by loaded pump starting. They consist of one set of shallow high-resistance bars and one set of deeper low-resistance bars.

e. Measuring motor torque. One torque measuring tool, a Prony brake, is a simple type of dynamometer used to measure the amount of torque produced by a motor to determine its brake horsepower (BHP) rating. For an electric motor, BHP is the mechanical horsepower available at the shaft at specified rpm and full load current. The BHP is defined in equation 16–2 as:

$$BHP = (Torque\ (in\ lb\text{-}ft)\ x\ RPM)\ /\ 5252 \qquad (16\text{–}2)$$

16–7. Locked rotor torque

For motors starting under load, each motor's structural anchorages must be designed with proper consideration of the motor's locked rotor torque. The electrical designer must coordinate with the mechanical and structural designers as necessary to determine the necessary design considerations and requirements for the motor mechanical connections and the structural anchors, which must be designed to withstand the applied motor's locked rotor torque.

16–8. Pull-out torque

This is the torque required to maintain near synchronous speed.

16–9. Motor selection

The choice between a squirrel-cage induction and synchronous motor is usually determined by first cost, including controls, and wiring. In general, the seasonal operation of flood-control pump stations results in a low annual load factor (ALF), which, in turn, diminishes the advantage of the increased efficiency of synchronous motors.

a. A life cycle cost analysis should be performed that includes first costs, energy costs, and maintenance costs. Another factor that should be considered is the quality of maintenance available since the synchronous motor and controls are more complex than the induction motor. The additional cost of providing power factor correction capacitors to squirrel-cage induction motors, when required, should be included in cost comparisons with synchronous motors. Also, the extra cost to provide torque and load WK^2 values higher than normal for a synchronous motor because loaded pump starting characteristics must be considered.

b. The ALF can be estimated from data obtained from a period-of-record routing study or from the electric billing history of a similar pumping station. If a period-of-record routing or billing history is used, ALF would be defined by equation 16–3 as:

$$ALF = We \,/\, (Pd \; x \; 8{,}760) \qquad (16\text{–}3)$$

where:

We = total amount of energy consumed during year
Pd = maximum of 12 peak demands occurring during year
8,760 = number of hours in a year

16–10. Power factor correction

a. Power factor is the ratio of total watts to the total root-mean-square volt-amperes. Utility companies may meter the reactive or out-of-phase component (kilo-volt-ampere reactive [kVAR]) of apparent power (kilo-volt-ampere [kVA]), as well as total energy (kilowatt hour [kWh]). They may charge additionally for higher capacity requirements driven by peak loads and low power factor. A general rule is that about 12 to 14% of line loss can be saved by improving the power factor 10%.

b. The power factor for induction motors vary according to size and rpm. The power factor should be corrected to 92 to 95% at full load through the addition of power factor correction capacitors. The power factor correction capacitors are usually located either within or on top of the MCC. The capacitors should be switched in and out of the circuit with the motor. Feasibility, needs, and benefits of using power factor correction capacitors should be discussed with the local electric power utility company during coordination of the pumping station service.

16–11. Noise level

The DoD considers hazardous noise exposure of personnel as equivalent to 85 decibels or greater A-weighted sound pressure level for 8 hours in any one 24-hour period (MIL-STD-1474E). Also refer to OSHA Regulations Standard 29 Code of Federal Regulations (CFR) 1910.95. The guide specifications provide requirements to obtain motors that meet this limitation. The designer, however, should evaluate the advantages and disadvantages of providing either the more expensive motors that meet these requirements or a room to isolate the operating personnel from the noise exposure. NEMA MG 1 provides more information on the subject.

16–12. Variable speed drives

Variable speed drives (VSDs) are also used to start large motors as a method to limit the starting inrush current. If it has been determined that a variable speed drive is necessary, the designer should determine the most efficient and economical method that meets the needs of the application. VSD drives are not normally required for lock and dam operation equipment. Normally the larger connected loads like dam gate hoists for example, are geared down enough that the use of VSDs to reduce starting current are not necessary.

16–13. Variable frequency drives

Adjustable speed is obtained by converting the fixed-frequency AC line voltage into an adjustable voltage and frequency output that controls the speed of a squirrel-cage motor. A rectifier converts power from 60-Hz AC to DC. An inverter, then, reconverts the DC power back to AC power, which is adjustable in frequency and voltage.

a. The starting speed of large motors can be controlled by programming a VFD to ramp up the pump motor speed from start to full speed, and thus becomes another means of controlling the inrush current. Drives are available in sizes up to 600 kW (800 hp) with variable-frequency operation from 2 to 120 Hz. Inrush currents can be reduced to 50 to 150% of nameplate rating.

b. VFDs are very efficient and provide a wide range of speed adjustment. Variable speed may be applied to a lock system to control miter gate movement by reducing gate flex, increasing reliability, and reducing equipment wear. Variable speed may not be the solution for all applications. Consider that the gate machinery in its relation to the system curve must be a compatible match. Most motors are rated for VFD use, but running at slow speed for long durations may cause excess heating. This is due to factors like the cooling fan is no longer moving enough air to cool the motor.

c. Both the electrical and mechanical designers must consider the amount and effects of eddy currents that may be produced by a pump's VFD-inducing currents in the motor shaft, which then travel to ground through the motor bearings. Coordinate with a motor manufacturer and a VFD manufacturer during design to obtain knowledge about possible VFD-induced shaft currents.

d. Coordinate during construction installation to determine what the actual VFD-induced shaft currents will be and how to protect the bearings as necessary from VFD-produced eddy currents that may damage the pump bearings. The motor and machinery need to be properly grounded to mitigate issues with induced stray currents. Check the type of bearings and bearing isolators as some styles are worse than others. This applies to both motor and machinery. Bearing damage due to circulating shaft currents can be reduced by using insulated bearings on the motor (one end only) and insulated couplings on the equipment. Installing a grounding brush mounted to the motor that rides on the shaft also eliminates the shaft currents.

e. VFDs can be good solutions. However, it is also important that operators/owners and users work with the vendor to consider avoidable issues.

(1) VFDs may have issues with harmonics, especially on long cable runs. Talk with the OEM about cable length calculations (may require shields) and if a filter addition is required for harmonic issues (manifested as noise and vibrations) that need to be addressed. A general rule was to recommend keeping cable length between the VFD and motor less than 150 ft, but further investigation is encouraged if lengths 150 ft. or

more are needed. Installing a shielded cable for VFD runs over 25 ft. is also recommended.

(2) The motor must be rated for the VFD service. Most new motors are.

(3) Depending on the enclosure type and the application (loads that are variable or fixed torque), the motor may have overheating issues due to the lower cooling fan speed as the motor speed diminishes, especially for prolonged periods of low-speed operations. Since most (HVAC) centrifugal pump applications are variable torque and the load diminishes with the speed reduction, the potential for this overheating issue will be lower.

(4) For motor operations above base speed, the ability to produce sufficient torque is diminished.

(5) It is better to select a base motor speed and operate in a range at or below that baseline than to continually operate above the baseline speed.

(6) From the aspect of system control, VFDs typically interface well with a computer's operating systems, electronic control circuits such as PLCs, distributed control systems (DCSs), and SCADA systems.

16–14. Electric motor enclosure ratings

An electric motor frame and enclosure must be designed, and the type selected for the environment in which it will be applied.

a. The level of environmental protection and method of cooling are defined and standardized by NEMA MG 1. NEMA MG 1 adopted the ingress protection and insulation contact ratings developed by the International Standards IEC 60034-5 and IEC 600034-6 for motor enclosure protection and cooling ratings, respectively.

b. NEMA MG 1 now simultaneously states the original NEMA MG 1 protection level and the corresponding ingress protection and insulation contact ratings expected for each type of electric motor. Refer to NEMA MG 1 for descriptions of the standard available classifications for motor protection and cooling.

16–15. Winding space heaters

Motors may be provided with winding space heaters to prevent condensation in the pump motor when installed in damp or wet locations.

a. The designer should work with the motor manufacturer to determine recommended winding space heater wattages for specific motor frame sizes. It is prudent to conduct market research for specific applications.

b. The designer should require the motor manufacturer to finally determine the size and type of the winding space heater(s) for each specific motor that is provided if the designer determines and specifies in the construction contract that winding space heaters are required.

c. Winding space heaters often are connected to the motor controls to energize when the motor is de-energized and de-energize when the motor is energized. For example, the winding space heater should be connected to a separate 120V single-phase power source that is switched OFF by an auxiliary contact from the motor starter when the motor starter is energized to run, and the auxiliary contact re-closes to switch ON to energize the winding space heater when the motor is de-energized.

16–16. Repairing, refurbishing, and rebuilding motors

Electric motors may be refurbished or rebuilt described as follows.

a. Repair and refurbishment. The electric motor refurbishment process includes replacing the motor bearings, reusing and baking the stator winding, reusing and baking the rotor winding, applying new paint to frame, testing, and new specification data plate. Also included are removal and replacement of motor appurtenances specific to each motor such as winding condensation heaters, thermal sensors, and moisture sensors.

b. Rebuilding and rewinding. The electric motor rebuilding and rewinding process includes the refurbishment process described above, but it also includes removal of existing windings and rewinding both the stator winding and rotor winding (as applicable) to original motor winding specifications.

c. Electrical Apparatus Service Association (EASA). EASA Standard AR100-2015 can be consulted regarding comprehensive requirements for refurbishing, rebuilding, rewinding, and testing of electric motors.

16–17. Factory testing motors

The designer should carefully consider the following factory motor tests regarding which tests are applicable and required for each specific project. The designer is sometimes questioned during construction phase whether the factory motor tests or some of the factory motor tests are required. The designer may have to carefully consider whether to allow the factory motor tests to be waived.

a. Factory complete tests. Factory complete tests include the following: Excitation Test; Impedance Test; Performance Test; Speed-Torque Test; Temperature Test; Insulation Resistance-Temperature Test; Cold and Hot Resistance Measurement; Sound Level Test; Vibration Measurement; and Conformance Tests. This list of tests was derived from UFGS Section 26 29 01.00 10, which also refers to NEMA MG 1.

b. Factory check tests. Factory check tests include the following: Routine Test; Cold Resistance Measurement; Insulation Resistance and Winding Temperature; Conformance Test; and Vibration Test. This list of tests was derived from UFGS Section 26 29 01.00 10, which also refers to NEMA MG 1.

c. Refurbished electric pump motors. Each motor must be given a check test as defined in NEMA MG 1. Also, refer to the EASA Standard AR100-2015.

d. Rebuilt and rewound repaired pump motors. Each motor must be given a complete test as defined in NEMA MG 1. Also, refer to EASA Standard AR100-2015.

16–18. Field testing motors

The designer should carefully consider the following field motor tests regarding which tests are applicable and required for each specific project. The contractor should provide an erecting engineer to conduct startup services. The approved erecting engineer must supervise the handling, installation connections, startup, and testing of the equipment to ensure that the pumps are installed properly per the manufacturer's instructions and requirements. The contractor must prepare and submit test reports of all completed field testing.

a. Also called the "megger" test, the conductor insulation of an installed pump motor's stator winding, and pump motor power lead conductors may be tested by using a megohmmeter applying a megaohm test.

b. The test is applied to cables at 500V, and the testing unit measures the resistance between each of the conductor combinations and between each of the conductors and ground in a circuit. Be sure to use voltages that are non-destructive for insulation resistance testing. The intent of this is not to test the dielectric strength with a high-potential (hipot) tester. Dielectric testing may be destructive depending on the test levels and the available energy in the instrument.

c. The general rule is that the insulation resistance should be infinite. However, insulation degrades over time, and as it does so, the insulation still has integrity if the insulation resistance is greater than 1 Megaohm. It is recommended to test and record the measurement of the motor when it's new (or as soon as possible) for a baseline to watch and monitor over time.

d. Depending on the rate of insulation degradation over time, this may be an indicator that the motor run conditions need to be investigated for overheating or vibration issues, for example. An immediate insulation problem exists if the measured insulation resistance is less than 1 Megaohm, which indicates that the insulation is breaking down. This problem should be investigated and corrected as soon as possible. Remember to de-energize and disconnect or de-terminate the motor before connecting the megohm meter!

e. Each motor should be at least "jogged" or "bumped" to rotate the shaft, otherwise each motor should be operated at full rated speed as allowable by its manufacturer and as long as it does not damage the equipment. If the test reveals a design or installation deficiency or a manufacturing error in operational unit components, the contractor must correct the problem.

f. Each motor should be given an operating test under load for a period as directed by the government.

16–19. Surge protection

a. Lightning-induced voltage surges. Electronic lock motor controls can be vulnerable to lightning-induced voltage surges on incoming or local power cables since it is characteristic of their operation to be uses in all weather. Therefore, special care should be taken to reduce the magnitude of these voltage surges to avoid major damage to the electrical equipment related to motors and control. A relatively small investment can greatly reduce the voltage stresses imposed on rotating machinery and switchgear by lightning-induced surges.

b. Protective equipment. There are two transient elements of a voltage surge that require different protective equipment. The protection of the major insulation to ground is accomplished by station surge arresters that limit the amplitude or reflections of the applied impulse waves within the motor windings. The protection of turn insulation by reducing the steepness of wave fronts applied to or reflected within the motor windings is accomplished by protective capacitors.

c. Medium-voltage motors. Medium-voltage motors (1,000V to 35kV) are especially relevant for heavy applications and require a motor with an output of 400kW and above. To obtain the most reliable protection of the motor’s major and turn insulation systems, a set of arresters and capacitors should be installed as close as possible to the motor terminals. Medium-voltage motors are more likely to pertain to lock systems with permanent dewatering pump systems, but not always.

d. Arrestor types. The arresters should be valve-type, station-class designed for rotating machine protection. The capacitors should be of the non-polychlorinated biphenyls type. The leads from the phase conductor to the capacitor and from the capacitor to ground should be as short as possible. If solid-state motor controllers are used, the addition of capacitors at the motor terminals may not be recommended. Chopped-wave equipment such as SCR-controlled motor starters can generate surges and harmonics. The capacitors can contribute to the problem by increasing resonance effects. The manufacturer should be consulted for the application.

e. Low-voltage motors. Motors of 600 volts and below have relatively higher dielectric strength than medium-voltage machines. Normally, when higher speed motors of this voltage class are connected through a transformer protected by station-class arresters on the primary side, no additional protection is warranted. However, due to the more expensive slower speed motors employed in pump stations, plus the critical nature of these motors, the minimal additional cost of lightning protection is justified. A three-phase, valve-type, low-voltage arrester should be provided at the service entrance to the station and a three-phase capacitor should be provided at each motor terminal.

f. Substation. The utility should be requested to supply valve-type, station-class surge arresters on the primary side of the substation transformer.

Chapter 17
Equipment and Machinery Controls

17–1. Introduction

This chapter provides general guidelines and considerations for designers when developing a control system for a lock and dam project. It is not intended to address specifically all the locks operating in the United States. Although much of the information presented is specific to miter gate locks, the same technology can be adapted to a sector gate, tainter gate, vertical lift gate, and other styles of locks and to the control of spillway gates, including those at FRM projects. As referenced in this chapter, a new lock control system does not refer to only a new lock construction project. Replacement or rehabilitation of an existing electrical system constitutes, for the purposes of this manual, a new control system.

17–2. Design considerations

a. General. The features and control preferences of a lock control system can vary greatly by USACE district, river system, location, weather, size, and traffic conditions.

b. Lock operations personnel. Many of the concepts provided herein will have to be modified to meet the specific needs of different lock operations personnel. It is important to remember that coordination with personnel at the lock is paramount when designing a lock control system. If the designer is considering visiting lock sites to evaluate their control systems, it is beneficial to bring along members of the lock operating staff. The lock operators might bring up areas of concern that the engineer might not have considered.

c. Lock maintenance personnel. Navigation and FRM projects are often found in rural locations making it difficult to attract, hire, and retain personnel capable of supporting the programmable logic controller (PLC) systems. The Designer must work with Operations to ensure the appropriate personnel are available to maintain the system(s) being designed. This may require recruiting and hiring of new personal or additional training for existing.

d. Engineer Research and Development Center information. In 2001, ERDC drafted a study for critical evaluation of lock automation and control equipment at USACE-operated navigation locks (TR-00-29, Wilson et al. 2001).

(1) The study determined that PLC-based lock automation systems could save 60% in construction costs and 30% in life-cycle costs compared to a standard hardwired, relay-based system with no backup capability. The performance scores for the PLC-based control systems evaluated were generally good to excellent at most sites visited, indicating that most lockmasters, electricians, and operators are generally satisfied with the PLC-based systems they use. PLCs have reduced the number of relays necessary for lock equipment operation.

(2) These systems have made it possible for the lock electrician to monitor the status of some equipment online in real time. The data processing capabilities of PLC-based automation also offer the potential for developing predictive maintenance applications.

17–3. Types of control systems

There are two basic types of control systems used at USACE navigation locks and dams: relay-based and PLC-based. Both have advantages and disadvantages and are covered in this chapter. The design PDT must evaluate the needs of the facility and personnel and the complexity of the control system requirements to determine which type will work best. It is important to involve the operation staff at the lock before deciding on a control system.

a. For example, a PLC system can reduce the amount of control wiring for a large navigation lock and make changes easier to implement over time, but appropriately trained personnel might not be available to maintain and troubleshoot the PLC system. Relay-based controls might be less sophisticated and are not as flexible as PLC-based systems. PLC-based systems can easily monitor analog signals such as water levels, gate position, and hydraulic pressure.

b. Relay-based control systems can and are being used at many navigation locks and dams for machinery (gates, valves, and hoists) controls, area lighting controls, horn control, equipment interlocks, and emergency stop pushbutton control systems. The environment in which the controls are to be installed must be considered when selecting a control system. It is noted that this document neither prefers nor mandates one over the other. It is the designer’s responsibility to select an appropriate control system based on all relevant considerations. Some considerations are:

c. Manual operation of a lock is defined as equipment operation initiated by individual action from the lock operator. The system has no automated sequences.

(1) It is recommended that the basic control system for any lock to be individual, hardwired pushbuttons, limit switches, control relays, motor starters, contactors, and pilot lights, and may include encoders, transducers, and meters for displaying positions, pressures, etc. For example, each miter gate leaf would have an OPEN, CLOSE, and STOP pushbutton or joystick for manual operation of the gate. This type of operation allows the lock personnel to control each piece of equipment individually, with the full complement of interlocks, limits, and failsafe devices.

(2) Interlocks (17–15) between lock gates and filling/emptying valves must always be in the control system, regardless of whether it is hardwired relay controlled, PLC-run, or hardwired backup for any type of control system. Manual operation with interlocks is the minimum normal control system at any lock.

d. Degrees of automation (using PLCs, not discrete relay logic), as discussed herein, vary by project site. Access to the hardwired controls should be provided at every control station, as appropriate, and at other areas around the lock, as deemed necessary by the lock personnel and design team. The hardwired controls should be simple and ergonomically designed with good visual feedback such as pilot lights and/or on-screen graphics (if system is electronic).

e. The hardwired controls should have a means of operating all the lock equipment including the gates, filling/draining valves, traffic lights, bubbler systems, warning horn, emergency stop, lock lighting, small pleasure-craft controls, and other equipment unique to each lock and required for day-to-day operation. The designer must spend ample time with the operating personnel to determine all the features to include in the hardwired control system.

f. On locks that the designer chooses to incorporate software HMI, such as larger ones with minimal hardwired backup, consideration should be given to providing a means of controlling the lock without bypassing the PLC if there is a loss of use of the HMI from a PC or monitor failure. This backup can be provided in a number of ways.

(1) *Redundant human-machine interfaces*. Consider providing redundant HMIs at the primary control location. This entails providing a duplicate PC/HMI system that the operator could seamlessly switch to if the primary system fails. An advantage of this arrangement is that the operator could be using the backup system for displaying important information while operating the lock from the primary system.

(2) *Multiple control locations*. In locks with more than one control location (for example, a lock with upstream and downstream control stands) provisions for full control of the lock from either location could be provided in the event the HMI system in one of the control stands fails. Normal control schemes may typically allow control of the filling and emptying valves from each control stand, but only control of the gate associated with that stand. The designer would need to work with operations and management to determine what control measures would need to be put in place to prohibit misuse of the system to allow the upstream gate to be operated from the downstream stand and vice versa.

(3) *Laptop computer*. A laptop or portable HMI running the same HMI software as the primary control system could be used to temporarily operate the lock at the main control console, or any other strategic operating location with network access. The HMI screens might need to be resized to accommodate the smaller laptop screen. It is recommended that this be done ahead of time and before the backup is needed.

(4) *Backup control box*. A small, portable, hardwired control box could be conveniently plugged in near the main control console area or at other strategic operating locations. This control box would provide direct inputs to the PLC and would still have all the PLC interlocks and limits in place, but the flexibility and feedback for the operator would be limited. The control box should be kept as simple as possible, consisting of pushbuttons (lighted for positive feedback) for the lock gates, filling and emptying valves, traffic lights, and other critical features unique to individual projects.

g. When implementing a PLC/PC-type control system, a minimal hardwired emergency backup system should be provided for each major piece of lock equipment. The system would be kept to a minimum number of control features and be as simple as possible.

(1) Critical interlocks, those that are designed to prevent equipment damage or personnel injury, should be incorporated into this minimal emergency backup, and it is recommended that as many interlocks as practical be included. These interlock requirements vary from project to project. Overtravel and other critical and failsafe devices should be hardwired into the control circuits, with no possibility of bypassing them from any of the controls.

(2) The minimal emergency backup system should consist of only the controls needed to operate gates, valves, traffic lights, warning horns, and other features unique to individual locks that are deemed critical.

(3) In all cases, a lock control system should include an emergency stop pushbutton that is directly wired using normally closed contacts to the motor starters and variable speed drives. Activation of this button should stop all major lock operating equipment immediately, regardless of the lock's operating mode.

(4) The designer should be careful not to make the minimal emergency backup system more complicated than the normal control system. Solid state components should be avoided where possible because the purpose of the hardwired system is to provide emergency backup to the normal solid-state control system. Excessive numbers of relays, wiring, displays, and solid-state encoders can lead to a backup system that is more complicated and difficult to maintain and troubleshoot than the PLC system. The emergency backup system should be electrically isolated from the PLC control system.

(5) Consideration should be given to providing pushbutton controls at the MCC, VFDs, and at remote motor starters, for use by the contractor during construction.

(a) These controls might save the contractor time and might take pressure off the system integrator by allowing the contractor to bump motors and hydraulic cylinders for mechanical alignment purposes without expecting the system integrator to have large portions of the PLC/PC programming debugged before moving equipment.

(b) These controls can be integrated either as part of the manual control system, or the emergency backup system, or de-energized after construction and checkout is complete.

17–4. Automated operation

Automated operation of a lock is defined as operation of major lock equipment (gates and valves) that is initiated by the PLC or from the lock control system without direct intervention from the lock operators. For example, the lock operator may simply command a hydraulic miter gate to open, and the PLC is programmed to first start the hydraulic pump and, after a delay, operate the direction and volume solenoids. When the gate reaches the recess, the PLC will close the hydraulic solenoids and automatically shut off the hydraulic pump.

a. Due to the control logic and components required to implement the algorithm, automated operation should be limited to use with PLC/PC equipment. Discrete control relay systems are not a good choice for lock automation. Also, the design of the lock control system and the extent of the automation, if any, must be coordinated with the USACE district's Operations Division (end user).

b. When considering semi-automated control systems, the design team's concerns should include safety issues that could arise because of a lock operator not being able to respond immediately to a situation on the lock wall. This EM documents considerations when designing a lock and dam control system but does not mandate a particular type of design. This EM will neither require nor restrict any type of control system, manual, automatic, or otherwise.

c. The most automated form of lock operation in the United States is called a semi-automatic lockage. In this sequence, the operator uses two actions, which could be a pushbutton or an HMI screen control action, to perform the entire lockage.

(1) The first operator action prepares the upstream end of the lock for entry or exit, and the second readies the downstream end. When a downstream-bound vessel approaches the lock, the operator initiates the first command, either by pressing a physical button or a simulation on an HMI screen, and the PLC checks and closes the lower miter gates, checks and closes the lower emptying valves, and opens the filling valves.

(2) At this point, the PLC waits until the lock chamber is at the same level as the upper pool and initiates the opening of the upper miter gates or lowering of the lift gate and the closing of the filling valves. In a semi-automatic lockage procedure, the signaling of vessel movement (traffic lights and air horn) are done by the operator.

(3) After the operator has determined the vessel is safely in the lock chamber and secured to the mooring bitts, the second command is initiated that closes or raises the upper gates, checks and closes the upper filling valves, and opens the lower emptying valves.

(4) The PLC then waits until the chamber has lowered to the level of the tailwater and initiates opening of the lower miter gates and closing of the lower emptying valves. When the gates are fully recessed and the vessel is clear to exit the chamber, the operator signals the vessel over the radio or by sounding the air horn, according to the policies for that lock.

(5) This process requires one person to operate a lock, freeing that operator up to enter lockage data, arrange queues, operate tainter gates, operate adjacent locks, and perform other duties. A semi-automated system streamlines the operation of the lock, reduces delays, and increases efficiency.

(6) This type of system should be considered for all new lock control systems, particularly those with high tonnage where an operator’s time is critical, those with a limited number of operators, or those with operators who perform various other duties such as maintenance. Locks that have high head, especially small locks, might require refinements to the semi-automatic lockage sequence because of extreme hydraulic conditions.

(7) For example, two modes of semi-automatic operation could be programmed easily into the PLC system to allow for differences in pleasure boat and commercial boat operation. High head causes rapid filling of small lock chambers and can create excessive turbulence if not properly controlled. By implementing a pleasure boat mode of operation, in which the valves stop at specified intervals to slow the filling rate, turbulence can be limited.

(8) Sequencing of the valves also can be controlled to pin the pleasure boats to one side of the lock, as is done when operating manually with existing control systems. Commercial boats typically can tolerate more turbulence, so the commercial boat mode of operation can be programmed to fill the chamber faster than the pleasure boat mode. Whatever sequences are programmed, filling times and methods of operation should be coordinated with qualified hydraulic engineers and lock operating staff.

(9) A semi-automated lock also should have a manual system, a hardwired emergency stop, and a minimal emergency hardwired backup system. In most cases, a semi-automated lock will have one centrally located operator. With visibility limited from a central operating point, a closed-circuit television system probably will be necessary. Various other forms of automation should be considered, as discussed herein.

d. Due to the control logic and components required to implement the algorithm, it is recommended that automatic operation of the filling and emptying systems be limited to use with PLC/PC equipment. One benefit of automating the filling and emptying operations is that over-emptying and over-filling can be minimized, if not eliminated, using preprogrammed algorithms based on pool and lock chamber water level differentials at the start and/or end of the filling or emptying cycle.

(1) Filling and emptying of the lock chamber can be automated in several different ways. The first, as discussed above, is in the semi- and automatic lockages. A simpler level of automation would have both filling valves operate simultaneously with a single operator command. The command either could be from HMI software or from a hardwired pushbutton input to the PLC.

(2) When automating the filling/emptying valves, the PLC can be programmed for any number of different sequences for different head conditions, pool levels, filling and emptying rates, delayed opening, pleasure crafts, light boats, and empty tows. Experienced operators must be consulted to determine the exact extent and requirements of automating the filling and emptying valves. This type of automation is generally simple to do, usually only requires programming once the PLC and field devices are in place and can be altered easily as needs change.

(3) Automating the filling and emptying of lock chambers should be considered with all new lock control systems.

17–5. Water level sensing equipment

Water level sensors could be used in both hardwired relay control and the PLC system. In the hardwired relay system, pool levels (upper pool, lock chamber, and lower) would be displayed on LED panel meters or similar. When making the decision to open the miter gates, the operator could compare the readings on the adjacent pool level meters.

a. In the PLC system, the pool water level sensors would be inputs to the system. This information would be used to display pool levels on the HMI screen and to provide the operator with some indication that pool levels are equal. In addition, one of the critical procedures of an automated lockage sequence is the reliable sensing of water levels and determination that pools are equal in regard to water level.

b. In other parts of this manual, actual hardware and installation are discussed. This section discusses automation of the water level sensing system. The system should have redundant sensors for malfunction identification (at least two sensors in each measuring location). Malfunction of one sensor should lock out semi- or fully automatic operation. Under these conditions, the operator would verify visually that the water has reached a safe level for manually moving gates.

c. Consideration should be given to providing a built-in system for determining, through a series of checks and comparisons, which sensor has failed and allow the automated sequence to continue, if possible, with that sensor bypassed. An alarm should be generated to alert maintenance personnel of the failure yet allow the lockage sequence to continue. Again, this type of automation does not require significant additional hardware, and the programming for such a system is fairly simple.

d. For example, abrupt changes in signal level could be monitored through program logic to determine that a sensor has failed. If one sensor in a pair suddenly drops below or rises above the previous level indicated, it probably has failed. The water level system can include other troubleshooting features such as determination of type of sensor failure (power loss, signal loss, out of range, out of calibration), power supply failure, and PLC input/output (I/O) failure. These help facilitate the troubleshooting and repair of an automated system.

17–6. Operator locations

The operation of a navigation lock varies by USACE district and location. Designers must coordinate with operations personnel during the planning stages to coordinate the control system requirements. Lock operations can be accomplished with single or multiple operators.

a. Local control requires the lock operator to be physically near the machinery during its operation. A small control shelter is located at each end of the lock chamber. The lock operator will have direct visibility of the equipment and machinery. Local control allows the lock operator to communicate with the deck hands and to recreational vessels from the lock wall. Dedicated operators may be stationed at each end of the lock, or a single operator may travel between locations. Navigation locks equipped with tow haulage units require the lock operator to work from the lock walls.

b. Central control allows the operation of the entire lock chamber from a single location. The lock operator will not have direct visibility of equipment and machinery, which will require the use of a closed-circuit TV (CCTV) system. Central control allows the lock operator to remain in the control room. Central control can be used for one lock chamber and is suited to the operation of multiple lock chambers.

c. When central control systems are used, it is strongly recommended that the maintenance program include the requirement for lock personnel to periodically be at the equipment when it operates, looking and listening for any indications of maintenance needs.

d. Many locks with local control feature an administration building. The lock control system (especially the PLC type) could be used to allow a lock operator to monitor the status of certain equipment on the navigation lock. However, in most cases, the lock control system should not allow operation of the lock equipment from the administration building.

17–7. Site characteristics

When designing a control system for a lock and dam, it is important to review all features of that project. Caution should be used when deciding if remote operation of a dam is the appropriate choice. There are instances when remote operation might not be preferred. For example, it might be preferred to operate the dam locally when large amounts of debris typically travel down the river through the dam.

a. It is impossible to provide an engineer design document that will be typical for all lock and dam control systems. That is not the intent of this document. Rather, the intent here is to promote ideas and consideration of certain features that affect the concept and design of a control system. Obtaining and reviewing documentation from existing lock and dam projects that have been debugged and functioning control systems is a good idea. However, it is important to remember that each site is different, and what works well at one lock will not necessarily work well at another.

b. It is recommended that the designer provide the contractor with the controls design (at least a performance specification) because USACE personnel are intimately familiar with the operation of a lock and dam. Designers must consider these and other features early in the design process.

c. The environment in which lock control equipment will be installed should be considered. Equipment must have some minimum level of protection against the ambient environment. Installations at USACE projects have demonstrated that both hardwired relay systems and PLC systems are rugged hardware systems.

d. Discrete relay control systems have demonstrated many years of reliability with simple strip-heated enclosures for which the heaters have been appropriately sized to the enclosure manufacturer's recommendations to minimize/eliminate condensation. Discrete relay systems generally do not need to be cooled, except for extreme installations.

e. PLC equipment is designed for industrial environments and can accommodate the wide range of temperatures and humidity at most, if not all, locks and dams. For example, it is common for PLC equipment to have ratings at or better than operation from 0 to 60 °C (0 to 140 °F), rated to operate in vibrations of 2G at 10 to 500 Hz, operating shock to 30G, and relative humidity of 0 to 95%, non-condensing.

f. Most of the time, the rejected heat in the PLC enclosure can warm the equipment or, if the ambient environment is cold enough, heaters may be used. Generally, PLCs are environmentally rugged components. While the design life of a given PLC system may be reduced compared to hardwired relay systems, design life can be a tradeoff for the increased functionality of the equipment.

g. The size of a lock is critical when deciding the number and location of control system equipment, such as whether or not to use discrete relays or PLC/PCs, consoles, I/O racks, cabling, fiber optics, CCTV cameras, industrial personal computers (IPCs), and emergency backup controls. While it varies by project, larger locks generally have more of this type of equipment, and it will be in a distributed manner to reduce cable lengths. Arranging control and communication equipment to reduce, as much as possible, the number of lengthy cable runs is critical to ensure a reliable system.

h. Failures from rodent damage, construction or operation procedures, weather, and lightning are less likely to occur in protected cabinets with short, protected cable runs fewer than 30 m (100 ft). While the initial cost of an extra intermediate I/O rack or communication point might not appear economical during the design phase, the cost of downtime and repair associated with failure likely will be much higher and at greater inconvenience.

i. Larger lock and dam projects will have more electrical and electronic components located at greater distances from maintenance buildings and control houses. For this reason, designers should look at the possibility of installing network connections in strategic locations so lock electrical maintenance personnel can monitor all the control system features. These network connections can be used by a laptop computer to instantly obtain troubleshooting and repair information on all PLC I/O points, HMI databases, and PC operating screens. Cybersecurity considerations should be evaluated for each location. See Chapter 19.

j. The funding required to install such communication points will be well spent, considering the time it can take to travel between locations on 366-m (1,200-ft) locks or projects with 15 or more dam gates. Also, time should be spent considering the possibility of locating these connections in areas where lock personnel will be protected from adverse weather conditions.

k. However, the farther repair personnel are removed from the trouble location, the harder it will be and longer it will take to restore the system to proper working condition. When trying to show economic justification for the extra funding, be sure to look at the significant consequences of downtime in addition to the relatively low probability of incidents when determining the risk of failure.

17–8. Layout

The physical arrangement of miter gates, lift gates, dams, spillways, service bridges, galleries, guide walls, maintenance buildings, control houses, and access to these features will have an effect on the arrangement of the control system components. Procedures such as flood control, winter shutdown, ice flushing, dewatering, open-river operation, and general facility maintenance can all be considerations when designing a lock and dam control system.

a. Single locks.

(1) Single locks, the most common at USACE sites, have an obvious need for a reliable control system because they lack the built-in redundancy of a second lock. It is imperative to provide some means of hardwired emergency backup controls at these sites, as discussed previously. These types of locks often are equipped with tow haulage units that increase direct operator involvement in the locking process.

(2) However, this does not preclude the justification or need for a certain level of automation. A semi-automated lockage process can free the operator to assist vessel crew members with lockages while the PLC monitors water levels and operates lock gates. Fully automating a lock at which there is heavy dependence on tow haulage units is not feasible at this point, given shared responsibilities between the vessel crew and the lock operating personnel.

b. Double locks.

(1) Generally, double locks consist of one larger main lock and one auxiliary lock. In the past, it may have required two or more lock operating personnel to perform lockages during heavy traffic at such sites. Federal budgets may not support larger crews in the future, so it is incumbent on the designers to consider this when laying out the control system. At some double locks, the smaller auxiliary lock is used strictly for pleasure boats.

(2) These locks might warrant consideration as user-operated facilities because an operator is on site controlling the larger lock and can assist if problems arise. If both the locks are used for commercial and pleasure traffic, a centralized control system in which a single lock operator can perform simultaneous lockages in both locks should be considered. Given certain types of traffic, volume of traffic, proximity to other sites, and other USACE district considerations, potential remote operation of such a facility should be reviewed during the design phase.

(3) Tandem locks consist of one long, segmented lock chamber with intermediate gates to facilitate high head lift in incremental steps. Tandem locks are used where the lift is too large to accomplish lockage in a single step. These locks, like those at the Panama Canal and Welland Canal, make excellent candidates for automation because the emptying of one chamber fills the other. Water levels must be closely controlled to keep from over-filling the lower chamber or over-emptying the upper chamber.

(4) A PLC-based system can precisely repeat a prescribed filling and emptying sequence to ensure a safe and efficient project. If conditions exist that alter the normal sequence, they can be programmed into the system and the PLC approaches an expert system.

c. Traffic. The volume and type of traffic that use the lock are perhaps the biggest considerations when deciding if there should be automation and, if so, the optimal degree of automation. It also determines the location of control points and CCTV cameras, and other electrical/electronic control design features.

(1) *Design*. In the case of new locks, the size of the lock and arrangement of the lock equipment have been designed for the location and traffic concerns of the project. However, on lock rehabilitation projects, the type and volume of traffic likely have changed since the lock was built. The new control system must be designed with current and future traffic projections in mind. Automation and remote control (see Chapter 18) are two features that can address these needs.

(2) *High volume*. High-volume locks, defined for the purposes of this chapter as those with annual tonnage in excess of 36,300,000 tonnes (40,000,000 tons), such as those on the Mississippi and Ohio rivers, generally can support automation to streamline their lockage procedures. With this amount of traffic, the lock is busy all the time and automation of certain functions, including the dam, help free the operator’s time to more efficiently operate the lock. Additional costs for redundancy, enhanced troubleshooting, spare parts, backup control systems, and reliability of equipment are usually easy to justify at these high-volume sites.

(3) *Low volume*. While lower usage locks might not support the same construction costs as higher volume locks, the control system can be designed for operation by fewer personnel. For example, when several locks in a system are relatively close, remote operation (see Chapter 18) from one point with automated lockage sequences at each site can enhance the efficiency of the system, increase lock availability, and cut operating costs. Control system designers should consider these possibilities, if not for immediate use, for future possibilities.

(4) *Commercial*. Commercial vessels comprise the bulk of the traffic at high-volume locks, while low-volume locks often have a large percentage of pleasure boat traffic. Automation is somewhat easier to implement for commercial tow lockages because vessel movement is slower, more consistent, and generally predictable, and vessel operators are usually more experienced in using the locks. For this reason, a semi-automated system will work well for high-volume locks.

(5) *Pleasure craft*. At all locks, the unpredictability and inexperience of pleasure boat operators, coupled with the lack of radio communication and the vulnerability of small-craft occupants, require lock operators to have more direct control over the lockage sequence. Automation of dam gates and lock filling and emptying can give the operator extra time to pay attention to the special needs of pleasure boat occupants.

17–9. Control rooms

The operational success of a lock and dam PLC/PC control system can be affected greatly by the interface between the operator and the computerized control system. Usually, the point of interface is a control console located in a lock control room. Control rooms should be designed with safety and the needs of the operator in mind.

a. Equipment. From an equipment standpoint, locations of consoles, CCTV monitors and controls, marine radios, public address systems, PC monitors, printers, and vessel-logging computers can be located essentially anywhere. With today's technology, the flexibility of such equipment allows the design of the control room to be based almost entirely on the interests of the lock operators.

b. Design. When using a computerized central control room instead of, or in addition to, a traditional hardwired localized control system, it often is difficult for a lock operating staff to determine its exact needs for the new system. Listed below are guidelines for determining the needs of individual control rooms and meeting those needs with an effective, ergonomic design. It is important to remember that no design will satisfy the needs of every operator, and the final product might have to be modified to meet the changing needs of the lock operators as they become accustomed to a new system.

c. Access. The designer should consider the accessibility of the control room and its equipment when determining the proper layout for a lock control system. The degree of accessibility required is often determined by the type of control system employed, namely manual versus automated. Once this determination has been made, the control house layout design should proceed with the safety and convenience of the operators in mind. Some points to consider for accessibility of a new or refurbished control room.

(1) In manual systems or systems with tow haulage units that require direct operator intervention to the locking process, the control room should be as accessible as possible from the lock wall. This might compromise the flexibility of the control room layout but will be more efficient for an operator who must return to the lock wall often during lockages.

(2) The layout of the control system components, such as those listed herein, should give the operator access to the lock wall and as much direct visibility as possible. Equipment within the control room will have to be arranged in a different fashion to allow an operator to use it in a more mobile mode. Operators will be entering or exiting the control room often and will need quick, handy control system interfaces, rather than elaborate ones designed for the operator who is at the controls on a continuous basis.

(3) Lock wall access to and from the control house is less significant with automated or remotely operated control systems. In this type of control system, the control room can be oriented to provide the most convenient accessibility to control console components without as much emphasis on access to the lock wall.

(4) Where possible, direct visibility of the lock should be provided. With access not as much of an issue, higher elevations, such as on top of a service bridge pier, provide a good location for a centralized control room.

(5) In an automated system having single operator control, CCTV monitors become the main focal point of the operator’s attention. These should be positioned to give the operator not only convenient access, but also a matching orientation of the actual lock equipment so quick reference can be made when examining the monitors. In other words, downstream views made looking at the landside of the lock should be the same when looking at the CCTV monitors. Orientation of the PC graphic operating screens also should match the physical orientation of the lock equipment.

d. Visibility. Direct visibility of the lock and the area around the lock should be provided if economical and architecturally feasible, even in highly automated control systems. Designers should not, however, compromise the economic justification of automating a system by providing excessive means of direct visibility of the entire lock and dam facility. Although this sounds contradictory, and on certain designs can be a fine line for the designer to walk, the designer must determine the operator’s need for direct visibility.

(1) Often, a control room can be designed where direct visibility and CCTV monitors complement rather than compete. This balance creates a more efficient and convenient working atmosphere. An operator does not have to fumble around looking for the correct orientation if the monitors are set up to provide the same views as direct visibility.

(2) In an automated centralized control room, consider positioning and orienting control consoles and CCTV monitors so that direct visibility is available without the operator leaving the console area, or continually rotating more than 90° in either direction to see the lock approach areas. In manual systems with local control houses located at the lock wall level, position consoles and CCTV monitors to provide convenient views of approach areas, guide walls, draining valve discharge areas, dam or spillway gates, and other areas that are hard to see from the lock wall level.

(3) Attention to these details will help the operator monitor the entire project while minimizing distractions. In the future, it is likely there will be less manpower at the locks, and operators could have other maintenance and security-type duties to perform simultaneously with vessel lockages. Designers must consider and plan for this by making the system convenient and safe to operate while increasing the efficiency of the project.

e. Layout. A good control system that is difficult to access or use is really not a good control system. Therefore, the layout of control rooms or areas is critical to the lock operator's perception of a quality system and, hence, the success of the system.

(1) *General*. As stated above, the parameters guiding the control room layout will be different for a manually controlled lock and an automated control facility. The size, type, and amount of traffic also should help determine the location, size, and layout of a lock control room.

(2) *Automated control systems*. Automated systems require much less direct visibility on the part of the lock operator. However, as stated above, direct visibility will enhance the efficiency and safety of the lock. Designing a control house in an area to provide maximum visibility is a good practice, provided it is economically feasible.

(a) It is noted again that, when central control systems are used, it is strongly recommended that the maintenance program include the requirement for lock personnel to periodically be at the equipment when it operates, looking and listening for any indications of maintenance needs. Remember that CCTV monitors can be used to provide quick, convenient visual feedback of vessel movement, status of gates, and debris in the water, while direct visibility usually provides better feedback of large, distant areas such as approach forebays.

(b) For this reason, a centralized control room usually makes a better system if it is located at a height above the lock wall with a good view of the upstream and downstream lock approach areas. Automated systems usually justify single control rooms for centralized operation of the entire facility by a single operator. Such a control room should be kept relatively small, with all the control and monitoring equipment within convenient reach of the operator.

(c) Administrative areas, maintenance areas, and visitor accesses should be kept separate from the control room to minimize distractions to the operator. A reasonably accessible break room with restrooms, a stove, microwave, and refrigerator should be considered where possible. Consider the possibility of providing a means for fresh air ventilation during pleasant weather. These all will help to increase the overall efficiency of the lock.

(3) *Manual control systems*. Since manual systems require much more direct intervention by the operator, control rooms should be kept near the lock wall area. This greatly reduces visibility of the lock approach areas and dam or spillway gate areas. A CCTV system can supplement the operator's efficiency by providing continuous views of these areas.

(a) This type of control room will require a different arrangement of equipment because an operator will be moving in and out while conducting lock wall duties, such as operation of a tow haulage unit, that are necessary in a manual control system.

(b) Control rooms of this kind will be exposed to weather, traffic, dust, and dirt much more than a centralized control house because they share duties with administrative,

maintenance, and visitor access functions. These factors could shorten the life of some control system components and should be considered when laying out such a control room. Protection of the equipment and convenience for the operator might be factors that require compromise in the layout of a manual control room.

f. Redundancy. Consideration should be given to providing backup control devices and redundant points of control in all control systems. The need for redundant control rooms or houses is not justified at most locks.

(1) In contrast to a control point, a control room or control house is an area where lock controls, CCTV monitors and controls, marine radios, telephone lines, vessel-logging PCs, water level readouts, weather instrumentation readouts, and dam or spillway gate controls are grouped together to facilitate operation of the entire project.

(2) The enhanced reliability and piecemeal failure tendencies of modern control and CCTV systems make the probability of a catastrophic control room failure significantly less than in years past. This decreases the economic justification for a full-blown redundant control room.

(3) Consideration should be given to providing local controls near the lock operating machinery. These controls can be in the form of a plug-in pendant, network connections for laptop PCs, permanently mounted hardwired pushbuttons with pilot lights, or a combination of these, depending on the needs of the lock operators and maintenance crews. These stations can be designed as local control points as well as redundant backup controls for the primary lock control room.

(4) Redundant control points in these forms do not add significant cost to the design or construction of a new control system and will go a long way to enhance the operator’s confidence in the operational reliability of the project. Often, redundant controls can be used to perform maintenance duties without distracting the operator or affecting operation of the lock.

g. Operating consoles. The operating consoles are the actual point of interface between a lock operator and a computerized control system. A design engineer should spend significant time reviewing all the factors that make a control system operator interface user friendly, efficient, convenient, and, most important of all, safe. Following are discussions and guidelines for some of the equipment located on a centralized control console.

(1) *Equipment*. Ultimately, it will be the responsibility of the designer to provide this equipment, other equipment unique to each lock, and capacity for additional equipment that will be added after lock personnel begin operating the facility. For locks that require smaller, more localized consoles, it will be up to the designer to determine the best location for the following control devices.

(2) *Construction*. The control console should be designed and constructed to act as a single unit. Modular off-the-shelf component construction is a good choice,

provided the components are of the same manufacturer and are intended to be connected to act as a single unit.

(a) Specifications should provide that all materials, including metal, hinges, shelves, finishes, and paint, be of top quality, with first rate workmanship and installation. This is important because repair and maintenance of the control console will affect all operations of the lock and dam. Control consoles may be many different shapes and sizes, depending on the type of control room and the functions required. All equipment contained within the control console should be easily accessible from the outside through hinged doors, slide drawers, or easily removed panels.

(b) Auxiliary equipment such as 120V receptacles, cooling and ventilating fans, filters, uninterruptible power supplies, power strips, radio and radar power supplies, and networking hubs should be specified in the design document. If a detailed design of the consoles is not a part of the plans and specifications, a contractor or lock operating personnel may try to fit all this equipment into a console structure that does not have the capacity to accommodate it. The result would be an overcrowded and hard-to-maintain control console.

(c) All control console design and construction should include provisions for adding components to the existing structure and expanding the console. Equipment the lock operator does not need to access, such as PLC I/O racks and complex CCTV switching circuitry, should not be in the operating control console.

(3) *Closed-caption television system*. While it is a good idea to consider a CCTV system with all lock control systems, automated or remotely controlled facilities require it. Since direct visibility will be limited, the CCTV system monitors should be considered the primary means of visual feedback to the operators. It is imperative to locate monitors where they will be convenient to view. Factors such as glare, operator comfort, viewing angle, and accessibility all should be considered when placing CCTV monitors in a control console.

(a) Generally, arranging CCTV monitors together above the console work surface, at a slight incline toward the operator, will satisfy these factors. Figure 17–1 shows the dam control console at Olmsted Lock and Dam. Note the three 49-in. LED monitors with up to nine camera views per monitor.

(b) When deciding the number of monitors to provide, a designer should consider that a lock operator needs to always monitor several different views of the lock during a vessel lockage. Certain areas of the facility must be monitored often for security reasons or for dam and spillway gate movements.

(c) Switching the same monitor between cameras on a continuous basis can be time consuming and inconvenient, leading to a tendency not to monitor certain areas of the lock. The cost of adding monitors to a CCTV system during the design phase is really not significant, considering the long-term flexibility, reliability, and redundancy they provide for the system.

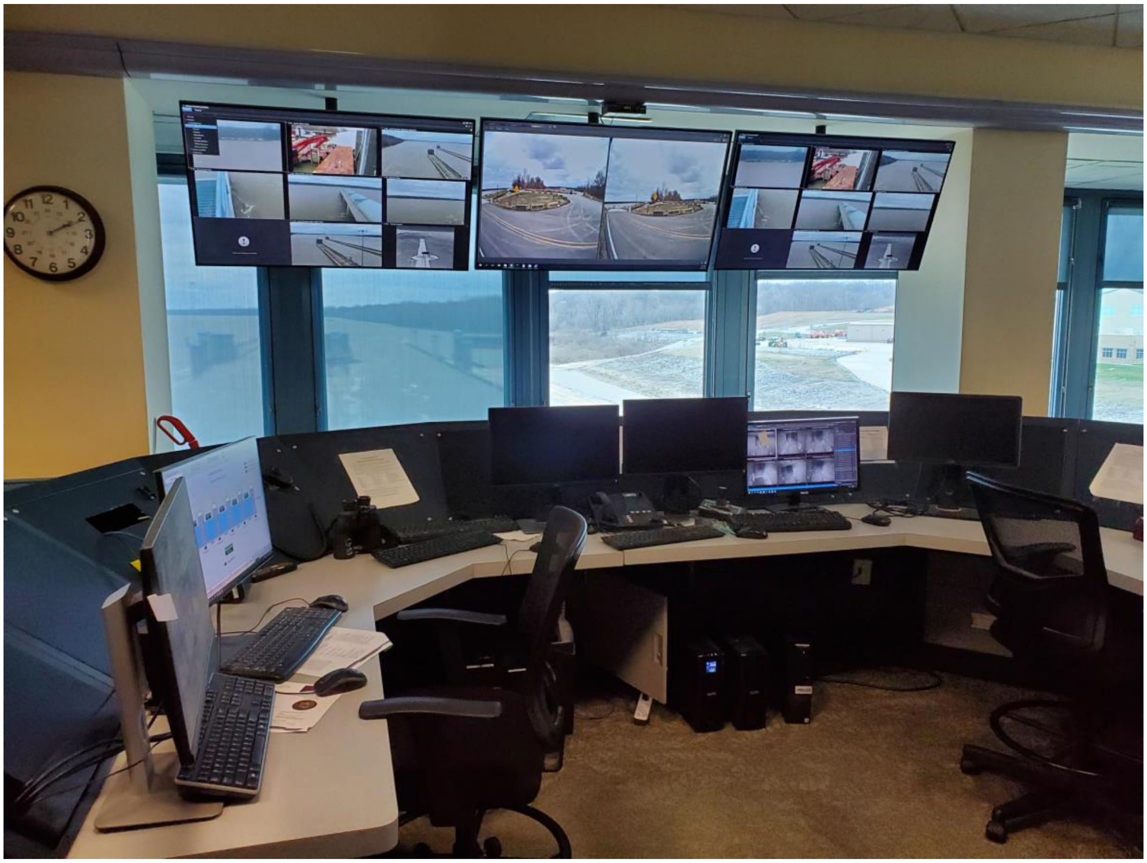


Figure 17–1. Olmsted Dam control console

(4) *Personal computer control network*. The primary means of operating a new lock control system normally will be via stand-alone touch screens or PCs running an HMI software. The PC will connect to the PLC processor using an Ethernet connection. The PC control network should remain isolated from enterprise (corporate) networks and should be limited to HMI traffic.

(a) Internet Protocol (IP)-based CCTVs should be connected on a network separate from the control system. Since the HMI operating screens are used to convey commands to the lock PLC operator, the PC monitors should be located where, aside from the CCTV monitors, they are the easiest and most convenient control system component to view. Since an operator will often be accomplishing other duties while operating the lock equipment, PC monitors located above the CCTV monitors and at approximately shoulder level will provide a good viewing angle.

(b) PC monitors should be as large as practicable, with a recommended minimum quantity of three for each lock chamber. Three monitors allow the operator flexibility to control different features of a lock and dam without excessively switching screens. Two monitors can be used at small, low-usage locks, or locks that do not control other features, such as those on the Columbia River where the powerhouse control room, not the navigation lock control room, controls the dam. A single HMI screen does not provide redundancy in case of video display failure.

(c) HMI screens often use graphical representations, and the monitors should be positioned to give the operator approximately the same orientation as direct visibility. With a mouse or touch screen as the primary operator interface, convenient drawers to store keyboards are a good consideration. This will keep the console top clear and allow more space for the operator to do paperwork.

(5) *Printers*. Providing network printers and/or printers for the vessel-logging PC as part of the control console is a good idea. However, a printer is not used with every lockage, and its location should not compromise the location or accessibility of the CCTV monitors and controls, the PC network workstations, or whatever direct visibility might be available from the control room. Printers can be shared with maintenance computers.

17–10. Applications

a. Lock gates. Lock gates typically are miter gates, sector gates, or vertical lift gates. Each gate type can be motor driven through gearing or a cable hoist or can be operated by a hydraulic cylinder.

(1) *Miter gates*.

(a) Motor-driven miter gates typically feature a motor, gearing (open, enclosed, or both), and a pinion gear operating a sector gear. The sector gear connects to the miter gate through a strut arm. A two-speed motor should be used to provide a low speed for starting and mitering the gate and a high speed in between. The miter gate always should start in the low speed, even when starting from an intermediate position.

(b) A reversing, two-speed contactor is used to control the motor. The starter will be mechanically interlocked for the open/close and low/high-speed functions. The starter schematic must include operation of the holding brake when opening or closing. End-of-travel limits can be provided by a limit switch or derived from a rotary position encoder. The limit switch can be used to select the gate speed. The speed also can be selected based on the gate position. Limit switches should prevent gate over-traveling when opening or closing.

(c) A single-speed, squirrel-cage motor can be used with an AC VFD in lieu of the two-speed motor. The items likely will have a shorter lead time and cost less than the two-speed motor. The AC drive also can provide a smooth acceleration and deceleration of the machinery.

(d) Hydraulically operated miter gates require the control of the hydraulic pump and directional solenoids. A non-reversing starter is required for the hydraulic pumps. The pumps may be centrally located or dedicated to each piece of machinery. Larger pumps might require separate main and pilot pumps. The control system should provide indication of pump operation and low-oil conditions in the reservoir. Operator control and indication requirements are similar to those of the motor-driven gate, but also require controls to start and stop the hydraulic pumps and any alarms.

1. The directional control valve is a mechanical or solenoid-operated valve or valves providing the open and close operations of the gate. Miter gates, including a rack and sector gear, will include physical limit switches to indicate when the rack is fully extended or retracted. Direct-acting cylinder applications may use the internal position of the hydraulic cylinder to determine when the gate is recess or mitered.

2. The internal position may be provided by an LDT or an integrated measurement system. The LDT provides an absolute position, while the integrated measurement system is a relative position. See Chapter 5 for more discussion. A relative position requires the miter gate to be moved to a known position (mitered or recessed) for re-calibration of the position.

3. The gate speed is controlled by the volume of hydraulic fluid flowing into the cylinder. The volume can be set by discrete solenoids or a proportional valve. A series of discrete volume solenoids can provide multiple gate speeds. This could be low and high or multiple speeds. The control system can select the gate speed by a limit switch and be flag-mounted on the rack (only for low or high speeds) or based on the gate position.

4. The proportional valve provides multiple gate speeds depending on the position of the proportional valve. The valve is controlled by an analog output signal. For example, a 4-20mA valve will open at 4mA, stop at 12mA, and close at 20mA. The farther from center (12mA), the larger the fluid volume and the faster the gate speed. The 8mA and 16mA positions will provide less volume and slower gate speeds.

5. Control of the hydraulically operated miter gates can be accomplished using either a hardwired relay control system or the PLC system. When controlling the gates with a hardwired relay control system, pushbuttons or joysticks are used to control the speed (flow of oil) of the miter gates through proportional flow control valves, or multiple fixed-flow valves.

6. When PLCs are used for the control system, analog outputs serve as inputs to the valve controller, and the joysticks or multiple-flow valves are used as a backup for the PLC system. A PLC system is well suited for providing an automatic closing or opening of the miter gate leaves through position feedback from an encoder or similar position sensing devices.

(e) Operator controls should include gate open, close, stop, and speed. The controls system should indicate to the operator gate closing, gate opening, gate speed. The control system also should provide indication of gate mitered (closed) and gate recessed (opened).

(2) *Sector gates*. Sector gates can be operated by a wire rope and drum, a rack and pinion, or direct-acting hydraulic cylinder. Electric and hydraulic motors can be used to transmit power to the machinery. The control application will be similar to the miter gate systems. Sector gates should allow the installation of limit switches in the gate recess to provide indication of gate position when using any of the three power systems.

One consideration unique to sector gates is the filling and emptying of a lock chamber and might require additional limit switches and control logic.

(3) *Vertical lift gates*. There are two types of vertical lift gate hoist systems. One type of hoists consists of a continuous wire rope and sheaves to route the wire rope from the hoist drum, across the lock chamber (or gate) to the opposite side hoist machinery, then back to the driven side of the hoist. In those installations, synchronizing of the hoist is accomplished mechanically.

(a) The other type of hoist system consists of machinery on each side of the chamber or gate. This machinery is operated independently. Machinery may be an electric or hydraulic motor-driven cable hoist or a hydraulic cylinder. In these installations, synchronizing of the hoist is typically accomplished through the control system.

(b) Motor-driven cable hoist machinery is operated by either a single-speed, squirrel-cage motor, a variable-speed hydraulic motor, or an AC (variable-frequency) drive. The AC drive permits the gate to operate at speeds less than the rated speed of the motor. The drive also provides a smooth acceleration and deceleration of the lift gate machinery. The drives may operate independently or as a master and slave when gate position and controls are joined by fiber optic cable.

(c) The AC drive should be operated closed-loop when used in any hoisting application. This will require an encoder mounted on the motor and a suitable interface card in the AC drive. The AC drive can provide control of the holding brake. The holding brake should include a limit switch to indicate to the drive when the brake has released. Limit switches should be provided to indicate overtravel limits for the lift gate. The overtravel raised limit should not permit the gate to travel above the top of the lock wall.

(d) Control of the AC drive (raising and lowering, speed, etc.) can be performed with physical inputs to the drive from the lock control system or via commands received across Ethernet.

(e) Considerations for hydraulic cylinders will be similar to those for the miter gate system. The control application will have to provide for the operation of the hydraulic pump and valves.

(f) When controlling hoist machinery on each side of the gate that operates independently, the position of the lift gate on each side of the gate should be instrumented to ensure the gate does not get skewed in the recess. A rotary position sensor on a sheave can be used to detect position of the gate. The position is scaled to an elevation in feet. The lock control system must monitor the gate movement to prevent skewing (one side of the gate higher than the other). The skew can be monitored by the AC drive or by the control system.

(g) The lock control system should stop the gate movement automatically when the skew becomes excessive, typically 3 in. The amount of allowable skew should be coordinated with the gate and structural designer. The gate skew is corrected by raising

or lowering one side of the gate independently of the other. The lock control system also can provide dynamic skew correction by slowing or speeding up the machinery when it starts to lead or lag the other side. It may not be advisable to overspeed the machinery when it is lagging the opposite side, so consider slowing the leading side.

(h) The gate position also is used to determine when it is in the raised or lowered position, since these usually are based on pool water level. For example, the gate might be considered raised when the top of the gate is 1 ft higher than the pool water level. The gate is lowered when the top of the gate is 16 ft below the pool water level.

(i) Operator controls should include gate raise, lower, stop, and skew correction. Separate controls should be provided for raising and lowering the gate during ice flushing operations. The controls can be programmed to raise and lower the gate at a slower speed. Indication should be provided to the operator when the gate is lowering and raising. These functions should be based on outputs of the AC drive or based on motor rpms reported by the AC drive.

(j) The control system should indicate when the lift gate is raised or lowered. The system also should warn the operator when a gate has stopped at an intermediate position. For example, an audible alarm could be generated if the lift gate has stopped and the gate is not fully lowered.

b. Filling and emptying valves. As with lock gates, several variations of valve machinery are used. Valve bodies can be controlled with a cable hoist, hydraulic cylinder and bell crank, or a direct-acting cylinder.

(1) The motor-driven cable hoist can be operated by a two-speed motor or a VFD similar to a miter gate application. A rotary limit switch on the hoist drum is used to provide the opened and closed limits for the valve. The limit switch should provide indication to the control system when the valve is nearly open or nearly closed, so the valve can operate at a slower speed.

(2) A rotary encoder on the hoist drum can be used to calculate a valve position but, due to the varying diameter of the hoist drum, it will not be linear. The hoist machinery must include a limit switch to detect slack cable in the event the valve body binds or cannot close fully due to debris. When tripped, the limit switch will stop the valve immediately. Consider an open overtravel limit switch to prevent the valve from raising too high and causing damage if the rotary encoder fails.

(3) A valve can be hydraulically operated through a bell crank system or with a direct connection. The rotation of the bell crank can be instrumented with limit switches to indicate the valve position. Some installations have placed limit switches at the cap end of the hydraulic cylinder to determine the valve position. A flag mounted to the cylinder can trip a proximity switch as it moves through its cycle.

(4) In a direct-acting cylinder application, the pivot point of the cylinder is at the cap end. The rotation of the cylinder cap will be small, making it difficult to instrument the open and closed positions. A cable reel sensor or magnetostrictive sensors

(Temposonics®) could be used to instrument the valve movement, but the designer should consider the possibility of physical damage from drift, ice, or other debris.

(5) Operator controls should include valve open, close, and stop. The control system should indicate to the operator when the valve is opening or closing and the valve speed. The system should provide indication of valve fully closed and fully opened positions.

c. Spillway gates. The hoist machinery for spillway gates may feature hoist systems driven by electric motors or direct-acting hydraulic cylinders.

(1) The hoist system using electric motors and gearing may use cable or chain at the hoist drum, but the gate control is independent of the material used. Hoist drums are located on the dam pier at each of the gates. The drums are connected by gears and a horizontal shaft. The drive side includes an electrical motor, holding brake, gear reducers, and starter. The motor usually is controlled by a reversing, across-the-line starter but can be controlled by an AC drive. A rotary limit switch should provide end-of-travel and overtravel limits. The limit switch is driven by the gate hoist machinery. Independent overtravel limit switches, either level arm or proximity type, should be installed as a backup in the event of rotary limit switch failure.

(2) Direct-acting cylinders can be used to operate spillway gates. Cylinders powered from independent hydraulic pumps must include a control system to raise and lower both ends of the gate equally to avoid skewing the gate in the opening.

(3) Gate position can be provided by a rotary encoder on the hoist drum or hoist machinery gearing. The relationship between the hoist machinery rotations and the vertical opening of the gate will not be linear due to the cable wraps on the drum.

(4) Gate position can be sensed by an inclinometer mounted on the upper strut of the spillway gate. The size of the opening in feet can be calculated using trigonometry. These forms of position indication will require a PLC to implement, but manual indication can be accomplished with either a staff gauge and a pointer installed on the gate or a rotary pointer and dial connected to the hoist machinery.

(5) Operator controls should include gate open, close, and stop. The controls system should indicate to the operator when the gate is closing and opening. Spillway gates are designed to operate at approximately 1 ft/min. The designer should consider a control system that provides a periodic reminder, such as an audible alarm, to the operator while a spillway gate is operating.

d. Bubbler systems. A bubbler system uses compressed air to remove drift and other debris from miter gate recesses. The system is made of a central air compressor, distribution piping, and solenoid-operated valves (SOV). The central air compressor will start when the air pressure drops in the system. Navigation locks with significant debris may be equipped with air compressors dedicated to each gate. Dedicated compressors usually are started by the operator or control system before gate operation.

(1) SOVs open when energized, and a spring closes the valve. Depending on the environmental conditions, SOVs may remain open in cold weather conditions. Therefore, it is advisable to locate the air SOVs in a heated enclosure or environmentally controlled space.

(2) Motor-operated valves (MOVs) require electrical energy to open and close the valve. An advantage of MOVs is the ability to instrument the valve position in the control system. The MOV requires internal limit switches that stop the motor in the open and close positions. In freezing locations, consider thermostat-operated space heaters to prevent the valve actuators from freezing, and heat tape cable for manual valves.

(3) Operator controls include bubbler on and bubbler off for each miter gate (solenoid valve) location. The control system should indicate when the bubbler system is activated to prevent wear on the air compressor. For PLC-based systems, air pressure can be instrumented with a pressure transmitter.

17–11. Relay-based (discrete relay) control systems

a. General. Relay-based control systems are prevalent in USACE projects and are still used frequently. Both relay-based controls, as well as PLC-based systems, should be considered for new and rehabilitated control systems. The appropriate selection should be based on each facility’s needs and resources.

(1) Discrete relay-based control systems are typically used in relatively simple systems, when the number of control components keeps the enclosure sizes, wiring, and troubleshooting manageable, when the control is mostly local, and when the system control logic is changed infrequently. They also might be employed where funding is limited and few personnel with the technical expertise to maintain a PLC-based system are available.

(2) All control systems have discrete relays. In a PLC-based system, these discrete relays typically are employed between output modules and field equipment. These interposing relays provide isolation to minimize transient damage to the solid-state equipment. They also are used to carry the heavier load currents that are beyond the rating of the solid-state equipment.

(3) Cost analyses (total cost of ownership) have been performed by USACE personnel when comparing PLC-based and discrete relay-based systems. Generally, the life-cycle cost comparison demonstrates that, in some instances, use of PLC-type control systems can be justified over relay-based systems. The cost comparison assumed that maintenance would be performed by lock personnel and that they are available at the project.

(4) Since there are so many factors (maintenance skill levels, proximity to equipment sources, operational preferences, legal considerations, lockage types, etc.) that vary from project to project and USACE division to division, methods of conducting cost comparisons on PLC versus discrete relay logic are not presented here.

(5) The basic control system for any lock should be a control-voltage source, hardwired limit switches, pushbuttons, pilot lights, relays, contactors, E-stops, and other similar control components. A hardwired, relay-based system may also include position encoders, transducers, and other status sensing electronic devices.

(6) Relay-based control allows the lock personnel to maneuver each piece of equipment directly and individually with the full complement of interlocks and other safety devices that might be required. Typically, there is little to no automation in projects using discrete relays. Access to the discrete controls should be at every control station and at other areas around the lock, as deemed necessary by the lock personnel and design team. The discrete control components should be simple and ergonomically designed, with good visual feedback, and arranged in a logical manner.

(7) The discrete controls should have a means of operating all the lock equipment, including the miter gates, lift gates, tainter gates, filling and emptying valves, traffic lights, bubbler systems, warning horn, emergency stop, lock lighting, small pleasure-craft controls, and other equipment unique to each lock and required for day-to-day operation. The designer must spend ample time with the operating personnel to determine all the features needed for the discrete control system.

b. Advantages.

(1) Relay-based control systems are simple to maintain and reliable. Control relays are relatively inexpensive and are produced by several manufacturers, making it relatively easy to replace them if they fail. Maintenance workers do not have to be specially trained when working on discrete control relays from project to project. Discrete relays do not require special power supplies and usually are operated at 120VAC.

(2) It is common for discrete control relay system lifespan to be 35 years or more with few instances of relay failures. There are two more common types of relays available: industrial control heavy-duty relays and those called ice-cube relays. Industrial control relays come with an integral mounting base, whereas ice-cube relays are usually plug-in and mount-in bases. The industrial control heavy duty relays generally have a longer life and are a better choice for navigation projects that are designed for a 50-year or longer life.

c. Disadvantages.

(1) Discrete relay-based control systems can require labor-intensive wiring when building control panels and, depending on the number of relays used, can require a lot of wiring in the control enclosure. Making changes to discrete relay-based control systems can be costly, depending on the scope of the change, especially compared to PLC systems.

(2) In larger locks or where controlled components might be quite a distance away, the designer must consider whether or not a DC control system should be used, because it is possible that inductive coupling from adjacent cables and capacitance of

the control cables could keep a relay (or LED pilot light, for example) energized when it should not be.

(3) Using discrete relay-based control requires much more control wiring than PLC-based systems. With the fluctuating price of copper, this could add significant cost to the project. However, once the copper is installed, it requires little to no maintenance.

d. Main control equipment.

(1) The lock MCC or a separate enclosure in the operations building (or similar, centrally located building) usually houses all the control relays. Since control relays are not equipment an operator will need to access on a daily basis, the enclosure housing them should be in a dry, low-humidity, low-traffic, protected area. Only qualified maintenance personnel should have access to the control relays. It would be wise to add 25% more panel mounting space to allow for changes, modifications, or expansion in the control system.

(2) Procurement, installation, wiring, and startup of the relay-based control system should be required by the contract documents. It is best engineering practice to provide well-written, complete specifications with well-defined control function parameters, to ensure equipment installation and operation will provide a reliable, lasting control system.

e. Discrete relays.

(1) *Instantaneous relays*. Relay-based control systems use discrete relays with contacts that usually are rated 10A continuous at 600VAC (NEMA A600). The relays are usually used in 120VAC control systems. The relays are available in the industrial control relay version (rugged, larger relays) and in a less rugged plug-in or bolt-in relay version (sometimes called an ice cube or miniature relay). These relays usually have clear, plastic housings and usually are rated 2A at 120VAC.

(a) The plug-in version is secured in place with steel bails that attach to the relay mounting base and wrap around the relay. Relays are available in NEMA- and IEC-type ratings. A NEMA-type rated device is considered more rugged, but also is usually larger than the IEC-rated device. Both types can be successful when used within their ratings. Control relays that are used between low- and high-current portions of a control circuit are called interposing relays.

(b) Another type of relay used for this function is called a contactor or starter. A contactor is used to carry the load current of the device controlled (motor, lights, heaters, etc.). A contactor with overloads is called a starter (see below for more on overloads). Auxiliary contacts also are used to provide interlocks between portions of the control circuit. A common example is an interlock between the raise and lower contactors for a motor.

(c) Interlocking relays keep the contactors from being energized simultaneously or keeps a piece of equipment from being energized under certain conditions. For

example, when the upper miter gates on a lock area closed, the relay operated by the limit switches on the miter gate keeps the opposite end miter gates and valves from being operated simultaneously.

(2) *Timing relays*.

(a) Analog type. Analog types of timers are available as motors or bellows. For critical timing functions, these timers might not be as suitable because they are less accurate than digital timers. For most USACE applications, they will be sufficiently accurate but might need adjustment during seasonal changes.

(b) Digital type. This type of timing relay is common and more accurate than the analog type. Also, they are available in a wider range of timing functions. Even though they are digital, they can be used without power supplies on standard control voltages.

(c) There are many options for timing relay contacts. Instantaneous contacts are always provided. Timed contacts include on delay, off delay, normally closed time opening (and normally open time closing) on energization, normally closed time opening (and normally open time closing) on de-energization, interval, one shot, repeat cycle (flasher) and multifunction. Input voltages vary among 12VAC/VDC, 24VAC/VDC, 48VAC/VDC, 120 VAC/VDC, and 240 VAC/VDC. Contact ratings are usually available in B300, R300, AC15, and DC13.

(3) *Undervoltage relays*. Undervoltage relays can be used to detect low-voltage conditions for hoist motors (to ensure minimum torque) or to ensure available voltages do not drop below those required for proper operation.

(4) *Overload relays*. Overload relays are used primarily in motor circuits to ensure the driving equipment (motor, gearing, and shafts) is protected.

(a) There are two categories of overload relays: thermal and instantaneous. Thermal overload relays have heaters or current transformers in the motor power circuit to sense over current based on heat buildup in the motor. Instantaneous overload relays trip instantaneously when the current set point is reached. This type usually is used for torque limitation on the drive machinery or load.

(b) Overload relay auxiliary contacts are in the control circuits and serve to de-energize the control circuit on an overload condition. Overload sensors are available in solid-state and eutectic alloy versions. Eutectic alloys melt on overcurrent. Solid-state overloads contain electronic components to sense the overload. Both types of overload relays are available in three different trip classes (10, 20, and 30), depending on the loads.

(5) *Selector switches and pushbuttons*. Selector switches and pushbuttons are available in different configurations such as maintained contact, momentary contact, illuminated and non-illuminated, locking, emergency stop types, and other less commonly used types. Contact blocks are separate and available in NEMA and IEC ratings.

(6) *Pilot lights*. Pilots for indicating status of equipment, alarm conditions, and other types of information are available in LED types, incandescent types (full-voltage or transformer type), or neon lamps. Push-to-test lights also are available, allowing the operator to push the lens to verify the lamp is working without having to remove the lamp for observation. The LED lamp is a preferred choice due to its long life.

f. Control wiring considerations. Hardwired relay control systems should use point-to-point copper wiring, stranded, with Type K hinge wiring to components mounted on doors of enclosures. USACE projects usually employ 120VAC control circuits.

(1) For long-life single- and multi-conductor cables that are installed in conduits or cable trays, insulations and jackets should be made of cross-linked thermosetting polyethylene or ethylene propylene rubber (EPR), rated 600VAC, 75 to 90 °C. Copper conductors typically are specified, although aluminum conductors can be used. Wiring types that typically are used in control enclosures for control equipment are Type SIS, MTW, and XLP. Stranded wiring is preferred.

(2) Unless load calculations require #12 American Wire Gauge (AWG) wiring size, it is suggested that #14 AWG conductors be used for flexibility, ease of installation, wiring space, and cost savings. When specifying control equipment, consider the requirements for wiring termination. Solderless box lug or screw compression connections are required because they provide a satisfactory and easier installation, compared to terminals such as ring or spade (fork) terminations. When specifying power supplies, optional screw terminations are suggested over the standard soldered termination.

g. Motor starting.

(1) As with most other control equipment, starters are available in NEMA and IEC ratings. As stated, NEMA generally is considered a more rugged device because of the range of loads for which they are designed. However, IEC-rated devices can be used, provided the load currents and applications are within the rating of the device.

(2) Several different types of starters are available and include full-voltage, across-the-line (FVAL), XM delta starters (to reduce the starting current and torque), reduced-voltage autotransformer starters (RVAT, for reduced starting currents and torques), solid-state, reduced-voltage starters, and VFDs. When selecting the motor starting method, the designer must consider required torques, voltage drops as a result of the starting motor, and load requirements.

h. Equipment enclosures. Relay-based system components should be installed in metal enclosures, complete with power sources, control transformers (if required), control relays, pushbuttons, selector switches, pilot lights, heaters, and any other equipment needed. The enclosure should be NEMA rated, as required for the area in which it will be installed, with locking door hardware. Outdoor enclosures should be rated suitably and shielded from sunlight if located in direct exposure. The enclosures should have at least 25% spare mounting panel space for upgrades and expansions.

i. Hardwired control system interfaces.

(1) The control system interface in a hardwired control system consists of discrete pushbuttons (maintained and spring-return type), selector switches (maintained and spring-return type), joysticks (friction hold and spring-return type), and LED pilot lights, although incandescent full voltage and transformer type are still in use.

(2) Pushbuttons and selector switches can be furnished in illuminated, non-illuminated, and key-operated versions. The contacts on these control devices should be rated for the load they will be operating. The vast majority of the time, NEMA A600 contact ratings are sufficient. When used with low energy level loads (inputs to PLCs, etc.), logic reed blocks or similar should be considered. These contact blocks can operate successfully with the low wiping currents of some electronic loads.

j. Grounding. All enclosures for the control components should include solid grounding provisions for operator safety. Most of the time, control circuit transformers will be grounded. However, it was common in older control systems (and some still use it today but mostly in component replacement, not new system design) to not ground the control transformer to prevent loose wiring connections in any part of the control system from causing a component to inadvertently energize.

k. Operating locations. The operating locations in a relay-based control system are usually kept to a minimum due to control wiring and wireway costs.

(1) Normally, all components are controlled from one end of the lock or the other (upstream gate or downstream gate). Additional, infrequently used control stands may be used to operate the gates or valves from the opposite side of the lock during inclement weather. When in this mode, there are two operators moving the gates, one for each gate leaf. It is common to provide filling and emptying valve controls at the control relay location, but the lock gates are controlled locally.

(2) It is strongly recommended that the distance from the control relays to the feature being controlled (valve, gate, motor, pilot light) be considered when laying out the control system. Inductive or capacitive coupling might keep some relays or pilot lights energized when they should not be. Manufacturers list the recommended maximum distances when using certain control relays and pilot lights, and this data should be consulted during the design of larger locks. It generally is not a problem in locks 1,200 ft long and 110 ft wide or smaller.

l. Contactors and starters.

(1) Contactors are NEMA- and IEC-rated devices that are used to carry and interrupt the larger currents required for motors and electrical loads larger than the rating of control relays. NEMA-rated devices are typically specified for USACE projects because they provide a more rugged, heavily rated component than do IEC-rated devices. IEC devices are more closely electrically sized to the load. Starters are contactors that include a thermal overload relay.

(2) Contactors and starters should be provided with additional auxiliary contacts for pilot lights, interlocking, and possible future use. Overload heater elements should be provided with auxiliary contacts for indication of trip condition to facilitate troubleshooting. Thermal overloads are available in at least two different types, eutectic alloy and solid state, and are available in three trip classes (10, 20, and 30) for various applications.

m. Variable speed drives. It might be desirable to use variable speed drives at some projects with relay-based controls. When using variable speed drives, it is important, for motor-cooling reasons, to coordinate the selection of the motor with the drive and the speeds at which it will be used. Not all motors are rated for use below their rated slip speed.

n. Alarms. The lock and dam control system should include audible and/or visual alarms for overtravel instances, low hydraulic oil, overloads, and the like. Alarms should alert operators and maintenance personnel to failure of lock operating equipment.

o. Sensors and field devices for hardwired relay control systems.

(1) *Input/Output devices*. The I/O devices that provide information to the relay-based control system are the same for those provided for PLC systems. However, there are more electronic-type field devices used with PLC systems. Sensors and field devices are important in the overall success of a lock and dam control system. Failure to specify quality materials and proper installation and testing of field devices will diminish operator confidence in the entire system.

(2) *Spare parts*. Redundancy and spare parts are an important part of the auxiliary equipment design process. Typical sensors and field devices for a navigation lock include:

(3) *Limit switches*. Dry contact limit switches are a common control system component. Different switches are used for different applications. These devices are particularly useful for end-of-travel or overtravel limit switches because they are absolute, passive, and require no electronic calibration. Limit switches of this type also can be provided with auxiliary contacts. Care should be taken to specify quality components because limit switches are critical to the correct, dependable, and safe operation of the control system. Time should be taken to write sound specifications for procuring, installing, and testing them.

(4) *Vein/roller/lever operated*. Simple vein or roller-operated dry contact limit switches are used for all types of moving machinery. It is a good idea to specify these with extra contacts. Specifications should include heavy-duty, oil-tight, corrosion-resistant ratings, number, rating, and type of contacts, NEMA 4X or 6P rating as appropriate, UL listing, operator lever type, and operating temperature range.

(5) *Magnetic/proximity/photoelectric*. By eliminating moving parts and providing a degree of submergibility, magnetic and proximity limit switches have replaced the vein-operated switches for use on the end of miter gate leaves for indication of proper miter,

and in the miter gate recesses for indication of a fully recessed gate. To avoid damage to miter gates, HQUSACE has mandated positive indication of the miter and recess positions. Be careful using photoelectric sensors for other than light control, as environmental influences, such as spiders and insects, can block the sensors with webs or debris.

(6) *Interlock considerations*. These switches must be installed and used in the control system as interlocks to prevent filling of the chamber (improper miter) or changing the traffic light to green (improper recess). The use of these types of switches is a good consideration in other areas where ice can hinder the operation of vein-operated switches.

(7) *Specifications*. When procuring magnetic or proximity switches, specifications should include number, type and rating of contacts, NEMA 4X or 6P rating as appropriate, UL listing, temperature range, copper or fiber optic leads, side or top mount, standard and extended operating ranges, and surge protection. The extra time it takes to properly specify a good switch is well spent.

(8) *Encoders, resolvers, inclinometers, and electronic transducers*. In a relay-based control system, it might be desirable to use some electronic equipment for certain position and level measurement and display tasks. They can be used with a relay-based system but require dedicated display devices and signal-handling equipment because PLC screens or computers are not used in the relay-based system.

(9) *Absolute position encoders*. It is strongly recommended that absolute position encoders be furnished for control systems instead of the incremental, if at all possible and practical. This will ensure that, after loss of power to the position sensor, the position of the machinery being measured will be known. See the PLC section for more about this type of equipment.

p. Planning the design. The discrete relay main control system should be in the electrical center of the components to be controlled to minimize the length of the conductors to the field components. It is recommended that some spare mounting panel space be included, or the equipment arranged to facilitate adding relays, should the system ever be revised and require more relays. The relays should be housed in a conditioned space, heated to minimize condensation. There usually is not a significant amount of heat rejected into the discrete relay-based control systems.

17–12. Programmable logic controller-based control systems

a. Programmable logic controller manual controls. The basic control system should be individual PLC inputs from an HMI software package, hardwired pushbuttons, limit switches, encoders, transducers, and discrete PLC outputs to motor starters, contactors, and pilot lights.

(1) For example, each miter gate leaf should have an OPEN, CLOSE, and STOP pushbutton for manual operation of the gate. This type of operation allows the lock personnel to control each piece of equipment individually with the full complement of

PLC interlocks, limits, and failsafe devices. This should be the minimum normal control system at any lock.

(2) Degrees of automation, as discussed herein, vary by project site. Access to the manual controls should be at every control station and at other areas around the lock, as deemed necessary by the lock personnel and design team. The manual controls should be simple and ergonomically designed, with good visual feedback such as pilot lights and/or on-screen graphics.

(3) The manual controls should have a means of operating all the lock equipment including the miter gates, lift gates, emptying and filling valves, tainter gates, traffic lights, bubbler systems, warning horn, emergency stop, lock lighting, small pleasure-craft controls, and other equipment unique to each lock and required for day-to-day operation. The designer must spend ample time with the operating personnel to determine all the features of the PLC manual control system.

b. Programmable logic controllers.

(1) PLC or PAC systems have become common on new lock construction and during rehabilitation on existing lock systems. For the purposes of this document, the terms PLC and PAC are interchangeable. The PLC should be industrial quality, off-the-shelf, standard equipment from a reputable manufacturer. The PLC is the primary means of control for all lock and dam operating equipment.

(2) Power equipment monitoring and plant lighting control are features that can enhance the efficiency, cost, and reliability of a lock and dam facility. The intent of this document is to provide to the design engineer guidelines and issues to consider when laying out a new PLC lock control system. Size, communication speeds, capacities, performance parameters, location, and the number of PLC components vary from project to project. Ultimately, it is the responsibility of the design PDT to determine what system is right for the project.

(3) The central processing unit (CPU) can perform all manipulations to input data, update all outputs, provide the information for HMI software to update operating screens, and accept operator commands from the HMI. The CPU should be located near the central control room area, but not in the main control console. The CPU is not something an operator needs to access on a daily basis. Whenever possible, the enclosure housing the CPU should be installed in a dry, low-humidity, low-traffic, protected area.

(4) Only qualified maintenance personnel should have access to the PLC system’s CPU.

(5) Specifying an appropriate amount of memory for the CPU is an important concern when designing a PLC system. Memory usage is different between PLC manufacturers, so it is important to specify an amount of memory that provides adequate capacity. Typically, CPU memory is specified in terms of Mb (megabytes), where each MB is 524,288 words (2 bytes).

(6) After becoming familiar with how memory is used in several PLCs, designers should determine the maximum memory requirements for the application. There are several general rules (for example, 5 words of program memory for each discrete device and 25 words for each analog device), but none can be used without first knowing the approximate number of output points (real-world outputs plus internal relay coils) in the system.

(7) Once that number is known, an estimate must be made for the amount and type of instructions associated with each output (the number of words required for each instruction is dependent on the CPU manufacturer and can be determined by consulting the manufacturer's PLC literature). Then, the minimum amount of memory required is the estimated memory required for each output multiplied by the estimated total number of outputs. It would be wise to add 25 to 50% more memory to allow changes, modifications, or expansion.

(8) Procurement, installation, and programming of the CPU should be provided for in the contract documentation. When writing contract specification requirements, particular care should be taken to include a unit with the highest performance available.

(9) Such parameters include the largest amount of memory, fastest communication speed, highest program execution rate (scan time), maximum amount and type of I/O capacity, number and flexibility of communication ports (serial RS-232, RS-422, Ethernet, etc.), special proprietary communication ports, self-diagnostics, and the largest set of internal instructions.

(10) Compromise might have to be made to get the ideal processor for an individual project. However, the designer should strive to get the highest quality equipment with the most capacity, performance, and options to ensure adaptability to future needs. Since PLC equipment does not become obsolete as fast as PCs and software, preparing for future capacity is a good idea.

(11) Without well-written and complete specifications with well-defined parameters such as those listed above, the designer is at the discretion of the contractor to provide a quality processor. Often, the processor's quality will determine the quality of the rest of the PLC system components and, hence, a large majority of the cost. A low bid contractor is not going to provide a state-of-the-art, top-of-the-line system unless it is well-specified in the contract documents.

(12) Determining parameters for a good system of input and output PLC components is not necessarily straightforward. Manufacturers often provide several different grades of I/O components for a top-of-the-line CPU. Parameters such as isolation, density of points, response times, operating voltage levels, power requirements, fusing, and LED diagnostics should be considered when specifying I/O components.

(13) Noise suppressors should be used to protect PLC equipment from the voltage transients, spikes, and electrical noise appearing on power circuits. Such noise

suppressors would be installed in each I/O rack enclosure and connected to the power supplies feeding each I/O rack.

(14) To guard both communication modules and communication cable (metallic only) from damage, I/O interface modules should be protected with overvoltage transient surge suppressors. To accomplish this, use a device that suppresses transients caused by lightning, inductive switching, and electrostatic discharge.

(15) In those applications where an inductive load, such as a motor starter or solenoid, is wired in parallel with an input module, a surge suppressor should be installed. A typical suppressor consists of a 0.5 μF, 400-V capacitor with a 220-ohm resistor in series. Procurement and installation of these should be coordinated with the PLC manufacturer.

(16) A designer first must determine the basic requirements for I/O component types in different locations on the lock and dam facility. Where there are dry contact-type inputs, digital (discrete) input cards should be provided. Such inputs could include traveling nut and rotary cam limit switch assemblies, pushbuttons, selector switches, relay and motor starter auxiliary contacts, vein and/or magnetically operated limit switches, thermostats, and photocells.

(a) Digital input cards can be specified to be isolated or non-isolated. Both types serve useful purposes in lock and dam applications and, in some circumstances, both types should be provided in the same I/O rack location, though this increases the required number of spare I/O card types.

(b) Certain digital inputs, such as control panel pushbuttons or limit switches, on the same assemblies can be grouped together on input cards using a single reference or neutral conductor and termination point. Often, a single common conductor can be connected to these types of input groups. This requires non-isolated digital input cards.

(c) More remote inputs operating at different voltage levels such as photocells, thermostats, and magnetic limit switches should be isolated from other inputs. Select a voltage level for each group of inputs to be the lowest possible without excessive voltage drop or capacitive coupling. In most cases, if voltage drop or capacitive coupling is a problem, an additional I/O rack assembly can be installed to reduce conductor lengths.

(d) A voltage greater than 120VAC should not be used for PLC input systems, except in special cases. With the reliability and hot-shadowing capability of most I/O power supplies, the recommended PLC control system voltage is 24V, AC or DC. With the density of points available on today’s small I/O cards, it is usually feasible to use an extra input to monitor power supplies and alert maintenance personnel to failures, as well as switching to an alternate unit without interruption in the control system process.

(e) A designer should try to maximize the number of I/O points of each type available at each location by specifying the highest available density cards. It is important,

though, not to compromise other features such as isolation just to achieve more I/O points.

(f) It is unwise and ultimately will cost more in inconvenience and downtime than the money saved at first by using a minimum number of I/O cards or lower quality I/O cards with more points on each card. Therefore, first determine the type of inputs and the requirements for isolation and voltage levels. Next, specify the highest density card that meets these requirements. Specify enough cards of each type to provide a minimum of 25% spare I/O capacity beyond any known expansion plans.

(17) There are many different types of digital outputs required in a lock or lock and dam PLC system. Some of the more common types include motor starters, solenoid- and motor-operated valves, pilot lights, relays and contactors, bells, sirens, and horns. As with digital input cards, some outputs can be grouped using non-isolated output cards. These outputs, usually pilot lights or relays of the same coil voltage, use the same common source and the same neutral wire.

(a) Other outputs with varying voltages and/or inductive load conditions require isolated digital output cards, sometimes called relay cards. These types of cards provide a single output for each card, are electrically isolated from other outputs, and can have different voltage levels for each output. All outputs should be fused, either internally to the output cards or externally at a power supply or at the load. This protects the card as well as the field wiring.

(b) Output loads should be reviewed to ensure they do not exceed the load capacity of the output cards. In cases where the load ratings required are high or marginally high, or have high starting currents such as motors, pilot (interposing) relays should be used to provide a smaller, more consistent load on the output card as well as isolate it from more unpredictable power system faults.

(c) When specifying output cards, designers should follow a rule similar to that for input cards. First, determine the need for output cards at different locations in the system. Second, determine the operating voltage level, the need for pilot devices, the need for isolation and fusing, and the quality of card necessary for the system. Third, specify the highest density card that meets all these requirements including the spare capacity, as stated above for the digital input modules.

(d) Whenever there is doubt, remember it is easier to remove cards or exchange them rather than add them if there is insufficient space or capacity.

(18) Analog input devices include rotating shaft encoders, resolvers, inclinometers, pressure transducers, resistance temperature detectors (RTDs), and hydraulic cylinder position tracking systems. Most PLC manufacturers can accommodate several different types of analog input signals, often using the same card. Input types include 4-20ma, 0 to 10V, -10 to +10V, and so forth.

(a) When specifying analog input modules, it is important to address features such as input current/voltage ranges, number of channels, impedance, resolution, accuracy

as a percent of full scale, electrical isolation, shielding, fault detection, update time, I/O bus power requirements, and fusing. Analog signals present a much greater challenge to designers because inaccuracies, without failure, can occur easily due to electrical magnetic noise, improper grounding or shielding, mismatched impedances, or combinations of these.

(b) If these items are not properly addressed by the contract specifications, problems with drifting signals ultimately will occur, possibly after a contractor is long finished with the job. These types of problems can be difficult to find and correct. Specifying high-quality, isolated, analog input modules will help keep these problems to a minimum.

(c) When designing a PLC system with analog inputs, a designer should first determine the location and type (current or voltage with range) of analog inputs required. Where possible, without making signal cables excessively long, these inputs should be grouped to make use of multi-channel analog input modules.

(d) Full-scale accuracy and resolution should be determined for each analog input by first determining the accuracy of measurement required to control the system. For example, if a gate raises and lowers a maximum distance of 9 m (30 ft), and the operator needs to know the position to the nearest 3 mm (one hundredth of a foot), the range of travel is 3,000 counts, with each count equal to 3 mm (one one-hundredth of a foot).

(e) Likewise, a rotating shaft, 4 to 20ma analog transducer mounted to the cable drum produces a 5ma current signal at 0 m (0 ft) and 15ma current signal at 9 m (30 ft) of gate travel. To achieve the accuracy required by the operator, the PLC analog input card must be able to resolve 10ma of travel into a minimum of 3,000 counts. Since the full-scale range of the transducer is 4 to 20ma or 16ma, this equates to 4,800 counts over the full range. This requires an accuracy of 1/4,800 or roughly 0.02% of full scale, with resolution of 4,800 counts or 13 bits of accuracy.

(f) Failing to perform this type of design analysis properly can result in a signal or analog input card that is not accurate enough through the entire range of travel to use for effective machinery control or position determination. When physical location, voltage/current range, accuracy, and resolution requirements for each analog input has been established, PLC analog input cards that meet all these requirements should be specified. If possible, a single type of analog input card should be used throughout the entire system.

(g) Previously, a jumper or dipswitch setting was used to configure each channel on a card for different current and voltage ranges, but now this usually can be configured in the programming software. Specifying electrical isolation levels, register update times, and fault detection features help ensure the contractor provides a quality product.

(h) The impedances of the analog input card, cable, and transmitting device should be analyzed when determining the voltage level of the power supply that drives the current loop. Shielding always should be accomplished according to written

recommendations from both the transmitting device and PLC manufacturers. Signal shield grounds should be isolated from power grounds.

(19) When motion controllers, variable speed drives, hydraulic linear variable differential transformers, or other control equipment require current loops for speed or position reference, designers might want to use analog output cards to interface the PLC system with such equipment.

(a) Since a margin for error exists when using analog control signals, designers should, before deciding to use analog output cards, consider digitally integrating such equipment using serial communication standards. This will make a simpler, more reliable control system that likely will be more flexible because of the amount of information that can be transmitted digitally.

(b) If, however, it is determined that analog output cards are necessary, the system designer should follow the same steps as outlined above for the analog input modules. Again, the objective is to perform a design analysis on each device that is driven by the analog output points to determine the exact requirements for the output cards, wiring, shielding, and power supplies. Always try to specify the highest quality component available for the system.

(c) Remote I/O components should be installed in metal enclosures, complete with power supplies, power line conditioners, isolators, I/O component racks, ventilating equipment, desiccants, heaters, air conditioners, communication equipment, pilot devices, and uninterruptible power supplies, as needed.

(d) The enclosure should be NEMA rated, as required for the area in which it will be installed, with locking door hardware. Outdoor enclosures should be rated suitably and shielded against sunlight if directly exposed. Remote I/O racks should be as required for the type of cards specified and should have at least 50% empty slots for upgrades and expansions. Where applicable, I/O rack addressing should allow the empty spaces to be used without readdressing an entire program.

(e) To achieve a reliable system, it is important that design engineers look at all of the components necessary in the I/O enclosures to ensure they are of proper size, rating, and capacity with proper space requirements for dissipation of heat. Calculations should be done to determine the need for and sizing of heating, air conditioning, and ventilating equipment. All this should be given in design specifications so a contractor will provide the highest quality equipment, helping to ensure a reliable system.

(f) One of the critical parts of the I/O enclosure design work is the grounding of the electronic and communication equipment contained within the enclosure and the enclosure itself. The NEC does not cover in sufficient detail the grounding of such equipment. Therefore, references to the NEC within plans and specifications do not guide a contractor very well in electronic ground systems. In general, it is wise to keep electronic grounds separate from power and conduit system grounds even if, ultimately, the two are tied at some grounding point.

(g) Keeping the electronic equipment out of the path of other potential ground surges is important. I/O racks, power supplies, communication interface equipment, and other electronic equipment should be mounted to the I/O enclosure metal using rubber or plastic standoffs to isolate them from the enclosure itself. Most electronic equipment is provided with a ground terminal and instructions from the manufacturer on how to ground the equipment. It is important to ground and shield all electronic equipment properly.

c. Network configurations. PLC systems can be networked in several different configurations. The general guideline is to locate I/O racks in areas where limit switches, motor starters, and solenoids are grouped. Networking of I/O racks on PLC communication channels should be laid out in a design document with consideration given to fail override and redundancy. Some general design guidance:

(1) The first objective is to determine the number and location of system I/O racks. A designer first must survey and chart all the I/O points necessary to operate the lock. This includes all discrete and analog points.

(a) Sorting the I/O point list by general location will give the designer an idea of where they are concentrated. I/O racks should be in areas where a significant number of I/O points are grouped, taking care not to use so many I/O racks that the overall number impacts the availability of the system by increasing the number of failure points. It is difficult to determine the minimum number of I/O points in an area that requires installation of an I/O rack. This varies from project to project and is relative to the overall number of I/O points.

(b) An important consideration is the number of lengthy control circuits that can be eliminated by the installation of an I/O rack. An objective a designer should have in mind is to keep hardwired, difficult-to-diagnose I/O circuits as short and accessible as possible. With fiber optic technology, lengthy communication circuits are not only possible but also easy to maintain, diagnose, and repair. Therefore, a designer should not be afraid to specify additional I/O racks in remote areas where there are relatively few I/O points.

(c) In any case, an availability analysis should be done to determine the optimum number of I/O racks for the application. In some cases, the analysis might show that fewer I/O racks with longer cable runs will provide the optimum system availability. In cases where single I/O are remotely located from I/O racks, consider using optical switches and sensors.

(2) After the location of I/O racks has been determined, it will be necessary to connect them in a network configuration. While different networking protocols have been used over the years, Ethernet IP has become the industry standard for PLC networks, as many devices are built with Ethernet capability. Using Ethernet also makes it easier to connect PCs and HMIs to the network for monitoring, logging, and control, as needed.

(3) Using Ethernet protocol in no way implies or advocates connecting a navigation lock network to the Internet, or any external network for that matter.

(4) Avoid a linear network configuration, where loss of one rack could impair or stop communications with devices past that on the network. While a star configuration can offer the most reliability, it also requires the most cabling (whether copper or fiber optic).

(5) A ring network also should be considered. If possible, adjacent locks should be on separate PLC processors and networks. Communication between I/O racks generally should be via high-quality fiber optic cables, as recommended by the manufacturer of the PLC system. Specifications should be written to provide the fastest I/O network communication speed available. This will help ensure the system the contractor provides is of high quality.

(6) Make sure Ethernet switches used on the network are of industrial quality and capable of supporting the chosen network. Enable IGMP (Internet Group Management Protocol) snooping to reduce bandwidth consumption by reducing multicast streams. Converters, power supplies, and other communication equipment should be supplied by the PLC manufacturer. A third party may provide such equipment, but only as recommended by the PLC manufacturer. This also will help ensure a quality PLC system.

d. Human machine interfaces. Input devices can consist of PCs with a mouse and keyboard running HMI software, touch screens, physical controls (pushbuttons, switches, etc.) wired to PLC I/O, or a combination of the above.

(1) *Keyboards*. Due to its widespread use, standard IBM AT keyboards should be used with PCs. Small footprint versions may be used, depending on console design. Custom-built consoles or racks with pull-out drawers may be used to house keyboards. Protection against dust and liquid can be achieved by using keyboard overlays.

(2) *Touch screens*. Touch screens come in several varieties, including infrared, surface acoustic wave (SAW), and resistive types. Of the touch screens implemented for lock and dam control, the SAW type is less prone to false inputs. The infrared-type touch screens are best used in applications that require a second acknowledgment for confirmation of each input. SAW-type touch screens are much more forgiving due to their design. They require firm pressure applied to the screen before registering as an input. Touch-screen HMIs can be used as a stand-alone terminal, or monitors with touch-screen capabilities can be used with a PC, instead of a mouse and keyboard.

(3) *Video display monitors*. There are two common types of video display monitors: liquid crystal display (LCD) and LED. Cathode ray tubes (CRT) are rarely used anymore due to excessive power consumption, heat generation, and large footprints, and should not be considered for implementation in a navigation lock control system.

(a) Advantages of LCD and LED monitors are low heat generation, small footprint, and lightweight build. These flat screens are available in large sizes, with high

resolutions and wide viewing angles. Their flat design, small footprint, lightweight build, wide viewing angle, and brightness are ideal for lock and dam control.

(b) Note, however, there are many flat-screen display manufacturers and not all models are equivalent. The primary characteristics to look for are high resolution and wide viewing angles. Touch-screen LCD and LED monitors also can be used, eliminating the need for a keyboard and mouse in daily use.

(4) *Industrial personal computers*.

(a) In applications where a PC is being used for monitoring and/or control, IPCs can be considered. IPCs are built to withstand a wide variety of environments. They are specially shielded against electromagnetic and radio frequency (RF) interference and certified to meet the Federal Communications Commission's electromagnetic interference (EMI) and radio-frequency interference regulations. They also are built for a wide range of temperature extremes and can withstand extreme thermal stress.

(b) IPCs are built with shock and vibration resistance for rugged and heavy-duty use. IPCs can be considerably more expensive than name-brand PCs with similar specs, so ease of replacement and downtime impact should be taken into consideration. IPCs also are called blind nodes and non-display computers, depending on the manufacturer. In the following discussions, the terms PC and IPC can be used interchangeably.

(5) *Power systems*.

(a) Uninterruptible power supplies. Clean, reliable power is perhaps the most important factor in assuring long life of a computer system. The simplest way to achieve this is through the use of UPS. Careful consideration should be given to designing the power supply for the computer system.

1. Large harmonic currents caused by nonlinear loads should be reduced with larger, grounded (neutral) conductors and with K-rated transformers suitable for nonlinear electronic loads. Note that a UPS is not a harmonic eliminator, and that multiple harmonic-generating devices connected to the UPS output could affect each other. The power system design should account for the harmonic distortion caused by the UPS on its line side. UPS should be circuited separately.

2. For centrally located computers, a large, floor-mount UPS might be suitable for providing backup power and surge protection. Several smaller floor-mount UPSs can also be used. For remote, stand-alone computers, a small UPS should be provided. Units should be sized carefully to handle the power loads for all the computer components including the computer chassis and all internal devices, as well as the video display monitor.

3. Peripheral components such as printers and network switches (if serving non-critical computers) might or might not need continuous power. Consider connecting these devices to the UPS, however, to provide them with lightning and surge protection.

4. Rack-mounted UPS can be used for rack-mounted computer equipment. Depending on the application, several rack-mounted units might be required because of their limited power capacity. It might be beneficial to use UPS that include communications capabilities. The UPS can be monitored and controlled with software through a communication link to the computer.

(b) Surge protection. All computer systems for lock and dam control should have surge protection. As a minimum, voltage surge protection should be provided for each lighting panelboard and at each power distribution panel that feeds computer equipment. It is recommended that surge-protected power receptacles or plug-in strips also be used.

(c) Grounding. Surge protection equipment is only as good as the grounding electrode system. A good grounding system should be installed in compliance with the National Electrical Code. Ground systems at old facilities that are retrofitted or rehabilitated for computer control should be upgraded to meet the needs of modern computer equipment.

(6) *Rack mount versus stand-alone systems*.

(a) For installations where several PCs are grouped in a single control room, rack-mount systems might offer a better solution than stand-alone systems. All the computer equipment can be mounted in a single, 19-in. equipment cabinet outside of the control room. Monitors, keyboards, and mouse units would be located in the control room and extended with special devices.

(b) This setup provides the ideal arrangement for upgrading, troubleshooting, and maintaining the computer equipment because all the major components are in the same enclosure. Also, work on the computers can be done without disturbing operators. Rack-mounted equipment should not limit replacement or retrofit options because industrial computer manufacturers always provide components suitable for rack mounting in standard racks.

(7) *Printing*.

(a) Printers are convenient during the development and testing stages of a new control system, but also can be used for data logging and vessel report generation during normal use. Consider using networked printers so any PC on the network can print to all of the printers. This provides the most flexible printing arrangement. With Windows XP or later, printers can be connected directly to one PC yet shared among all PCs.

(b) Alternatively, and perhaps more flexibly, printers can be purchased or provided with their own network interface card, so they act as an addressed network device. This allows PCs to be shut down without disrupting printing capability.

e. Network fundamentals. It is important to review the fundamentals of networks before discussing their applications to lock and dam control systems. A network is a group of two or more linked computer systems. There are many types of computer networks, including local-area networks (LANs) and wide-area networks (WANs). With LANs, the computers are geographically close (in the same building or group of buildings). With WANs, the computers are farther apart and connected by telephone lines, fiber optics (either privately owned or leased from a telcom), microwave, radio waves, or VSAT (Very Small Aperture Terminals, a two-way satellite ground station). In addition to these types, the following characteristics are used to categorize different types of networks.

(1) *Topology*. The geometric arrangement of a computer system. See Figure 17–2 for the three principal topologies used in LANs.

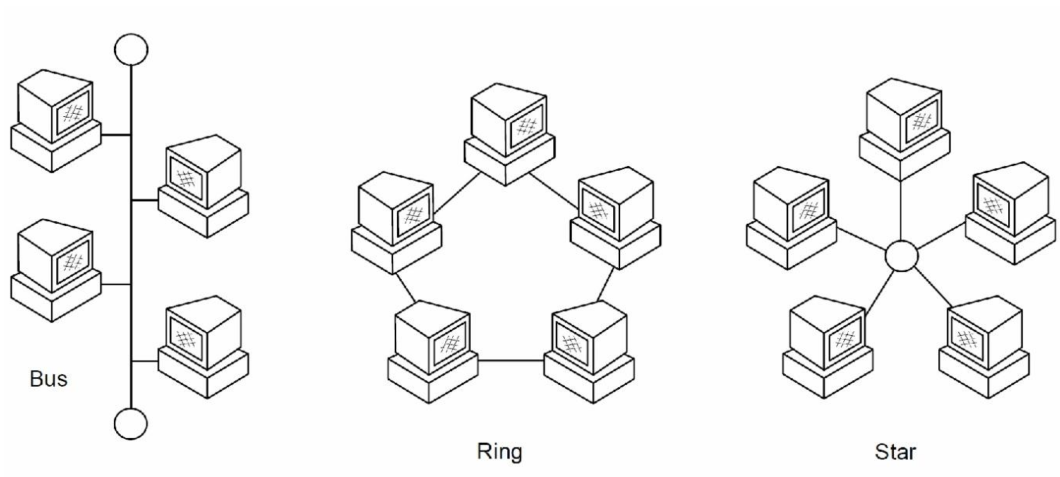


Figure 17–2. Local area network topologies

(a) Bus topology. All devices are connected to a central cable, called a bus or backbone. Bus networks are relatively inexpensive and easy to install. Ethernet systems typically use a bus topology. The downside is that a failure anywhere along the bus will isolate all computers past the failure.

(b) Ring topology. All devices are connected in the shape of a closed loop, so that each device is connected directly to two other devices, one on either side. Ring topologies are more expensive and can be more difficult to install, but they offer high bandwidth and can span large distances. Another advantage is a single failure anywhere along the ring will not isolate any devices, keeping the network active to all but the failed device.

(c) Star topology. All devices are connected to a central hub. Star networks are relatively easy to install and manage, but bottlenecks can occur because all data must pass through the hub. Star topology is usually the most expensive, as long cable runs might be needed to connect all devices to the central hub. The advantage of star topology is that failure anywhere on the network, other than the central hub, will not affect any other devices on the network.

(d) Variations. Variations on these topologies exist. The bus and star topologies, for example, can be combined to form a hybrid LAN. This arrangement is useful where several remote PCs need to be networked to a central LAN, such as in a control room. The remote PCs connect in a star configuration to a network hub that is connected to a local bus. See Figure 17–3 for an example of a hybrid LAN. This topology has worked well at Locks No. 27 on the Mississippi River.

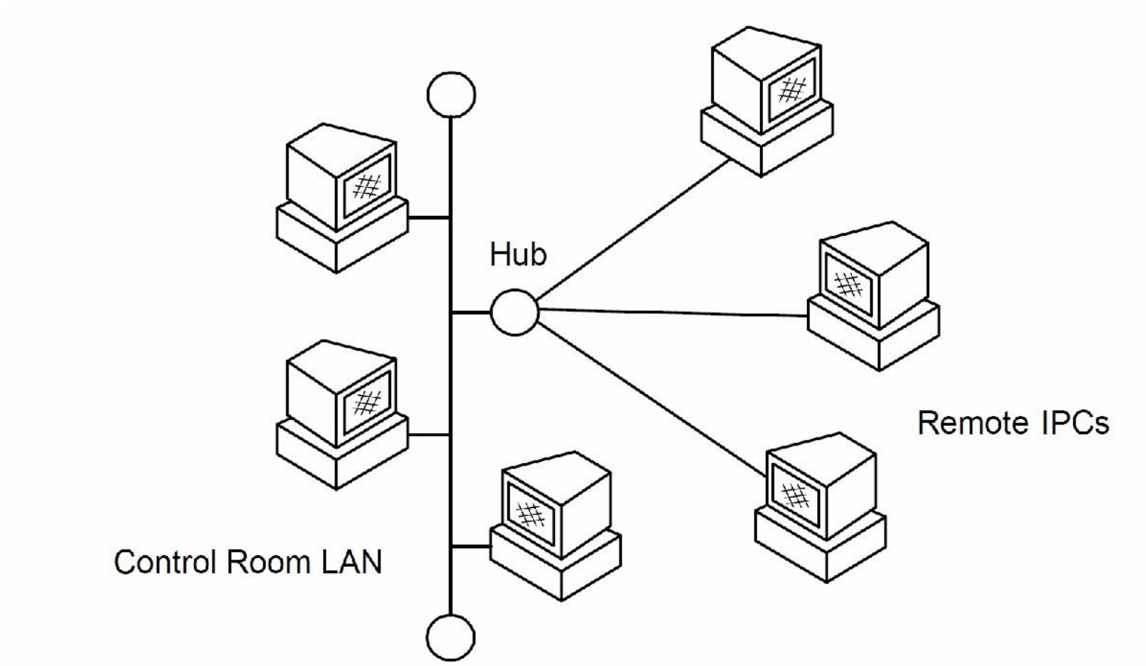


Figure 17–3. Hybrid bus and star local-area network topology

(2) *Protocol*. The protocol defines a common set of rules and signals that computers on the network use to communicate. One of the most popular and widely used protocols for LANs is Ethernet. Ethernet supports data transfer rates up to 10 Gbps.

(3) *Network considerations for lock and dam control*. The same considerations apply to lock and dam networks that apply to any sizeable network. They include reliability, availability of management and troubleshooting tools, scalability, and cost.

(a) Reliability. Highly reliable networks are critical to the success of a network at a lock and dam, so ease of installation and support are primary considerations in the choice of network technology. Ethernet networks are by far the most widely used. Due to this popularity, equipment and wiring systems have become increasingly reliable. They are also relatively simple to understand and administer.

(b) Availability of management and troubleshooting tools. Management tools for Ethernet, made possible by widespread adoption of management standards, including Simple Network Management Protocol (SNMP) and its successors, allow an

administrator to view the status of all desktops and network elements, including redundant elements, from a central station.

(c) Use. Ethernet troubleshooting tools span a range of capabilities, from simple link indicator lights to sophisticated network analyzers. As a result of Ethernet's popularity, many people have been trained on its installation, maintenance, and troubleshooting.

(4) *Network design for lock and dam control*. To design a reliable network, it is important to understand some of the limitations of the different technologies available and to decide which features are required for the particular application.

(a) Design consideration.

1. An important design consideration for a lock and dam network is the size of the facility. If the lock and dam is controlled from a single point, with no plans to add control points away from the main control room, distance is not a problem. However, for distributed control, in which control points might be hundreds or thousands of feet apart, distance becomes a critical factor in the design of the network.

2. Table 17–1 shows that Fast Ethernet and Gigabit Ethernet may be implemented at large facilities with widely separate control points using fiber optic cable. In most instances, Fast Ethernet will also require fiber optic cable between distant control points. For 183- and 366-m (600- and 1,200-ft) locks, control points located at each end of the lock exceed the maximum network distance for copper wiring.

Table 17–1
General rules for maximum network distance

	Fast Ethernet 100 BASE-T	**Gigabit Ethernet 1000 BASE-T Long Reach (LX)**
Data Rate	100 Mbps	1 Gbps
Cat 6 Unshielded Twisted Pair	100 m	100 m
Shielded Twisted Pair/Coax	100 m	100 m
Multi-Mode Fiber	400 m (half duplex) 2 km (full duplex)	550 m
Single-Mode Fiber	10 km	2 km

(b) Noise. Another important consideration in network design is noise from radio and electromagnetic interference. Locks and dams can be extremely noisy environments, especially with large motors, variable speed drives, and so forth. Lightning and surge protection are other important considerations. Fiber is naturally suited to protect against noise, lightning, and surges because it is non-conductive, using glass as the medium of transmission instead of copper.

(c) Operating plan. During design of the network, an operating plan must be developed, and a network topology based on the operating plan, a suitable network

protocol, and the network architecture must be selected. The operating plan includes selection of operating locations, number of control points at each location, and primary versus secondary control points.

(d) Operating locations. The operating locations may include a central control room with backup control points situated at strategic locations at opposite ends of the lock chambers. At each of these control points, the total number of operating workstations must be determined. Typically, primary control points, or those that are used for normal operation, might have two workstations in case one fails. Secondary, or backup, operating points might have only one workstation, depending on how critical and how frequently that location is used.

(e) Operating points. Using the maximum network distances as a guideline, the operating points should be grouped by distance of separation. Those that are within 100 m of each other should be considered local, while those beyond 100 m should be considered remote. One operating point should be selected as the primary control point if there is no central operating location. The most logical network topology should become clear from this analysis. In most cases, the topology will be the bus topology, star topology, ring topology, or a combination.

(f) Protocol selection. Next, the network protocol must be selected. Ethernet is the protocol of choice, but consideration should be given to other protocols depending on the application. Ethernet has several shortcomings of which network designers should be aware. Foremost, it is a non-deterministic protocol, meaning there is no guaranteed time in which communication between two or more nodes has been completed. This probably is not a problem for lock and dam control, but some industrial applications require a deterministic network to ensure control of critical processes.

(5) *Design details*. Once the network is designed, the details can be completed. This includes selection of hardware and software (operating system).

(a) Network routers. Routers are used for controlling communications between two locations, such as between a WAN and a LAN. Routers typically are not used in lock and dam networks. They are, however, used to provide control communication from the lock and dam back to the district office for the lock performance monitoring system (also called the OMNI system). Routers might have application in remote control of locks and dams. The network should be designed keeping the option of remote control in mind. See ER-1110-2-1156 (Chapter 20) for more information.

(b) Network switches. A switch can be the center of a star topology network system. Switches can be used to convert between different physical network media, such as fiber to twisted pair and vice versa.

(c) Network repeaters.

1. Repeaters are used to extend the length, topology, or interconnectivity of the physical network medium beyond the limits imposed by a single segment. They perform

the basic actions of restoring signal amplitude, waveform, and timing applied to normal data and collision signals.

2. The designer should be aware that there are limitations in extending networks using repeaters and plan the network accordingly. For example, repeaters add delay when retransmitting communication signals. The overall delay for all repeaters in a chain must not exceed the acceptable limit.

(d) Network interface cards.

1. Network interface cards (NICs) provide the connection between the computer and network. NICs are available in many varieties for connection to twisted pair and fiber networks. Consideration should be given to using the type of NIC best suited for direct connection to the network.

2. For example, fiber NICs should be used for direct connection to fiber media, without converting to a different media using a transceiver. The drawback to this approach is that more than one type of NIC is required for the computers attached to the network. The advantage of this approach is that fewer components are required, thus the system reliability consequently should be higher.

(e) Wireless networking. Wireless networking is generally prohibited for control system networking. Consult with the cybersecurity mandatory center of expertise before using wireless in a new control system.

(6) *Cabling*. Good cabling is essential to a reliable network. There are two types of cables used for transmission in a network: twisted-pair and fiber optic. See UFC 3-580 for additional information.

(a) Twisted-pair cable. This type of cable consists of two independently insulated wires twisted around one another. One wire carries the signal, while the other wire is grounded and absorbs signal interference. Twisted-pair cable is the least expensive type of LAN cable. 100BASE-T, also called Fast Ethernet, is one adaptation of the IEEE 802.3 Ethernet standard and uses a twisted-pair cable with a maximum length of 100 m. 1000BASE-T, also called Gigabit Ethernet, is another adaptation of the Ethernet standard and is 10 times faster than 100BASE-T. Cables in both systems connect with RJ-45 connectors. Star topologies are common in 100BASE-T and 1000BASE-T systems.

(b) Fiber optic cable. This type of cable uses glass or plastic fibers to transmit data. A fiber optic cable consists of a bundle of glass threads, each capable of transmitting messages at close to the speed of light.

1. Fiber optic cables have several advantages over traditional copper communication lines: much greater bandwidth, meaning they can carry more data; less susceptible to electromagnetic interference; and much thinner and lighter. The main disadvantage of fiber optics is that the cables are more expensive to install.

2. There are two basic types of fiber: multimode and single mode. Multimode fibers have a large core (25 to 300 μm) and permit non-axial light rays or modes to propagate through the core. Single-mode fibers have a small core (5 to 10 μm) and allow only a single light ray or mode to be transmitted through the core. This virtually eliminates any distortion due to the light pulses overlapping, as in multimode fiber. Multimode fiber is used more commonly in small LANs, while single-mode fiber, because of its higher capacity and capability, is used for long-distance transmission. Telephone companies typically use single-mode fiber because of its ability to transmit long distances without the need for repeaters.

3. There are a variety of connector types for fiber optic cable. Some common ones are ST (straight tip), MT-RJ (Mechanical Transfer Registered Jack), SC (subscriber connector), and LC (Little Connector). Per UFC 3-580-01, do not use ST or MT-RJ fiber optic adapters and connectors for new construction unless specifically required for interface with existing equipment being reused. SC is a push-pull device that uses a ceramic ferrule to deliver highly accurate alignment in a fiber-optic link. It's a square-shaped connector—also known as "stick and click" for its SC acronym—that comes with a locking tab that enables the push-on and pull-off operation. LC is also a push-pull connector, but unlike SC's locking tab, it employs a latch with a smaller ferrule, and that makes it hugely popular in data communications and other high-density patch applications.

f. Motor control centers. The demarcation point between the PLC/PC computerized control system and the traditional electrical distribution and control system is the MCC or, in some cases, a 480-V switchboard-type motor controller enclosure.

(1) *Motor starters*. Starters should have sufficient auxiliary contacts to provide both hardwired and PLC feedback. It is always a good idea to have extra contacts for future use. Overload heaters should have auxiliary contacts for input to the PLC system. This will provide enhanced remote troubleshooting capabilities. Solid-state motor starters with PLC network connections are also good considerations for critical motors.

(a) While the primary means of energizing motor starters will be the PLC I/O system, it is a good idea to provide a means of energizing the starters at the MCC. This can be via simple dead-man-type pushbuttons that can be de-energized when the PLC and minimal hardwired control systems are completely functional. When using a hydraulic system, these MCC pushbuttons should be accompanied by similar pushbuttons for energizing hydraulic solenoids.

(b) By doing this, the designer provides a way for the general contractor, during construction, to bump motors and cylinders for shaft alignment, cylinder attachment, clevis pin attachment, shim and key installation, and so forth. This will relieve the system integrator of the burden of providing untested solid-state controls before actual gate operation. This also will provide the system integrator with opportunities to check transducer signals and feedback devices without the responsibility of operating the equipment.

(c) In general, motor starters should be provided with pilot control relays to interface them with the PLC I/O cards. While some PLC isolated output cards are rated for enough current to energize smaller starters, larger starters will require pilot relays. Pilot relays provide a way to isolate the PLC system from starters and potential damage from 480-V system faults.

(2) *Variable speed drives*. Mechanical loads that require soft starting, multiple speeds, or ramp up/ramp down features warrant consideration for a variable speed drive. This could be a DC drive or a variable-frequency AC drive. Traditionally, DC drives have been used because they provide much greater control of motor speed and torque. Varying the voltage changes the speed and inversely changes the torque of a DC motor in a linear manner.

(a) In contrast, AC drives provide very fine control of speed with varying or constant torque. In addition, AC drives can be supplied with the inherent feature of an across-the-line bypass contactor in the event of solid-state inverter failure. Therefore, when specifying variable speed drives, first consider an AC adjustable-frequency drive (AFD), also called a VFD, with either constant or varying torque.

(b) It is a good idea to require that the AFD be of the same manufacturer as the MCC. Large drives that do not fit in MCC-type construction will require free-standing enclosures to house them. Space is an important requirement, and a designer should consider that an engineered drive occupies significantly more space than the inverter itself. An engineered drive consists of following.

1. *Isolated bypass*. Except in cases where emergency, across-the-line starting will damage mechanical or structural equipment, AFDs should be provided with an isolated bypass, across-the-line contactor. The AFD should include full controls, accessible from the PLC system, for switching to the inverter-bypass starting mode. Determine the control features and/or operational procedures that will require special consideration to start the load in this fashion. Such considerations should be programmed in the PLC and/or AFD controller. These details should be well covered within the specifications, to ensure proper coordination by the AFD manufacturer and the system integrator.

2. *Network communications*. The AFD should be provided with a means to communicate directly with the PLC processor via an ethernet connection. This networking capability should be an inherent feature of the drive and might require the AFD to be of the same manufacturer as the PLC system. This might limit the number of PLC manufacturers that can supply the system, but it is a necessary requirement when providing a reliable, coordinated PLC/AFD system. The network communication should provide all status and diagnostics of the drive to the PLC system for remote troubleshooting capability.

3. *Hardwired stop override*. The AFD should be provided with a means of stopping the drive independent of the PLC system. Activation of this override should come from the lock hardwired emergency stop system. Indication of the status of the stop override should be available on the PLC network.

4. *Dynamic braking*. All AFD systems require dynamic braking of the load. Gates and bridges that are lowered by gravity require excessive dynamic braking to control the speed of the falling load with the electrical-magnetic braking torque of the motor. Manufacturers should be consulted to calculate the exact amount of dynamic braking required for the system. A conservative approach to such calculations will prolong the life of the resistor banks and possibly the inverter. Failure of the dynamic braking system, such as overheating, should be an input function of the PLC system to provide help in troubleshooting.

5. *Isolation transformer*. All AFDs reflect harmonics back to the power distribution system. Such harmonics can damage transformer neutrals as well as affect other digital switching loads. For this reason, an appropriately sized K-factor-rated isolation transformer should be provided with each AFD. The designer should consult the AFD's manufacturer to determine the exact size and ratings of the isolation transformer.

g. Software. Since most general contractors do not have the expertise to install and configure PC and PLC networks, a system integrator should be used for this purpose. A system integrator is a company that designs, installs, programs, and provides startup and maintenance services for commercial/industrial control and computer systems. The successful implementation of a computerized control system depends largely on the capabilities of the system integrator. It also depends on the capabilities and support of the engineers responsible for the control system after it is installed.

(1) Few control systems are perfect immediately after installation. Most require tweaking to incorporate missing features or to adjust parameters that were not defined during testing and startup. On lock and dam applications, often after the project is operating, the lock personnel will request some changes as they become accustomed to the system. There are three major software components in a computerized lock and dam control system: operating system, PLC, and HMI.

(2) The operating system is software that every computer must have to run other applications. It performs basic tasks, such as recognizing input from the keyboard or mouse, sending output to the display screen, keeping track of files and directories on the disc, and controlling peripheral devices such as modems and printers. Operating systems provide a software platform on which other programs, called applications, can run. The application programs are written to run on a particular operating system. The choice of operating system determines which applications can be run.

(3) The designer should work with the system integrator during initial configuration of the operating system and network to set up user accounts and passwords. Since operating computers typically are used 24/7, a single operator account should be created so all shifts use the same account and password. Administrator accounts should be set up for system administrators or engineers who administer the computers and network.

h. Programmable logic controller programming software. The PLC processor programming software should be as provided by the PLC manufacturer. It might be a third-party product the PLC manufacturer recommends in its written literature. The programming software should have provisions for configuring I/O rack addresses, simulating program execution for debugging, and downloading to the PLC processor. The programming software should conform to Part 3 of IEC 61131, the standard for PLC programming languages, should operate on current operating system platforms, and should include editors such as:

(1) *Function block diagram*. This editor depicts process data flow suited for discrete and continuous control application functions and should include predefined elementary function blocks as well as user-defined function blocks. Language written in other editors, as listed below, can be nested within the Function Block Diagram (FBD). See Figure 17–4. In the FBD, control sequences are programmed as blocks that are wired together in a manner resembling a control circuit.

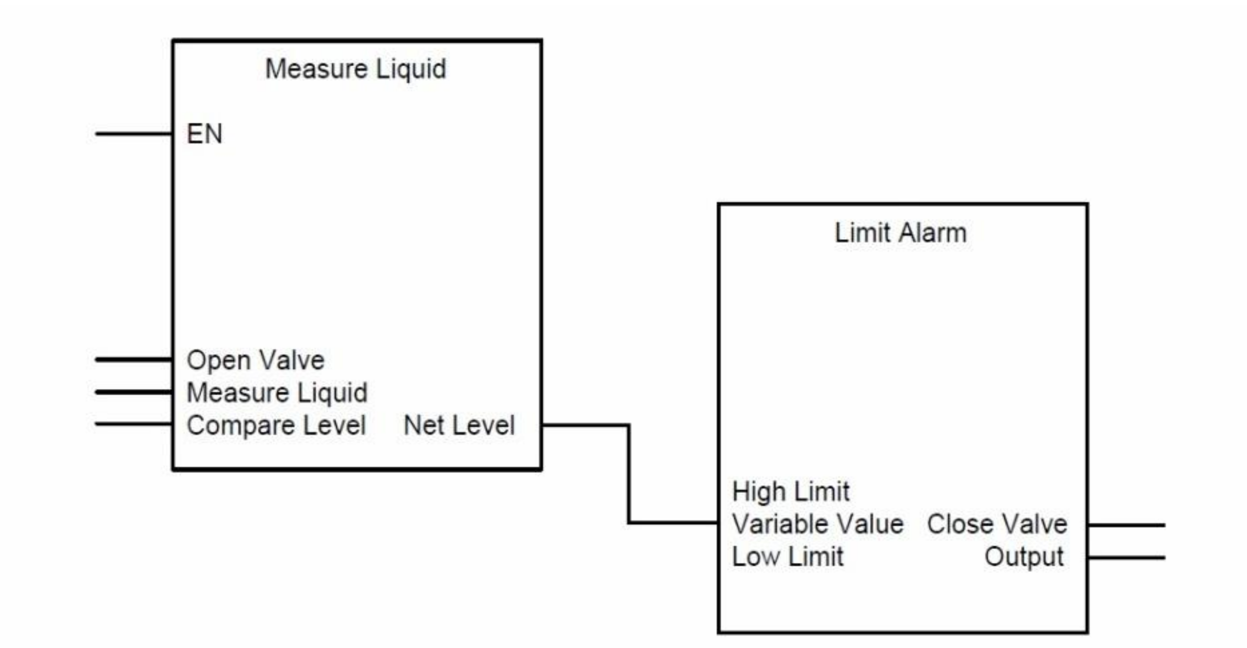


Figure 17–4. Function block diagram

(2) *Ladder diagram*. This language allows programming in the familiar left-to-right contact and coil arrangement in an order familiar to most electricians and maintenance personnel. The ladder logic editor should allow the use of other editors, such as Function Block and Structured Text, to be incorporated into the ladder programming. This will simplify the programming because electricians and maintenance personnel will not have to be familiar with the complex logic of the other editors. The Function Block or Structured Text editors simply perform predetermined logic within the body of the ladder diagram. These can be grouped in subroutines to simplify the appearance of traditional ladder logic. See Figure 17–5.

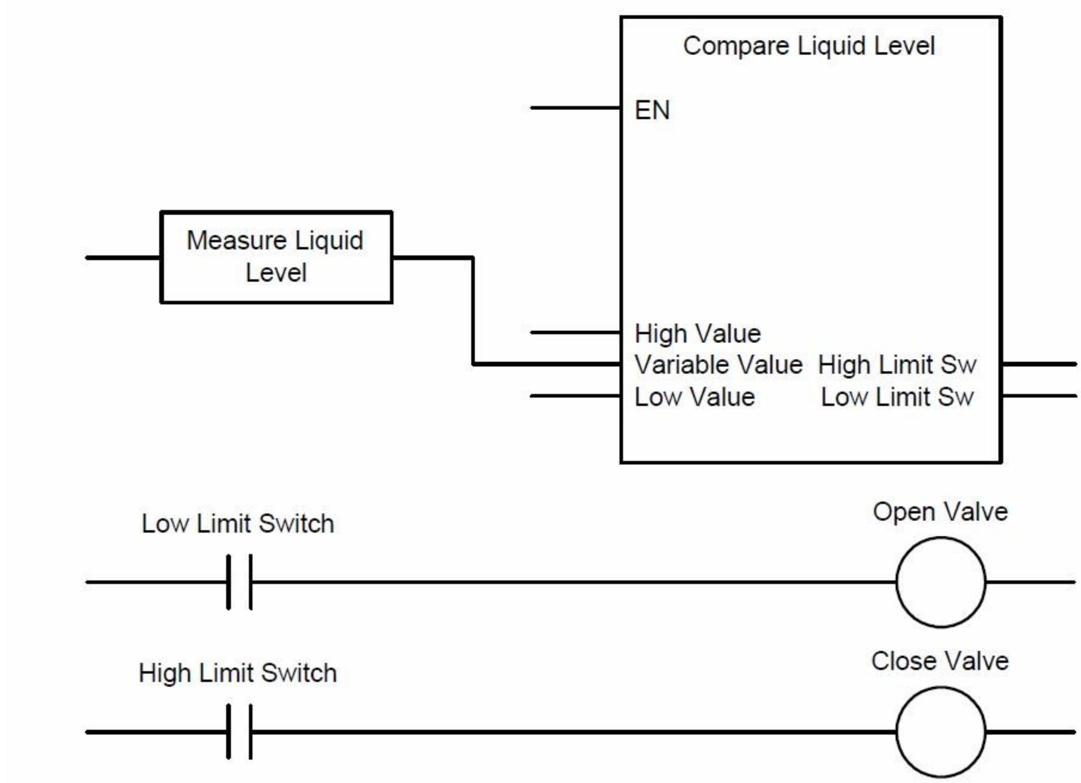


Figure 17–5. Ladder diagram

(3) *Sequential function chart*. The sequential function chart (SFC) editor provides a graphical method of organizing a control program using programming from other editors nested within. The SFC editor should include three main components: steps, transitions, and actions. Steps are individual control tasks in which programmed logic operators are used to perform a particular control function. Actions are the individual operators of that task. Transitions are merely mechanisms to move from one task to another. With SFC, the processor continues to perform the actions in a step until the transition condition is true (repeat the step containing the action of filling a tank until the transition condition of comparing level against full is true, then move to step of closing the valve). See Figure 17–6.

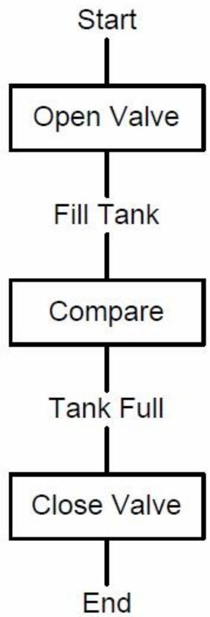


Figure 17–6. Sequential function chart

(4) *Structured text*. The Structured Text editor is a high-level language resembling Pascal or Basic and is used to perform control logic programming. Structured Text often is the easiest way for the novice to write and understand control logic because of its inherent resemblance to sentences.

```
LET LowLimit = Low_Limit
LET HighLimit = High_Limit
LET Value = Liquid_Level
WHILE Value < HighLimit
IF Value < LowLimit THEN
DO Open_Valve
END IF
END WHILE
DO Close_Valve
```

(5) *Instruction list*.

(a) Instruction List editor is a text-based Boolean language. The basic Boolean operators can be used to create more complex control applications. Similar to Assembly Language, the Instruction List editor is a low-level language useful for simple control processes; its logic is repeated often. Instruction List allows the logic for these processes to be programmed once, then recalled in latter instances in the program.

```
Start:   LD Liquid_Level      :Move value of liquid level into argument
GT Low_Limit                  :Compare with Low Level Limit
ST Open_Valve                 :Move (1 or 0, based on above) into output
GT High_Limit                 :Compare with High Level Limit
ST Close_Valve                :Move (1 or 0, based on above) into output
End:
```

(b) It is important to specify the PLC programming software in sufficient detail using the IEC 61131-3 standard because this will ensure the contractor provides a quality software package that complies with worldwide industry standards.

i. Human-machine interface software. HMI software provides the graphical user interface for operating the lock and dam. This software can run on any of the PCs on the network, or on a dedicated touch-screen panel running its own operating system (typically Windows CE), and can communicate to the PLC through the network. The designer should plan the system to determine which PCs or panels need to communicate directly to the PLC. Most HMI software can operate either as a client node, in which it piggybacks off another computer for access to the PLC, or as a server node, in which it communicates directly with the PLC processor. In general, a small number of HMI servers on the system will enhance the communication speed with the PLC processor and reduce the risk of one server inhibiting operation from another one.

j. User interfaces. One of the key ingredients to a successful computerized control system is the general perception of the system by the operators.

(1) Most operators will not care what operating software is used or how much memory it has or about the scan time of the PLC processor. Therefore, an argument can be made that the most important part of the control system is the interface that allows the operator to use the system. For most new lock and dam control systems, this will be the operating screens, whether stand-alone, touch-screen panels, or monitors with PCs.

(2) These must be designed and programmed with considerable care to ensure a completely user-friendly interface that is convenient and, most important of all, safe to operate. The HMIs in the main control console should have all the operating screens necessary to control and monitor the entire project.

k. Semi-automatic operating screen. On locks with semi-automatic operating systems, a screen, such as in Figure 17–7, should be included to facilitate complete normal lockage from one operating screen. The screen should include control of both ends of the lock, the traffic lights, warning horn, emergency stop, and other critical features unique to each project.

(1) *Considerations*. The designer should try to keep the semi-automatic or automatic operating screens (Figure 17–7 and Figure 17–8) complete, yet compact and

concise, because too much information or control of auxiliary equipment can make the screen confusing to operate.

(2) *Animated graphics*. Animated graphics, based on real-time data from transducers and sensors, makes the screen more friendly to the operators. The screen should be designed to allow a busy operator to look at and very quickly ascertain the status of the major lock operating equipment.

(3) *Manual operating screens*. The system should include screens for manually operating each piece of equipment (Figure 17–9 and Figure 17–10). Special, seldom-used, operating procedures such as interlocks bypassed should be included on these screens. The system probably should have a special operating screen for each major piece of lock equipment gates and valves. This control will be accomplished through the PLC system with the full complement of safety interlocks and permissions, but it allows independent, non-automatic operation of the individual pieces of equipment.

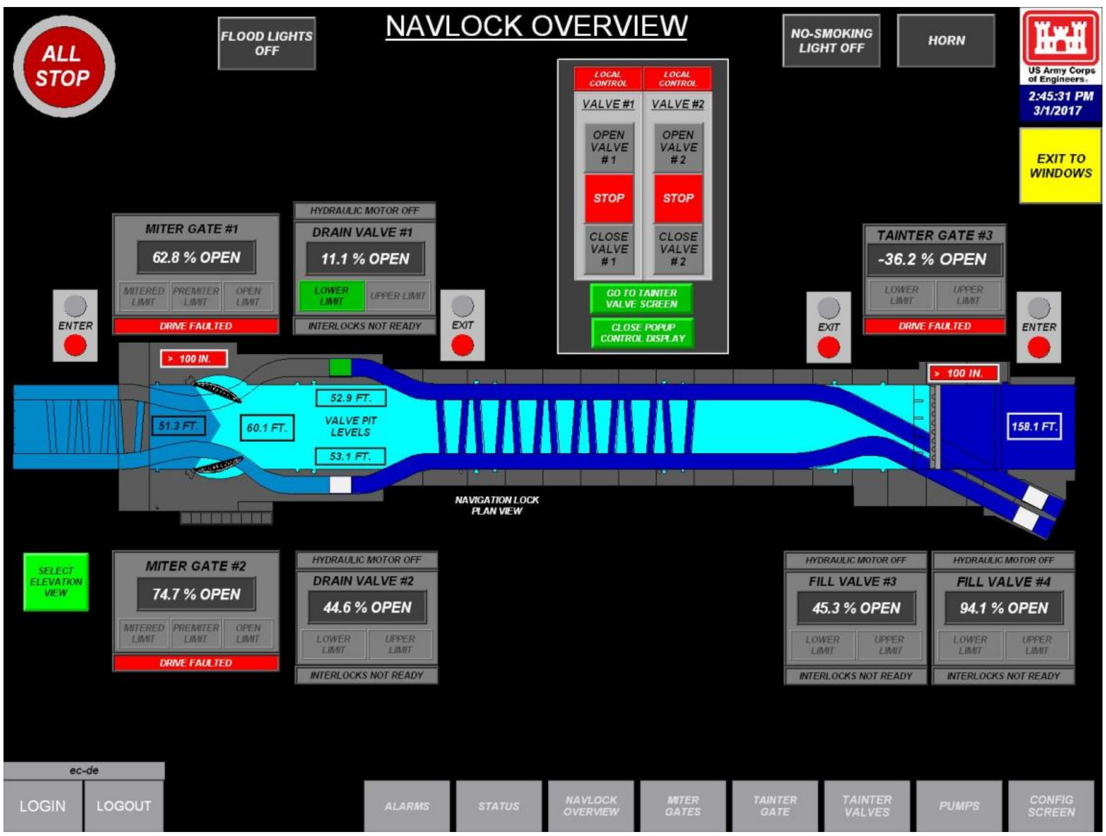


Figure 17–7. Semi-automatic operating screen used at The Dalles Navigation Lock

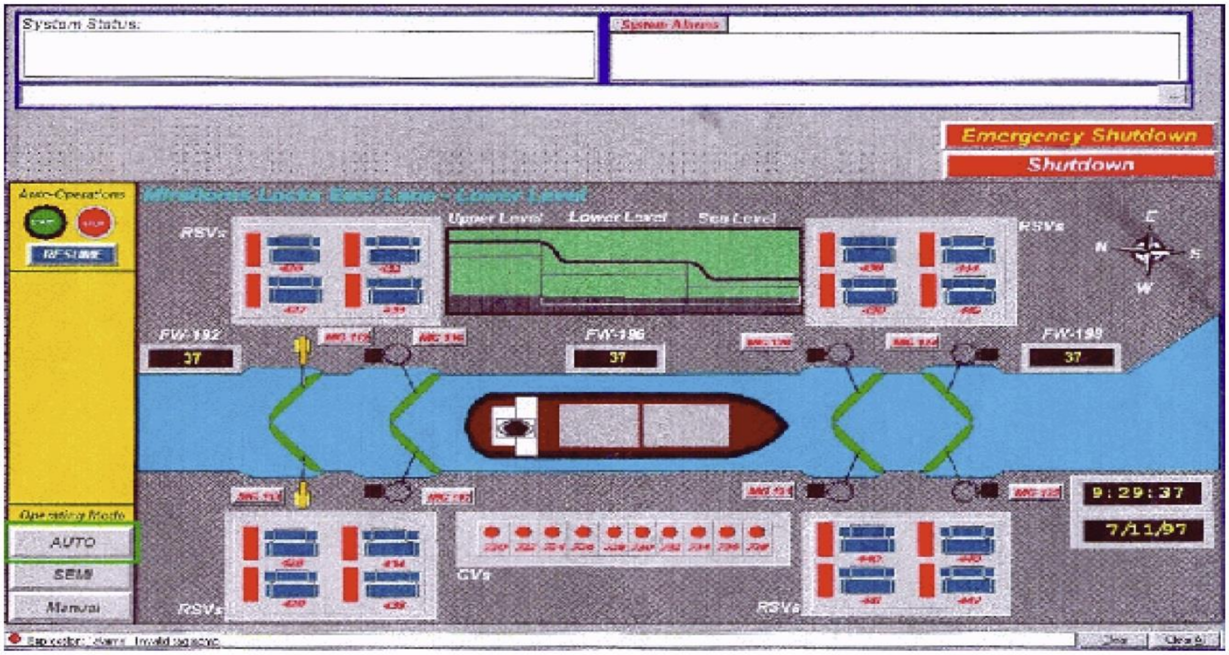


Figure 17–8. Automatic operating screen proposed for use on the Miriflores Locks, Panama Canal

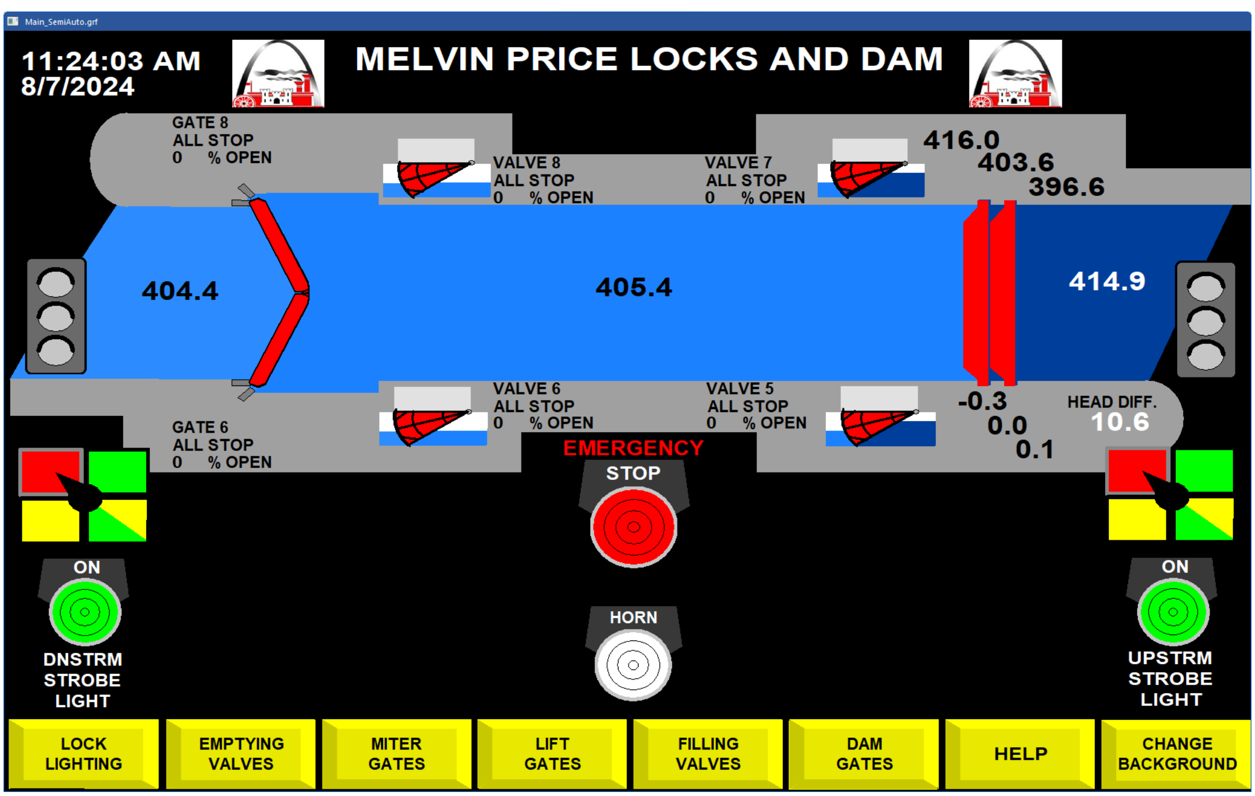


Figure 17–9. Miter gate manual operating screen used at Melvin Price Locks and Dam

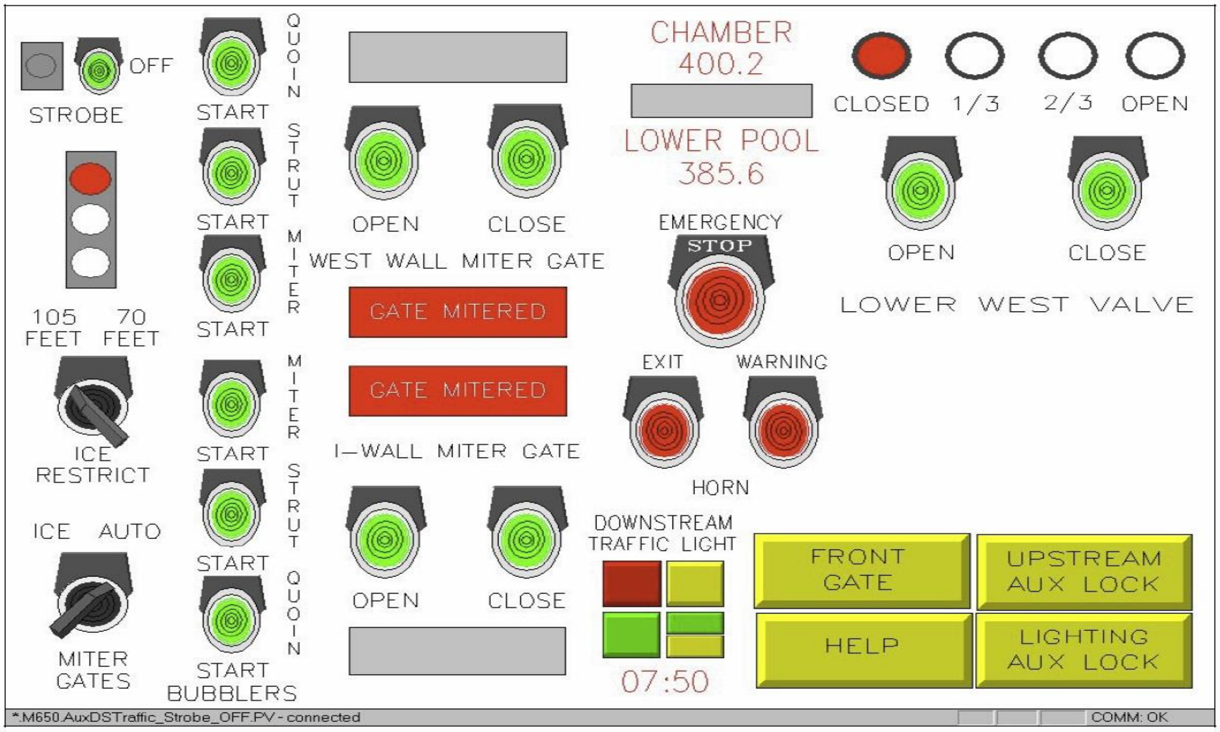


Figure 17–10. Manual operating screen used at Lock No. 27

(4) *Troubleshooting screens*. A good operating system interface should include simple troubleshooting screens (Figure 17–11) that the shift chief (head lock operator) can use to identify problems. These screens alert the shift chief of situations that can stop or affect the operation of the lock but are not necessarily equipment failures. These instances could be emergency stop pushbuttons that have been left depressed; equipment access doors with lockout switches; interlocks that have been bypassed on an auxiliary control panel; or emergency controls that are being used somewhere on the locks. The troubleshooting screen is intended to alert the shift chief of these situations so an investigation and correction can begin. This should be the first screen the shift chief pulls up when equipment will not operate properly.

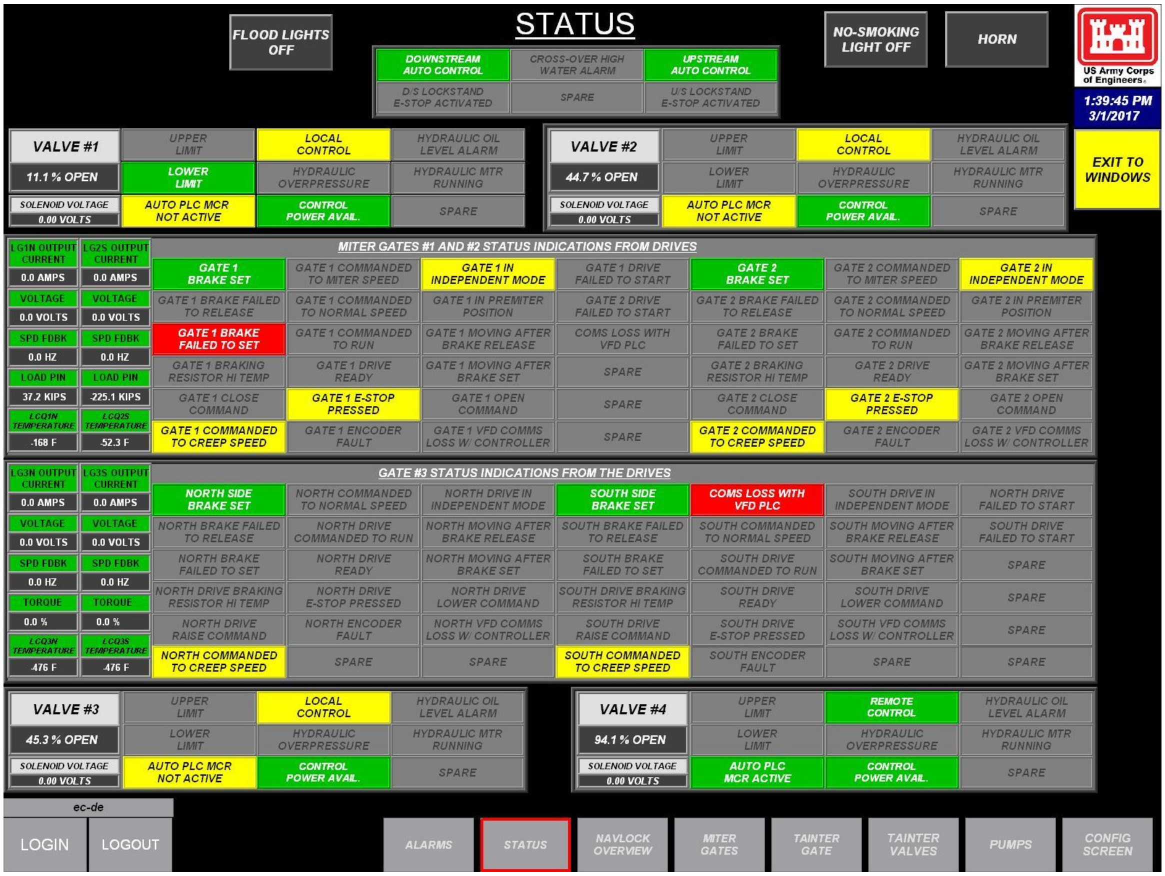


Figure 17–11. Status screen for troubleshooting used at The Dalles Navigation Lock

(5) *Alarm screens*. Alarm screens should be provided to alert operators and maintenance personnel to failure of lock operating equipment. Included on such a screen should be failure of any PLC component that can be diagnosed by reading registers in the processor (most PLC equipment failures can be found this way). These typically include PLC communication failures, I/O failures, AFD failures, water level sensor failures, and position sensor failures (Figure 17–12).

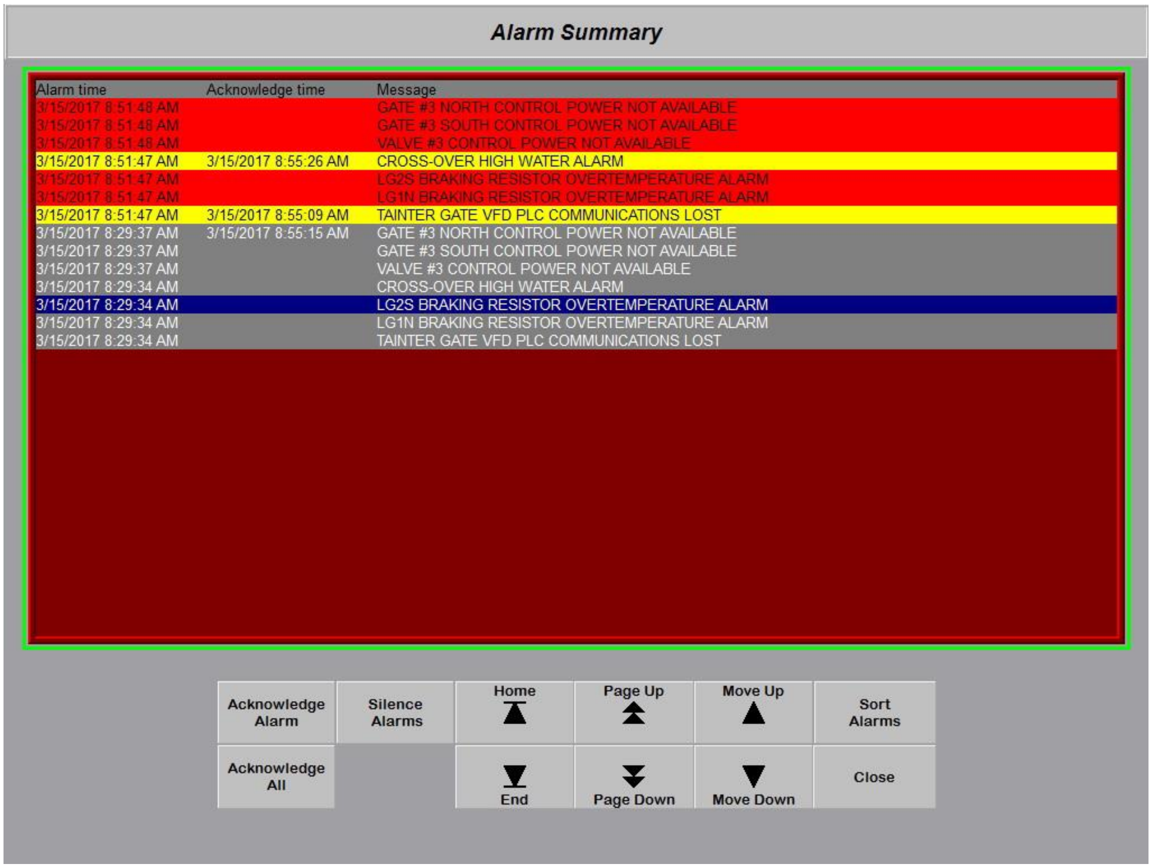


Figure 17–12. Alarm summary screen used at The Dalles Navigation Lock

(6) *Configuration screens*. Working with the PLC program once it is commissioned should be kept to a minimum for maintenance staff. Anything that would typically need to be configured within the program itself can be relegated to a configuration screen, accessible by a higher-level maintenance login. The less maintenance has to access the program directly, the fewer opportunities there are for creating potential problems (Figure 17–13). It can be difficult for someone unfamiliar with the entire program to understand the consequences or repercussions that a single seemingly innocuous change could make. Going into the program itself to make changes should be limited to engineers or the developers of the program. There will be times maintenance staff will have to go into a program to make changes, and it is recommended that this be done under engineer supervision.

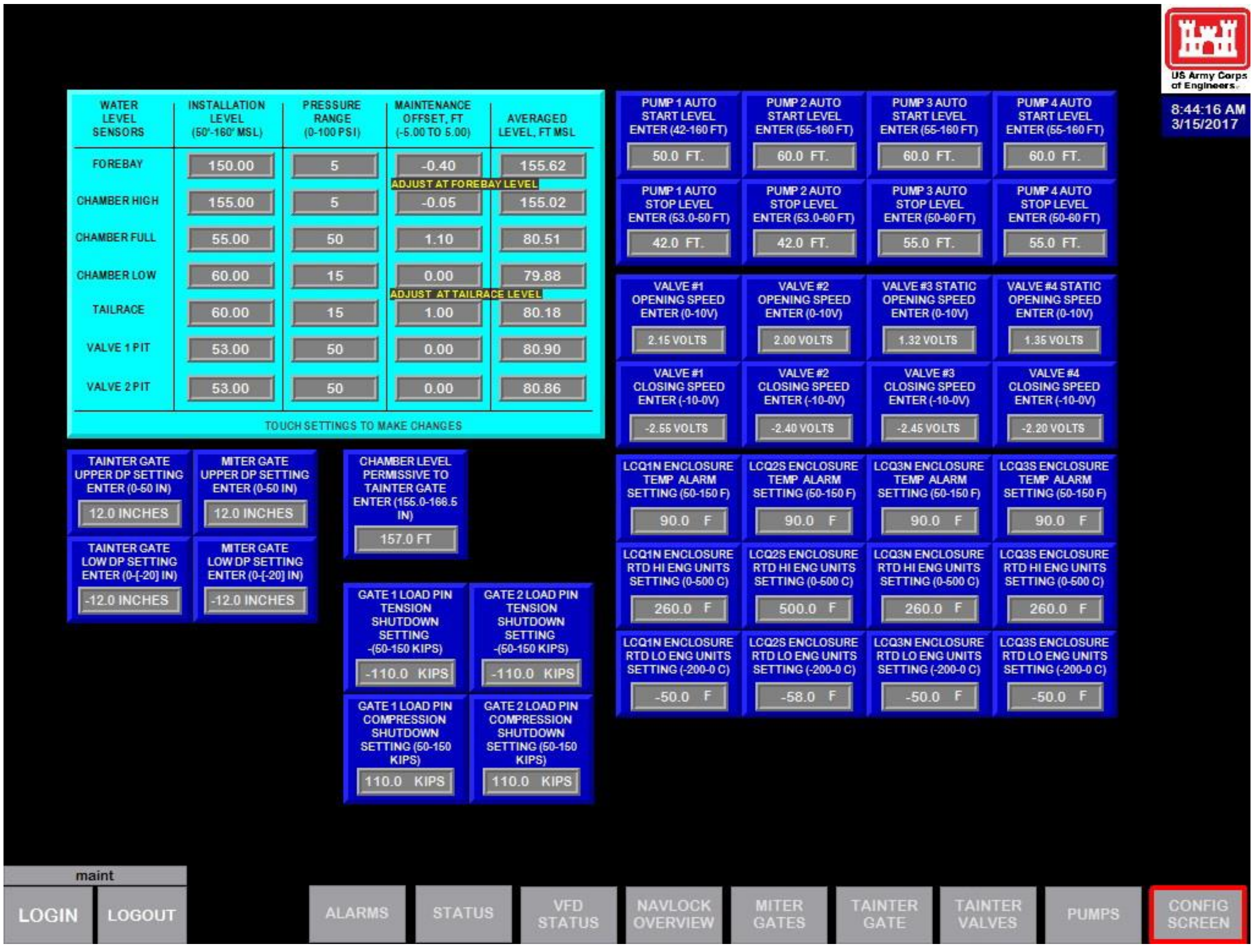


Figure 17–13. Maintenance configuration screen used at The Dalles Navigation Lock

17–13. Sensors and field devices for programmable logic controller systems

Selection and installation of a quality PLC/PC system is only part of the work necessary to complete a successful lock control system. The I/O devices that provide information to the computerized control system are just as critical in the overall success of a lock and dam control system as the PLC itself. Failure to specify quality materials and proper installation and testing of field devices will diminish operator confidence in the whole system, regardless of how good the PLC system might be. Also, consider that these devices often serve a dual purpose when they are used in the emergency backup system. Redundancy and spare parts are an important part of the auxiliary equipment design process. Discussed next will be typical sensors and field devices for a navigation lock, but the list is not complete or all inclusive.

a. Limit switches. The most common PLC input device is a dry-contact limit switch. Different switches are used for different applications. These devices are particularly useful for end-of-travel or overtravel limit switches because they are absolute, passive, and require no electronic calibration. Limit switches of this type also can be provided with auxiliary contacts for a hardwired backup system. In this day of not using brand-name and "or equal" specifications, carefully specifying all the important features is essential to ensure the contractor provides a quality product. Limit switches are as critical, if not more, than any other feature of the control system, and time should be taken to write sound specifications for procuring, installing, and testing them.

(1) *Vein/roller/lever-operated*. Simple vein or roller-operated, dry-contact limit switches are used for all types of moving machinery. It is a good idea to specify these with extra contacts for hardwired applications. Addressable limit switches that can be connected directly to the PLC network, eliminating the need for I/O racks, are becoming increasingly popular and are a good consideration for non-critical applications in which there are few limit switches and great distances between them. Their use on locks and dams has been limited, generally because lock operating machinery is grouped together and has enough limit switches in one location to justify an I/O rack. Specifications should include heavy-duty, oil-tight, corrosion ratings, number, rating, and type of contacts, NEMA 4X or 6P rating, UL listing, operator lever type, and operating temperature range.

(2) *Magnetic/proximity/photoelectric*. By eliminating moving parts and providing a degree of submergibility, magnetic and proximity limit switches have replaced the vein-operated switches for use on the end of miter gate leaves for indication of proper miter, and in the miter gate recesses for indication of a fully recessed gate.

(a) HQUSACE, to avoid damage to miter gates, has mandated positive indication of the miter and recess positions. These switches must be installed and used in the control system as interlocks to prevent filling of the chamber (improper miter) or changing the traffic light to green (improper recess). The use of these type of switches is a good consideration in other areas where ice can hinder the operation of vein-operated switches.

(b) When procuring magnetic or proximity switches, specifications should include number, type and rating of contacts, NEMA 4X or 6P rating, UL listing, temperature range, copper or fiber optic leads, side or top mount, standard and extended operating ranges, and surge protection. The extra time it takes to specify a good switch properly is well spent.

b. Electronic sensors. Position and level measurement require the installation of an electronic encoder such as those mentioned below. Encoders should be specified without the need for external or third-party converters, decoders, linearizers, or signal conditioners.

(1) These devices have much higher failure rates than PLC I/O cards and cannot always be diagnosed for problems through the PLC system. Encoder signals should be fed directly into a PLC analog or SSI input card. It is usually not a good idea to use electronic encoders in a hardwired backup system. The need for scaling and offsetting factors, easily accomplished in the PLC software, coupled with the distances that the signal must travel often will cause reliability, noise, and calibration problems when used

without a PLC system. These problems could, depending on how the system is wired, interfere with the normal PLC system.

(2) Electronic encoders require special installation, wiring, and shielding to provide long-term reliability and accuracy. The design must prepare appropriate detailed plans and specifications to require construction contractors to provide the quality, detailed equipment, and detailed installation that the facility requires.

c. Pressure transducers. Pressure transducers are used to measure the level of water in and around the lock and dam. A pressure transducer produces an analog signal directly proportional to the amount of water in which it is submersed. Typically, a designer should put at least two transducers in the upstream pool, two in each lock chamber, and two in the downstream tailwater.

(1) Such transducers also can be used to measure the amount of leakage in manholes and crossover tunnels. Placing two transducers in areas of critical applications allows for reliability and accuracy checks of the PLC software. In an automated system, the pressure transducers become one of the most critical control components because each automated sequence depends on determination of equal water levels without visual check from an operator. In this case, it is essential to have good reliability checks and failover programming built into the PLC program.

(2) When specifying submersible pressure transmitters, design engineers should take the time to consider transmitter construction (titanium provides excellent corrosion control), unique pressure rating, excitation power supply level, output signal and wiring, accuracy, repeatability, electrical connection (should include molded integral cable of sufficient length for each application), resolution, and installation instructions. It is important to note that merely stating that the transducer must be installed according to manufacturer’s recommendations might not be sufficient.

(3) There are many different applications for such transducers in industry, and many are not in harsh environments such as a river near a lock and dam. The installation should provide protection from ice, debris, silt, and zebra mussels; should facilitate easy maintenance and replacement; and should provide unobstructed atmospheric reference pressure to the breather tube.

d. Rotating encoders. Angular position of rotating machinery, such as cable spools, gears, chain sprockets, and miter gate machinery, is accomplished through the use of rotating angle encoders.

(1) Rotating encoders could include absolute encoders or single and/or multi-turn resolvers. It is strongly recommended that absolute position encoders be furnished for control systems instead of the incremental type, if at all possible and practical. This will ensure that, after loss of power to the position sensor, the position of the machinery being measured will be known. It is also highly recommended that the encoder be accurate enough to allow for the entire movement of the gate or valve travel, and the distance of travel should be considered when selecting an encoder.

(2) Typically, these are mounted adjacent to the machinery and attached via shaft couplings. Shaft couplings should be one-piece, flexible stainless steel and sized to match exactly the encoder shaft and adapt to the machinery shaft. Installation details should include provisions for making the machinery shaft extension absolutely true and for aligning the shafts as true as possible through the use of properly installed stainless steel shims.

(3) Details to include in the specifications are environmental housing (NEMA 4, NEMA 4X, etc.), output signal and wiring, power supply and excitation requirements, number of turns needed to resolve entire travel of machinery, repeatability, accuracy, resolution, lightning and surge protection for primary and secondary windings, shaft size, operating temperature range, and installation instructions. Also, it is important to ensure that the rotation of the shaft extension to which the encoder is coupled is linear with the movement of the machinery. If not, programming must be added to the software to correct this.

(4) Keep mind that wire cable wound on a drum is not a linear application because the length of cable unreeled during each rotation varies with the amount left on the drum. Each successive wrap of cable on the drum is shorter than the previous one by the cable diameter multiplied by 2π. Gear tooth counters also would fall in this category.

e. Inclinometers. Inclinometers are used to track angular tilt of the machinery or structural member on which they are mounted. A good application for such a device at a lock and dam project is the position of the tainter gates. Angular rotating encoders do not work as well in this application because the rotation of the cable drum or chain sprocket is not linear with the change in opening between the gate and the sill. Also, because a tainter gate can become frozen during times of heavy ice and because drift can be lodged under the gate, the rotation of the machinery is not necessarily indicative of gate movement.

(1) A submersible inclinometer mounted on the tainter gate strut will give an accurate indication of gate movement. By programming simple interlocks in the PLC software, slacking of the hoist cables or chains can be avoided in the event the gate does hang up. As stated, the signal from the inclinometer should be fed directly into the PLC control system as a raw electronic signal. All scaling, trigonometry, and linear and angular offsetting should be done in the PLC software.

(2) It is important that this type of device be thoroughly engineered in a design document. Some parameters to determine in a specification are housing construction, NEMA 6P (might require separate purged enclosure), angular operating range, resolution, accuracy, repeatability, vibration sensitivity, axis of measure (to ensure proper mounting), excitation power supply requirements, output signal and wiring, temperature operating range, and detailed installation requirements.

f. Hydraulic cylinder position transducer. With the increasing popularity of hydraulic cylinders in navigation lock equipment design, several manufacturers offer position-sensing transducers integral to the cylinder construction. The type of transducer and the output signal vary by manufacturer, therefore, a design engineer should consider this and specify the type of position-sensing system that is best for the equipment. The output signal should be directly compatible with the PLC system I/O cards available. As stated above, it is not a good idea to use third-party converters and signal conditioners to massage the signal before it is read by the PLC.

17–14. Control cabling

a. Wire and cable to be used in locks and dams are specified in various UFGS publications. Control cabling can consist of exclusively copper wiring or a combination of copper and fiber optic cabling. The copper-only control cabling system is usually at control voltages from 24V to 120V and used in discrete relay control systems. In the case of PLC/computer/electronic control systems, control cabling will be a combination of copper wiring (from 5VDC to 120VAC) and fiber optic cabling.

b. When specifying wire and cable for a project, the designer should consider the environment in which the cables will be permanently installed and the design life of the project. For the usual project design life (40 to 50 years), it is desirable to specify cable insulations and jackets of the cross-linked, thermosetting polyethylene type.

(1) See NEMA WC70 and UFGS 26 05 19.00 10 for details on specifying cables with thermosetting insulations and jackets. This cable has a rugged outer jacket, insulation, and typically has desirable characteristics regarding resistance to oils and to water absorption in long-term, submergence conditions. When selecting the cables, pay attention to the duration and depth of submersion of the cable. It is noted that 120VAC control cables typically can be procured with thermosetting jackets and insulations. However, control cables such as fiber optic and wire line data transmission systems (small cables such as Ethernet, PLC communication cables) might not be readily available with thermosetting jackets.

(2) The reliability and costs should be considered when specifying these wire line data transmission and fiber optic cables to ensure that additional costs that might be required for thermosetting, durable jackets (if available) are justified. Most cables are available with PVC thermoplastic jackets and are best suited for use above grade in buildings but might be used on the locks and dams to avoid cost premiums, if acceptable to the designer and end user.

c. The 120VAC control cables can be rated at 75 °C but are usually available to 90 °C if desired. Wire line data cables usually are rated to 60 °C and have been used in USACE locks and dams. The designer might choose to require a special insulation and jacket, if available from a cable manufacturer, if it is determined that reliability and cost justify the use of the cable.

d. Splices in copper, 120VAC control cables are acceptable but not preferable. Splices in fiber optic or wire data transmission system cables, such as Ethernet, are not preferable and should be avoided if possible. If splices are used in fiber optic cables, losses at splices or any connecting points should be considered when performing optical power budget calculations. If required, use higher power transmitters or repeaters to maintain sufficient optical power for successful communications.

17–15. Interlocks

a. General. Locks must have equipment interlocks to prevent inadvertent and unsafe movement of lock operation components. Properly designed lock operating and control equipment and skilled and trained lock operators act as a system to ensure safe and reliable operation of USACE locks. District Operations and Engineering personnel will perform work necessary to assure that navigation interlock systems (including hardware, software, standard operating procedures [SOPs], and training) employed at their district's locks meet the performance requirements herein. The following interlock standards have been adapted from the IMTS 2014 Interlock Standards.

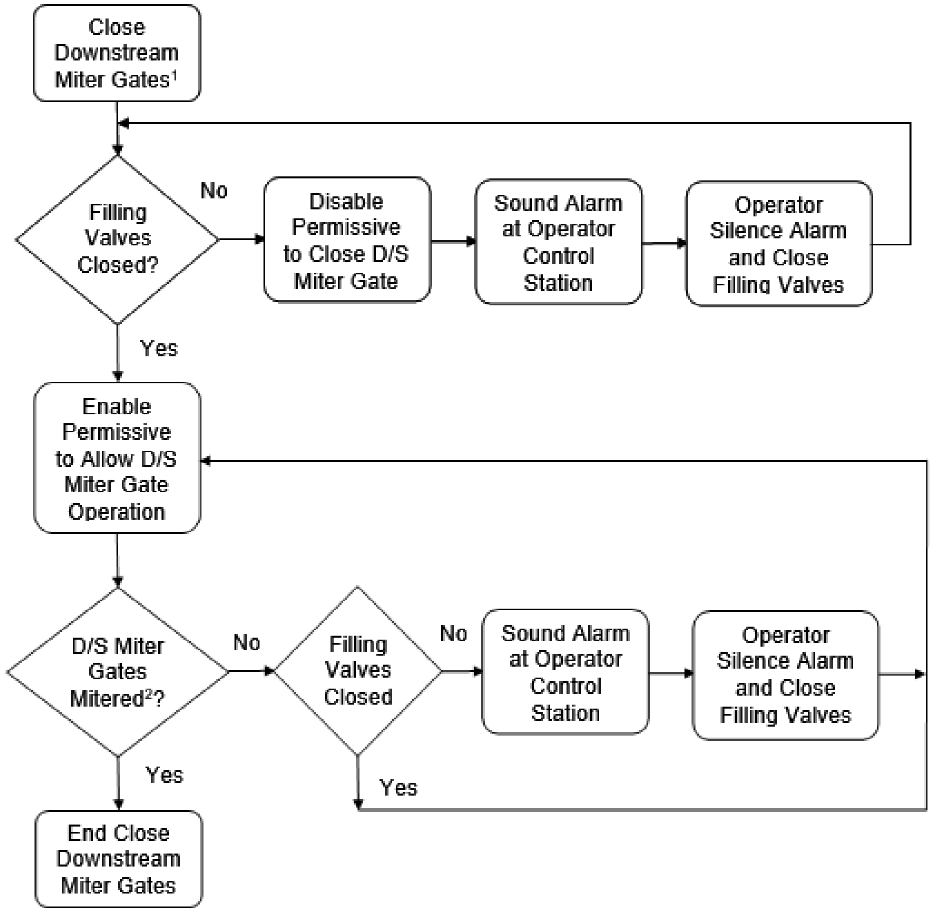
b. Minimum requirements. USACE has experienced several miter gate failures. Most are attributed to closing the miter gate while water flow is present in the lock chamber. Interlock requirements include gate-to-valve, valve-to-gate, and valve-to-valve.

(1) *Gate-to-valve*. The gate-to-valve interlock prevents the operation of a lock gate while any valve at the opposite end of the lock chamber is open. For example, the upstream miter gate should not close while an emptying valve is open.

(2) *Valve-to-gate*. The valve-to-gate interlock prevents the opening of a valve unless the lock gate at the opposite end is in the closed position. A filling valve should not be opened unless the downstream miter gates are closed (mitered). Likewise, an emptying valve should not be opened unless the lift gate at the upstream end of the lock is in the raised position.

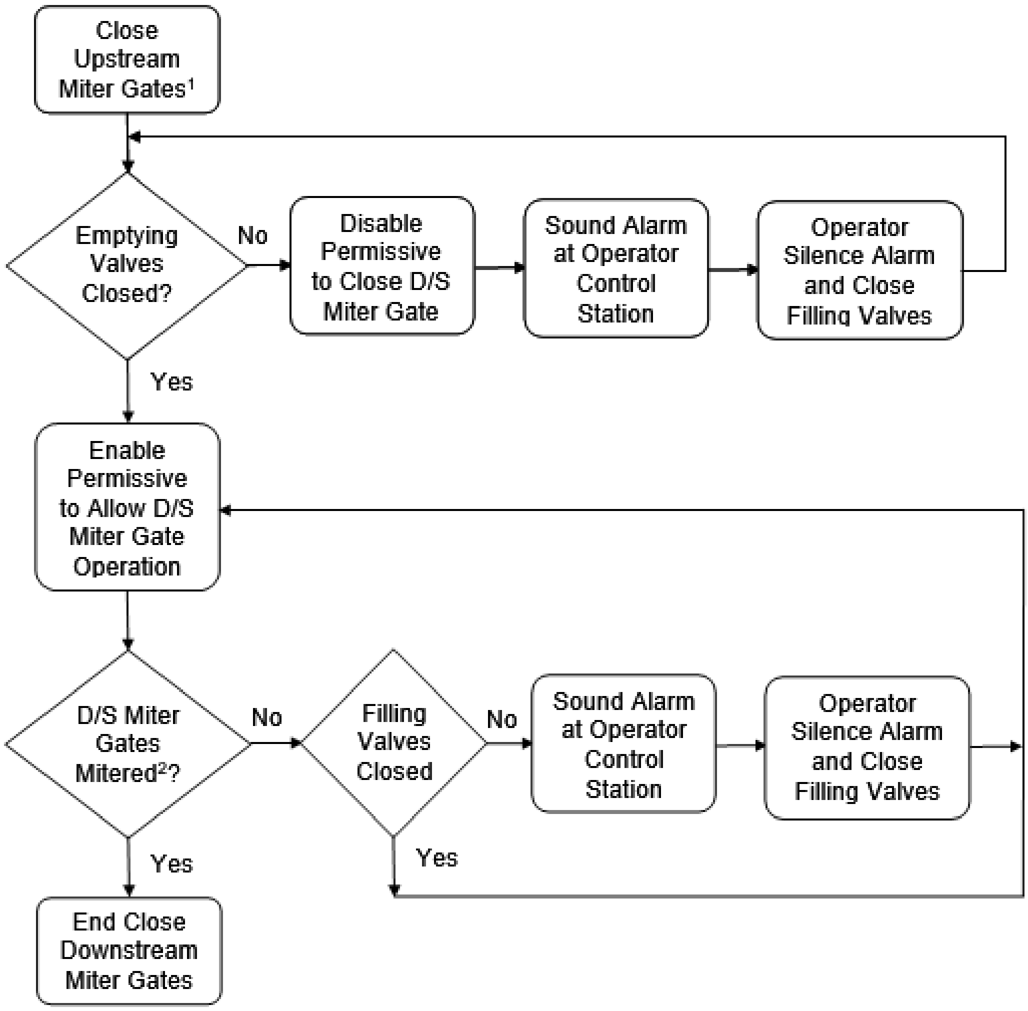
(3) Valve-to-valve. The valve-to-valve interlock prevents the filling and emptying valves from simultaneously opening, allowing water flow in the lock chamber. For example, all filling valves must be closed before opening an emptying valve.

(4) *Interlock sequencing diagrams*. See Figure 17–14 through Figure 17–23 to review the interlock sequencing diagrams.



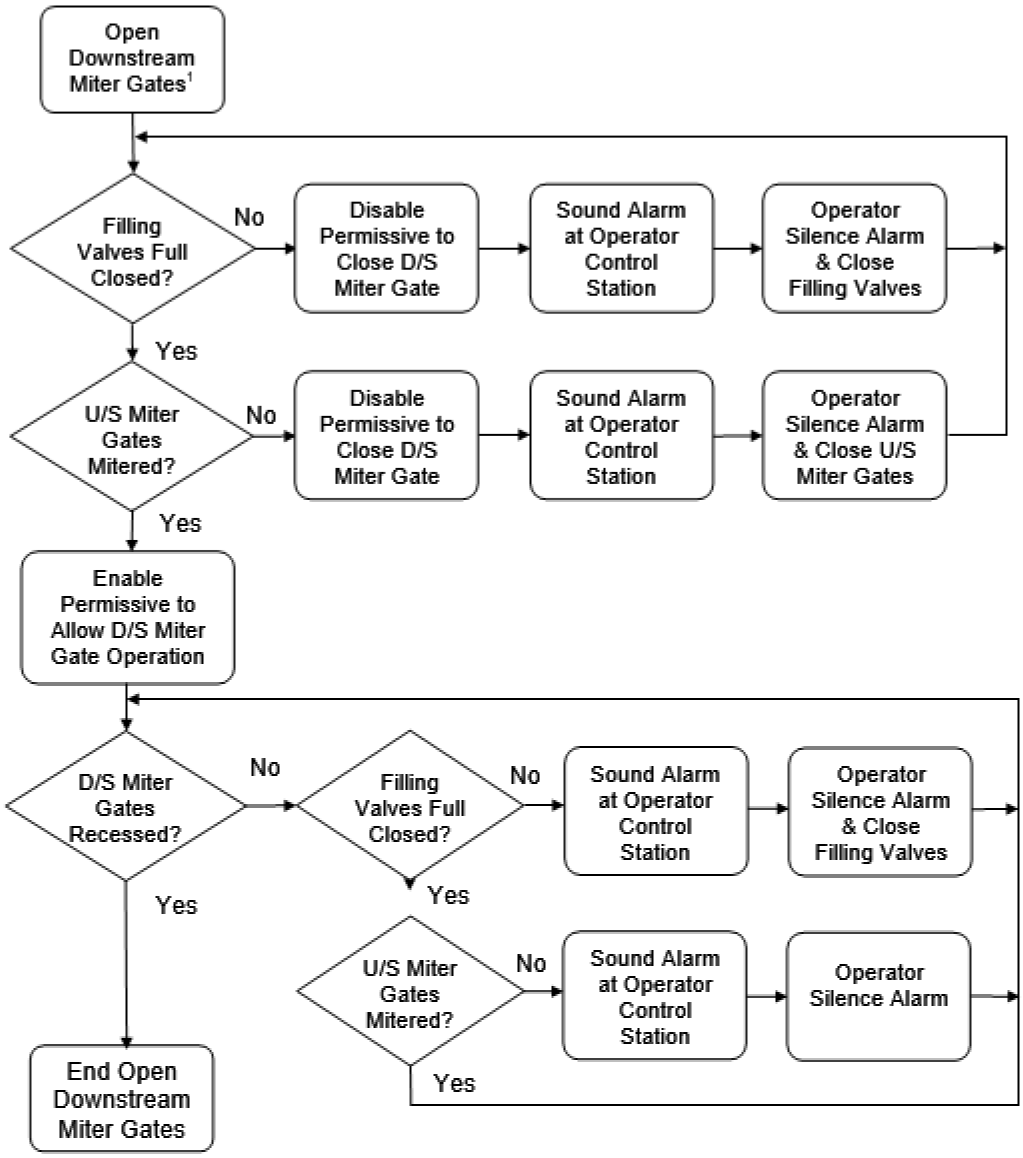
Note:
1. This sequence starts with the emptying valves open. The closing of the emptying valve in sequence is a site-specific determination.
2. The logic permits the lock operator to have control to stop the miter gates any time prior to their becoming mitered. The lock operator must be prepared to stop movement of the miter gates if conditions warrant.

Figure 17–14. Closing downstream miter gate interlock logic



Note:
1. This sequence starts with the filling valves open. The closing of the filling valve in sequence is a site-specific determination.
2. The logic permits the lock operator to have control to stop the miter gates any time prior to their becoming mitered. The lock operator must be prepared to stop movement of the miter gates if conditions warrant.

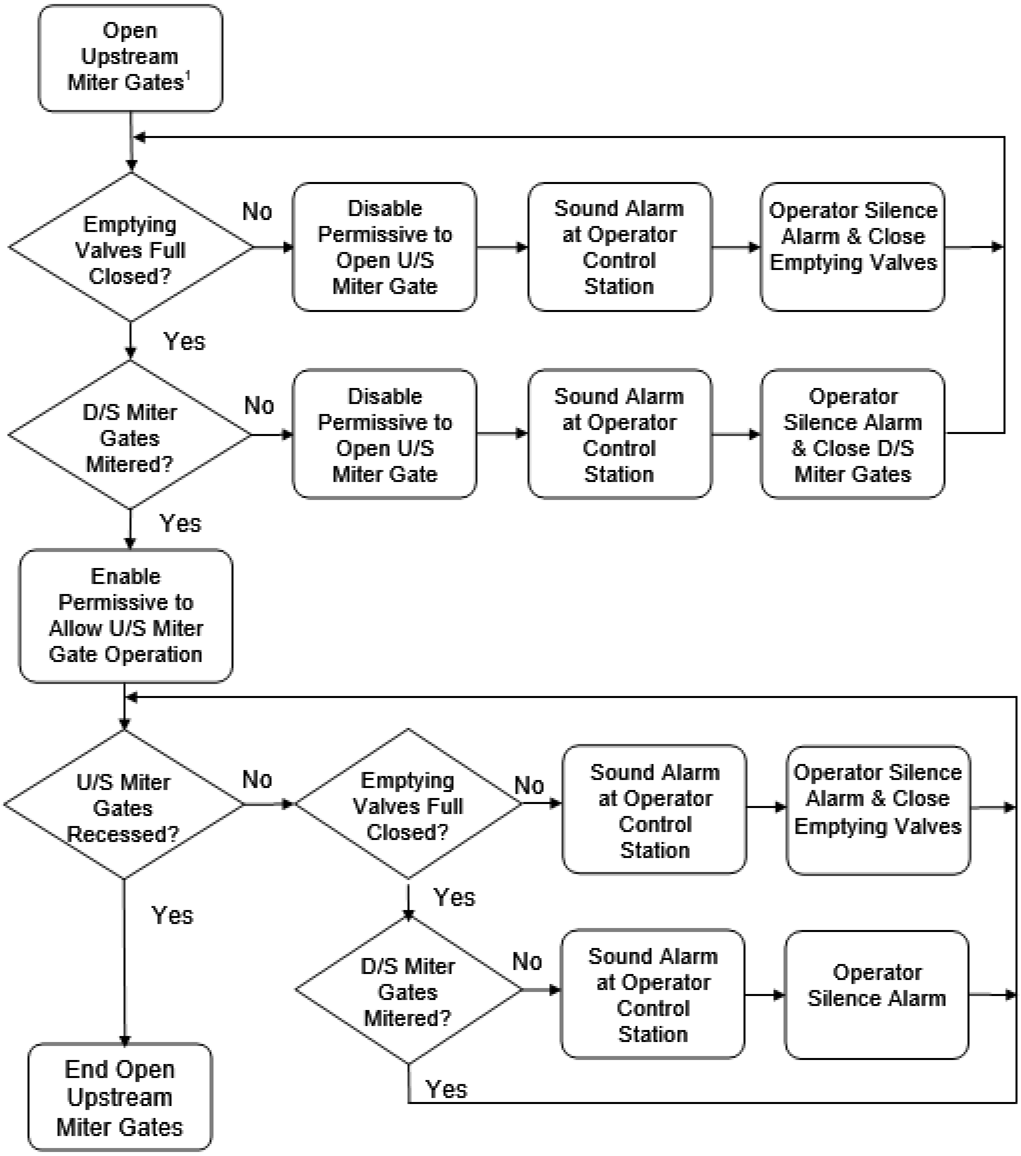
Figure 17–15. Closing upstream miter gate interlock logic



Note:

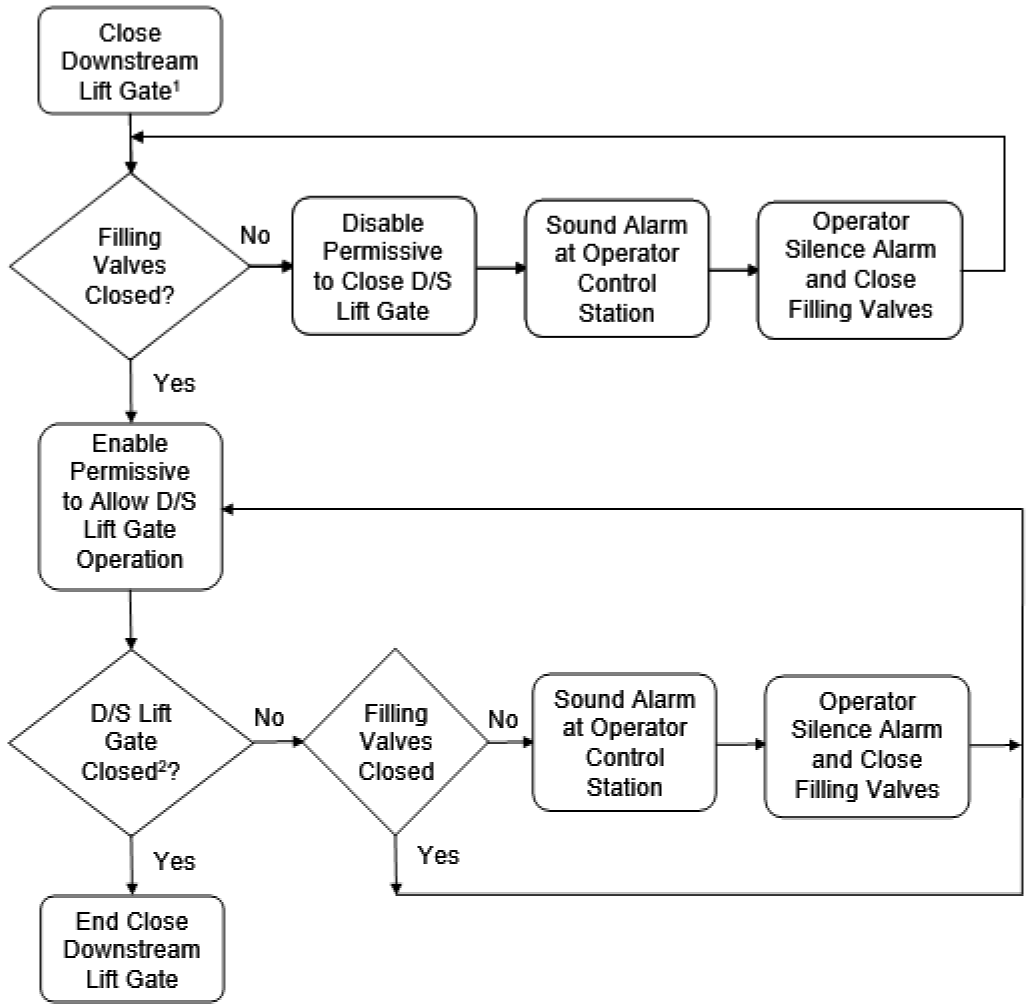
1. This sequence starts with the emptying valves open. The closing of the emptying valve in sequence is a site-specific determination.

Figure 17–16. Opening downstream miter gate interlock logic



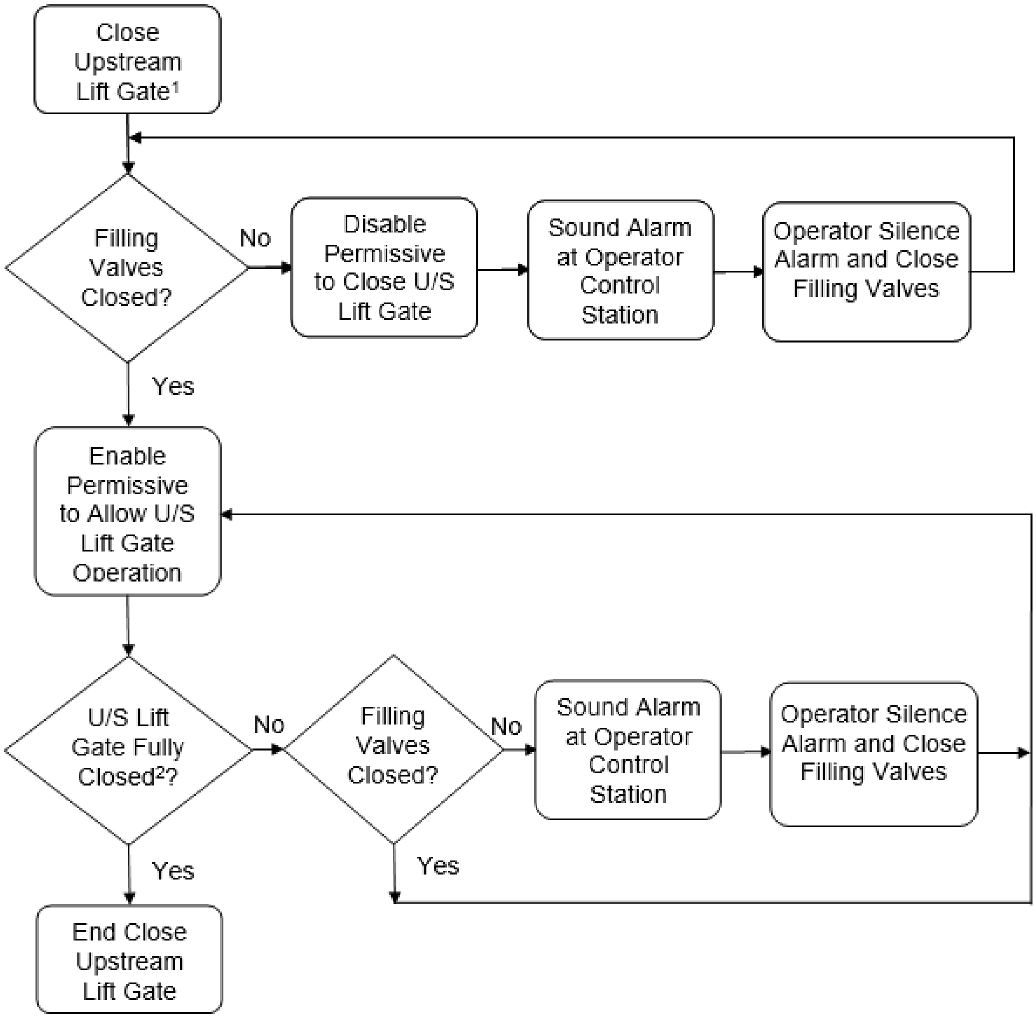
Note:
1. This sequence starts with the emptying valves open. The closing of the emptying valve in sequence is a site-specific determination.

Figure 17–17. Opening upstream miter gate interlock logic



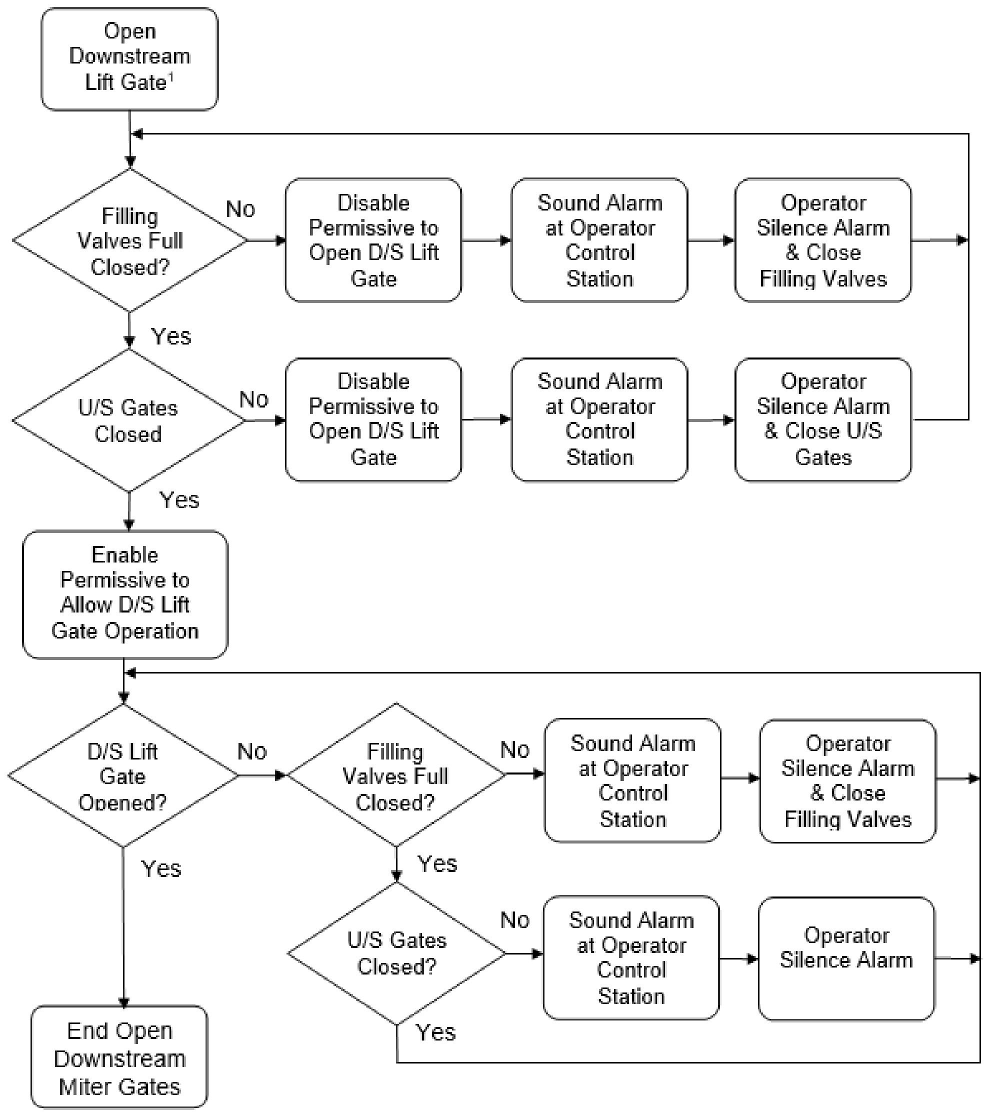
Note:
1. This sequence starts with the emptying valves open. The closing of the emptying valve in sequence is a site-specific determination.
2. The logic permits the lock operator to have control to stop the lift gate any time prior to their reaching full close position. The lock operator must be prepared to stop the lift gate if conditions warrant.

Figure 17–18. Closing downstream lift gate interlock logic



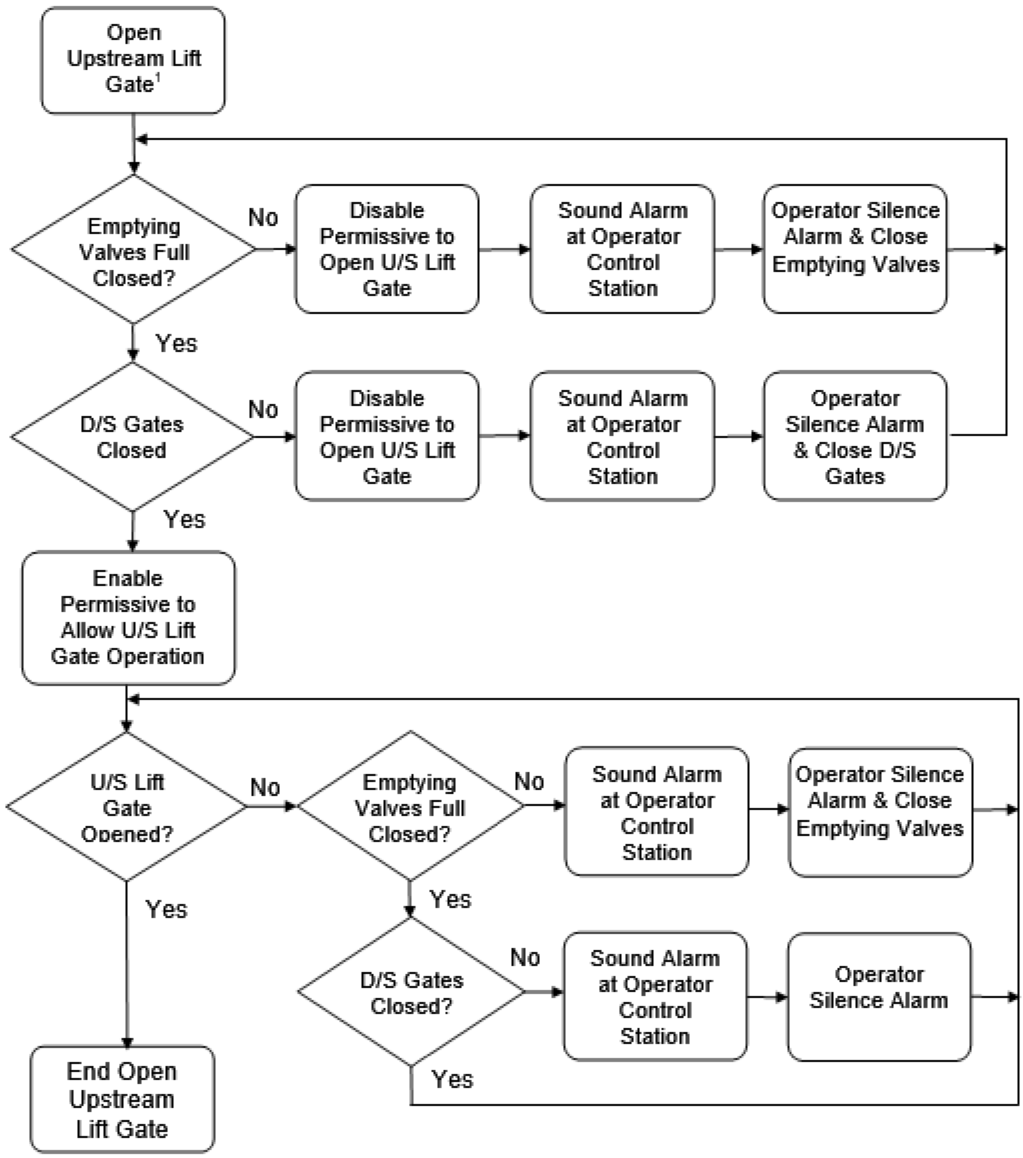
Note:
1. This sequence starts with the filling valves open. The closing of the filling valve in sequence is a site-specific determination.
2. The logic permits the lock operator to have control to stop the lift gate any time prior to their reaching full close position. The lock operator must be prepared to stop the lift gate if conditions warrant.

Figure 17–19. Closing upstream lift gate interlock logic



Note:
1. This sequence starts with the emptying valves open. The closing of the emptying valve in sequence is a site-specific determination.

Figure 17–20. Opening downstream lift gate interlock logic



Note:
1. This sequence starts with the filling valves open. The closing of the filling valve in sequence is a site-specific determination.

Figure 17–21. Opening upstream lift gate interlock logic

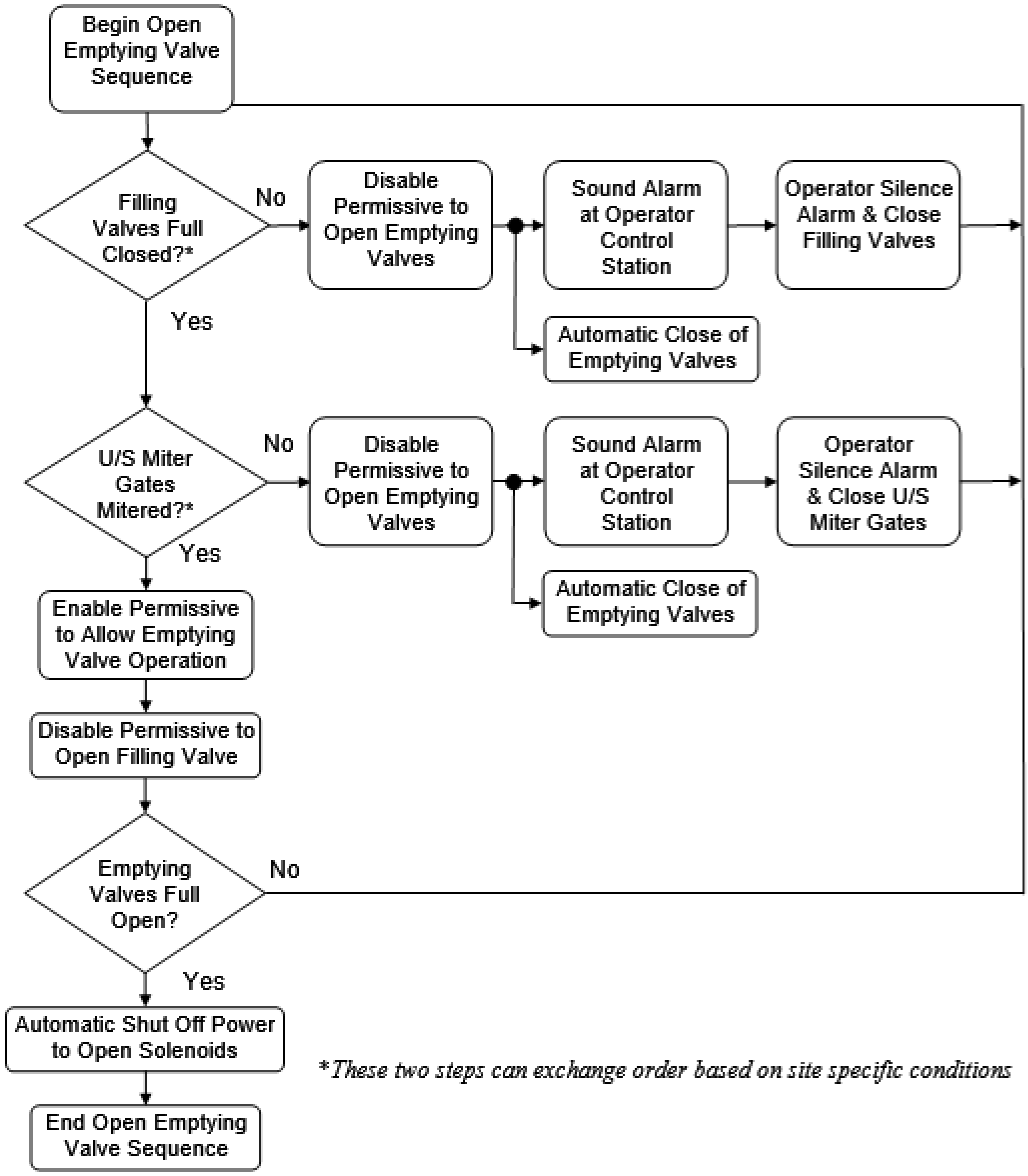


Figure 17–22. Opening emptying valve interlock logic

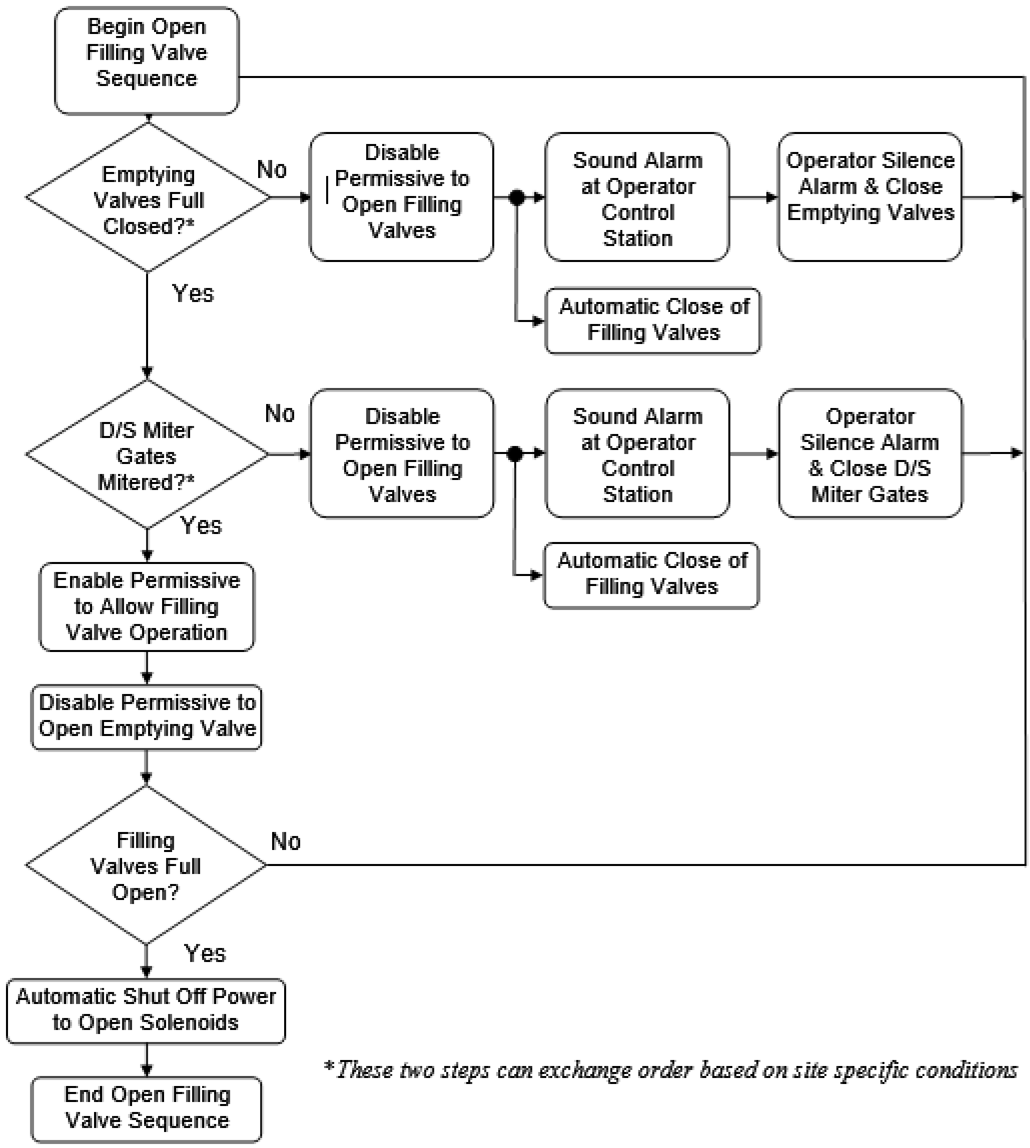


Figure 17–23. Opening filling valve interlock logic

(5) *Additional interlocks*. The lock control system designer should consider the requirement for additional interlocks beyond the minimum in the interlock standard.

(6) *Water levels*. A miter gate should not be operated while a head exists on the gate. The lock control system can be designed to compare the water level on each side of the gate and permit opening of the gate when they are equal. Similarly, a lift gate should not be lowered unless the pool and chamber water levels are equal. These interlocks would be difficult to implement in a relay-based control system but can be done easily in the PLC-based system.

(7) *Ice flushing*. A key advantage of a lift gate installed on the upstream end of the lock is the ability to flush ice downstream. This is accomplished by lowering the lift gate below the pool water level and allowing the ice to flow over the top of the gate.

(a) This condition will create water flow in the lock chamber. The downstream lock gates must be in a suitable position before the ice flushing operation. Ideally, the downstream gates will be mitered, but ice flushing operations could be performed when the gates are recessed fully. In periods of severe ice conditions, the buildup of ice behind miter gates might prevent them from recessing completely.

(b) USACE has experienced several miter gate failures during ice flushing operations when the gates were not recessed fully. Ice flushing requirements and their interlocks should be coordinated between the designers and operations personnel.

c. Bypassing interlocks. Operation of a navigation lock likely will require the operator to bypass the interlocks for certain conditions.

(1) For example, heavy rains might send drift downriver to collect upstream of the miter gates. Bubbler systems can move drift to permit opening of the lock gates, but the drift must be locked downstream. Bypassing the valve-to-valve and valve-to-gate interlocks will permit the opening of the emptying valves, create water flow, and move the drift into the chamber. Once the lock chamber has emptied and the lock gates are recessed, the filling valves are opened to create flow and move the drift out of the lock.

(2) Designers must plan accordingly when overriding the interlocks. The system should be designed to minimize the possibility of the lock operator leaving the interlock bypass enabled. The bypass system should include key switches, indicating lights, etc. When using a key switch, keys should be removable only when the interlocks are not bypassed. PLC-based systems can employ logic to automatically turn off interlock bypasses after a time delay. The lock must develop an SOP for the interlock bypass system, so designers should coordinate its requirements with operations personnel.

d. Field devices. Input devices such as limit switches are necessary to implement the interlocks. Limit switches are used to indicate valve closed, gate mitered, gate recessed, etc. The inputs must be reliable to ensure proper interlocks. The reliability of the input can be increased by installing instruments on the gate or valve, not its operating machinery. The designer should consider the environmental conditions in which the switch is installed and provide redundancy.

(1) USACE has experienced a miter gate failure when the machinery (rack and sector gear) indicated the gate was closed but was open due to a failed strut arm. Limit switches should be located at the miter end of the gate. A magnetically operated switch will ensure a gate has mitered correctly. Limit switches should be mounted in the gate recess. Rocker switches will be susceptible to damage from debris and high water. Proximity switches can trip from a flag mounted on the gate, and there is little chance of experiencing a false-positive condition.

(2) It is difficult to instrument the valve body on filling and emptying valves. Doing so would require the limit switch to be submerged where it would be susceptible to damage from ice and other debris. Replacement of the limit switch would be difficult and costly. The valve can be instrumented at the bell crank. The pivot point of the bell crank might not always be above the water level but is fairly accessible. Hoist-cable operated valves can be instrumented with a rotary limit switch on the hoist drum. A slack-cable limit switch can prevent the machinery from reaching the valve-closed position, in the event the valve body cannot close fully due to a piece of debris.

(3) Permanently submerged lift gates cannot be instrumented directly at the gate. While the lowered position might be constant, the raised position is based on the pool water level. The gate-raised and gate-lowered positions are determined by a rotary encoder on a sheave or drive gear and hardwired, rotating cam, or traveling nut limit switches.

(4) Limit switches used for interlocks should be wired normally open to provide a fail-safe condition. This will require the application of electrical voltage to the limit switch and, to complete the interlock, be in the tripped (closed) position. When limit switches are used for end-of-travel indication, they usually are wired normally closed. If power is lost to the limit switch or a wire is broken, the machinery will not move because the end-of-travel condition is made. A failed condition should not permit completion of the interlock.

17–16. Emergency stop

a. General. It is likely that many of the current lock control systems are equipped with an emergency stop pushbutton. This pushbutton may be an input to a PLC system or part of a hardwired system designed to stop the operation of any machinery on the navigation lock. The term “emergency stop” has specific requirements in terms of NFPA 79, Electrical Standard for Industrial Machinery.

b. Supply circuit disconnecting means. Chapter 5 of NFPA 79 requires the electrical supply for the machine to terminate at a disconnecting means. This may be a molded-case circuit breaker or switch, motor circuit switch, or even a plug and receptacle for a cord connection.

c. Machinery stop functions. Chapter 9 of NFPA 79 defines three categories for a machinery stop function:

(1) Category 0 is an uncontrolled stop by immediately removing power to the machine actuators.

(2) Category 1 is a controlled stop with power to the machine actuators available to achieve the stop, then remove power when the stop is achieved.

(3) Category 2 is a controlled stop with power left available to the machine actuators.

(4) Each machine must be equipped with a Category 0 stop. Most navigation lock machinery operates with the Category 0 stop by de-energizing a reversing-contactor to a motor and setting a holding brake.

d. Emergency stop operation. Emergency stop must meet the following requirements from Chapter 9 of NFPA 79:

(1) It must override all other functions and operations in all modes.

(2) Power to the machine actuators, which causes a hazardous condition, must be removed as quickly as possible without creating other hazards.

(3) The reset of the emergency stop command must not restart the machinery, but permit only the restarting.

(4) The emergency stop must function as a Category 0 or Category 1 stop. A risk assessment for the machinery will determine which category is required. NFPA requires, “Final removal of power to the machine actuators must be ensured and must be by means of electromechanical components.” While this a reference to a relay, the standard does permit a solid-state device (drive) to be the final switching device when it meets the “relevant safety standard.”

e. Machinery risk assessment. The requirement to perform a risk assessment of the machinery is referenced in many sections of NFPA 79. The risk assessment must determine the circuit reliability required for the emergency stop function, but the standard does not define the reliability classes. The risk assessment also may dictate the monitoring of safety circuits and the use of safety relays and circuits.

f. Emergency stop system design. The scope of NFPA 79 does not include the design requirements for the emergency stop system and its components. Annex A of NFPA 79 refers to ISO 13850. When related to solid-state devices used in safety functions, the annex refers to IEC 61508 and IEC 61800-5-2.

g. Emergency stop devices. While the standard does not address the design of the emergency stop function system, it does detail the requirements for emergency stop devices. The devices must be readily accessible and continuously operable. A device should be located at each operator control system and other locations that require emergency stop. Devices might be required on the lock wall near the machinery for use by operations and maintenance personnel. The device may be, but is not limited to, a pushbutton-operated switch, pull-cord-operated switch, foot-operated switch (no guard), push-bar-operated switch, or a rod-operated switch.

(1) Pushbutton-type devices must be red with a yellow background. The device must be self-latching with direct operation. The actuator of the pushbutton must be of the palm or mushroom-head type and must effect the emergency stop when depressed.

(2) Devices cannot be flat switches or “graphic representations based on software applications.” This means an object on an HMI cannot serve as an emergency stop device.

h. Other considerations. Consideration should be given to illuminating the pushbuttons to indicate when the emergency stop is active. Illuminated pushbuttons also can be programmed to flash to remind the operator that equipment is operating. This might be important if one is operating from a centralized control room that is remote from the equipment. It also serves as a reminder if the HMIs fail.

17–17. Procurement considerations

a. Computer hardware. One of the most difficult tasks of putting together a computerized lock control system, whether automated or not, is the acquisition of quality, state-of-the-art computer hardware. Often, large construction contracts have too long a construction period to write specifications around state-of-the-art computer equipment. Even PLC components might be superseded in design during major construction of a new lock and dam.

(1) *Government-furnished equipment*. GFE is not always a good idea because of the issue of responsibility during installation. In theory, GFE is a good idea; but in practice, many agencies have had trouble administering contracts with a large amount of GFE. Optional bid items and change orders are usually difficult to negotiate and costly when issued near the end of a large contract. Some guidelines for procurement of such equipment:

(2) *Personal computers*. Computer hardware will usually stay state-of-the- art for only about a year and somewhat current for up to three years. Therefore, it is not recommended to specify PC-type hardware in a contract of duration more than nine months.

(a) Even at that, with reproduction, advertisement, contract award, notice to proceed, and shop-drawing phases, the equipment model design will likely be well over a year old when the government assumes ownership of the control system. Contracts of duration longer than nine months should be looked at with the possibility of doing a small follow-up contract to install, configure, and program the computer network.

(b) When upgrading the PC hardware and software, use purchase orders with hired labor for installation or write small contracts with a system integrator. Trying to incorporate computer upgrades into another contract usually is not a good idea because of the different trades involved and the contract duration time. An important part of the successful procurement of a quality system is completely engineered plans and specifications that do not allow a contractor room to substitute cheaper components or installation methods.

(3) *Programmable logic controllers*. Having better stability than PC components, PLC equipment generally will stay current on the market for five to ten years. Once

installed, a PLC system should be expected to require a complete upgrade every ten to fifteen years.

(a) However, it is critical at the time of project startup to have a state-of-the-art PLC system. Therefore, if the construction contract exceeds one year in length, it might be worthwhile to leave the PLC system out of the contract and write a follow-up one to install and program the PLC system. In the big construction contract, items such as raceways, cable trays, field devices, and even some field wiring can be put in place to minimize the effort of the PLC system installer. The first contract must be managed well to ensure everything is in place.

(b) Too often, staff relies on operational tests to confirm the contractor has completed all work, and in this case, the first contractor might be long gone when the operational tests are performed. It is important to develop some in-house expertise on PLC systems to assist in administering both contracts and providing startup, assistance, and long-term maintenance to the lock. This will be the key to whether the control system is successful or not. Down the road, the problems with administering the contract may be forgotten, but the reliability of the PLC system always will be an issue.

b. Computer software. Not unlike computer hardware, software does not stay current for more than three years in most cases, and often is superseded by new versions within a year. It may be written in the specifications that the contractor must provide the latest release of a particular software; but, at some point, the contractor must purchase the software and that needs to be written in the specifications so that there is no dispute as to what revision is the latest at the time of purchase.

(1) *Operating system*. The operating system software should be purchased at the same time as and by the same contractor as the computer system hardware. This will alleviate compatibility problems between the operating system software and other software or hardware.

(2) *Human-machine interface software*.

(a) The latest version of HMI software and the PLC system should be purchased at the same time. With most HMI packages, upgrades should take place probably on a three-year basis. Problems arise when operating systems, such as Windows 10, are revised to the degree that a plant's current version of the HMI software will not run on the new operating system software. These are times when a design engineer or software maintenance personnel must be careful when upgrading software.

(b) Databases usually can be transferred when the HMI software is upgraded, but not always. Before writing specifications, it is recommended that the designer gain a thorough understanding of the marriage of the operating system software and the HMI, as well as a thorough knowledge of what is on the market. All projects should factor in monies to upgrade the HMI software every three years.

c. Sensors. Non-electronic sensors such as dry-contact, vein-operated limit switches, traveling nut limit switches, and magnetic limit switches may be purchased and installed in a large construction contract. However, if the construction contract exceeds one year, consider purchasing encoders, pressure transducers, inclinometers, hydraulic cylinder position-tracking devices, and other solid-state sensors in a separate, follow-up contract, perhaps with the PLC/PC system hardware. Again, raceway and wiring can be put in place for these items; but to ensure that the latest versions are acquired, it might be best to purchase the sensors later.

d. Training.

(1) Training should be provided for in all contracts and purchase orders. Generally, a contractor will not raise their bid price too much to cover training; so, consider putting a generous amount of training in the specifications package. Furthermore, it is a good idea to provide for enough training, stressing quality and qualifications of instructor, to force the contractor to put some extra money in their bid. This will ensure better training when the time comes.

(2) If the system is easy to operate and maintain, delete some training or reserve it for cross-training personnel from other locks or projects. Ideally, training should be provided well in advance of equipment installation. It is a good idea to record all training sessions on video, to be used later as a reference and training tool.

(3) Training requirements are covered below. The design team should select the applicable portions of the training below for the control system furnished: hardwired relay or PLC type.

(4) The contractor's system integrator should provide the PLC/PC system training. Schedule enough sessions for enough personnel to more than ensure that everyone gets sufficient instruction. Three things to include in the contract are number and length of training sessions, qualifications of instructors, and material to be covered and training aids to furnish.

(a) Hardware.

1. The PLC hardware training should cover everything from simple I/O card installation and removal to termination of fiber optic and copper communication cables. Discussion should cover hardware diagnostics, interpretation of system LED indicators, automatic failover of communication channels, power supply connections, fuses, line conditioners, lightning protection, and all other hardware in the PLC I/O racks. The instructor should provide hardware similar to that used on the project, complete with power supplies, I/O cards, communication cards, and all equipment necessary to allow trainees to assemble a small PLC system ready to program, as stated below.

2. The PC system hardware training should cover all connections to the chassis, including network, printer, mouse, keyboard, and power. The discussions should cover the installation and removal of CPU, video, and network cards. The contractor should discuss all connections to equipment such as routers, modems, printers, hubs, and Network Attached Storage (NAS) drives for backup.

(b) Software. Software training should be included with the hardware training, and accomplished on the same hardware during the same training sessions. This will help bridge the gap between the hardware and software.

(c) Operating system software.

1. The software training should start with a thorough review of how to navigate the system operating software. Particular attention should be paid to how the system operating software interacts with the PLC programming software and the HMI software. System log-in and boot-up procedures should be shown. Passwords and restricted access should be discussed and explained. Location of directories and file storage folders for the PLC programming software and the HMI should be addressed in the training. Things such as operating-screen file transfers and file backup procedures should be discussed.

2. Any special custom icons used to short-cut loading of the PLC or HMI software should be reviewed. The contractor should show how to reload and configure the system operating software in the event of failure. This is a good time for government personnel to point out some features they would like to see changed, such as passwords, initial loading screens, profiles, etc. At this point, a system integrator usually will make these changes at no additional cost because it does not impact the schedule. Sometimes these changes can be made during the training session, enhancing the quality of the training.

(d) Programmable logic controller programming software. The contractor should demonstrate how to install and configure the PLC programming software package. The training should cover complete I/O rack and slot addressing, as well as communication software installation and configuration. PLC ladder logic should be developed for the mock PLC system developed, as stated above. Documentation of the program also should be covered. An application for the training PLC system should be developed, loaded to the processor, and shown to be working.

(e) Human-machine interface software. The same procedure should be followed for the HMI software training. After demonstrating how to navigate the package, an application for the training PC/PLC system should be developed and shown to function properly.

(f) Sensors training. The contractor should provide training on all field devices, including limit switches, pressure transducers, encoders, inclinometers, and other I/O equipment. The training should cover the installation and replacement of these devices, as well as their respective interfaces to the PLC system if a PLC control system is used.

(g) CCTV system training. It is important to mandate sufficient CCTV system training in a construction contract. As with the PC/PLC training, the specifications should include three things: the qualifications of the instructor(s), the amount of training, and the topics to cover.

1. The instructor should be an integrator who has commissioned CCTV systems at other projects with the same components. The instructor need not be a representative of the hardware manufacturer, and, in fact, the quality of training will probably improve if the instructor is an integrator who actually makes the equipment function, rather than a manufacturer's representative.

2. Specify enough training in the contract to force the CCTV supplier to build sufficient monies into their bid. This is because large manufacturers often will tell electrical contractors during the bid process that they will provide the training at no cost if they use their equipment. In this case, a salesman will come to the site and read from an operating manual. This is not quality training. If a supplier has to build some cost into the bid, they will be more flexible in providing the training and, after award of the contract, quality rather than quantity can be stressed.

3. Topics should cover everything from installation and configuration of all hardware and software to long-term access and maintenance of the equipment. Constructing a mock system as part of the training is always a good way for maintenance personnel to learn the new equipment.

e. Closed-caption television system. CCTV equipment does not evolve as fast as computer hardware and software. However, if your contract duration is more than two years, it is best to furnish and install the equipment with a follow-up contract to ensure procurement of the latest technology. In all cases, it is probably best to have a CCTV system supplier and integrator do the work. They should be a firm regularly engaged in providing, installing, and performing startup and long-term maintenance of CCTV systems. As with the PC/PLC equipment, thoroughly engineered plans and specifications are the key to the procurement of a successful CCTV system.

f. Warranties and service contracts. Troubleshooting, repair, and long-term maintenance of computerized control equipment is a critical part of a successful lock control system implementation. It is recommended that a plan for such action be in place before procurement of such equipment. Some things to consider:

(1) *Warranties*. Most construction contracts include a one-year warranty on labor and materials. It is a good idea to have the contractor make a written transfer to the government of any manufacturer warranty on equipment covered by this manual. Some of these warranties might exceed one year. Procure additional years of extended warranty with caution because there is a point of diminishing returns. Namely, some equipment will become outdated before it fails. Also, it has been shown that a majority of equipment failures occur within the first year or so of operation. Once the wrinkles are worked out of a system, many of the components can be expected to last a reasonable amount of time relative to the time it takes for their obsolescence to drive replacement.

(2) *Service contracts*. The requirements for service contracts should be commensurate with the type of control system furnished. The more electronics furnished on a project, the more consideration should be given to service contracts.

(a) For hardwired relay control systems with a small to moderate number of electronics, a service contract usually is not needed. For systems with PLC and PC control, it might be desirable for the construction contract to require a service contract or service agreement with the contractor's system integrator. This is usually more preferable than searching for a low-bid third party to service the system. It is recommended that this agreement be limited to one year with the government's option to renew for a second. By doing this, the USACE district can evaluate the contractor's performance and become more familiar with the control system.

(b) Specify in the service contract that it must be the responsibility of the contractor to furnish spare parts, as they feel necessary, above and beyond that specified in the original contract. Also, specify response and repair times, as well as a list of government points of contact (POCs) to avoid confusion when problems arise. Require that the contractor make a full report of changes and procedures that were made to correct the problem, both temporary and permanent. This report should specify all parts that were replaced.

(3) *In-house maintenance*. The best way to maintain systems such as these is through the use of well-trained, in-house electricians and electronic technicians supplemented with help from USACE district engineers when required. When personnel and budget restrictions allow, a district should have at its disposal a crew of such personnel that can perform routine maintenance as well as emergency repairs at all district locks.

(a) Busy locks might be able to justify a highly trained electrician/electronics mechanic dedicated to that lock. This is the best way to maintain the system. Keep in mind that, in addition to the high skill level necessary to service computerized control systems, this person must have a thorough knowledge of fundamental electrical principles. This is important because the computerized control system is only a convenient front end to make operations and maintenance safer, more reliable, and more flexible.

(b) Beneath all this is the basic concept of electrical power transmission and conversion into mechanical work via a motor or solenoid. For this reason, it is better to put a sound electrician through the proper training and upgrade them to an electronics technician than to take a computer programmer and try to teach them fundamental electrical principles.

g. Testing and startup. All construction projects should have well-defined testing and startup procedures in the contract requirements. All testing should be witnessed by government representatives from engineering, construction, and operations. This will ensure that the test procedures are correct, relevant, and that all hardware and software (in the case of a PLC control system) pass the test. Each system should be tested individually, then as a total lock control system. The design team should select and modify, as appropriate, the applicable portions of the testing and startup requirements below for the control system furnished, whether it be hardwired relay or PLC type.

(1) *Programmable logic controller system*. It is recommended that the system integrator, before installation, assemble a small system using the proposed PLC components to demonstrate how the system will work. This also will be a good training tool for district personnel.

(a) This should be done off site, at the system integrator's shop, to enhance the training aspects of the testing. Mixing training with testing at this point can be a good thing, as long as there are clear requirements for each, as stated herein and above, provided for in the contract.

(b) Once the system is in place at the lock, test each I/O point on the system, making a chart to verify each has been tested. This test should be done independent of field devices using dry-contact switches and pilot lights for digital I/O, and function generators and meters for analog I/O. This will test the entire PLC communication network. The test should be performed using each of the redundant PLC communication channels. The contractor should be responsible for correcting any and all deficiencies shown by the test. Field devices such as limit switches, encoders, and transducers now can be tested using the PLC system, with confidence that the communication and I/O rack wiring are properly in place.

(2) *Personal computer system*. The system integrator should be required, at the same time as the PLC factory test, to set up a mini version of the PC network. The network should include the PLC processor and all appropriate software to allow programming, troubleshooting, and execution of a ladder program and an HMI application. During this test, in the presence of government personnel, at least one PC should be brought online, from the ground up, including the following steps:

(a) Connect all peripherals such as monitor, mouse, modem, etc.

(b) Install the network cards.

(c) Install and configure Windows operating software.

(d) Verify communications with all other network devices.

(e) Install and configure all PLC programming software.

(f) Install and configure all HMI programming software.

(g) After this has been done, the system integrator should demonstrate that numerous large files and directories can, with speed and accuracy, be copied over the network. At the same time as the PLC factory test, a mock ladder program and HMI application should be developed to ensure compatibility of all hardware and software. Again, this test procedure serves as a good training exercise for government personnel.

(h) After the system is in place at the locks, all network communications should be verified again to check all field wiring. Knowing from the factory test that all network software parameters are configured correctly will aid in determining startup problems at

the site. While testing the PLC I/O points, a test HMI application can be used. This will make the I/O testing easier, as well as demonstrate further that the PC network is properly in place.

(3) *Field devices*. Immediately after installation, check all field devices using meters to determine that they have freedom for necessary motion, put out the correct signal when input power is applied, operate correctly with the movement of machinery, and are protected from operations, debris, and weather. After all I/O points have been checked, field devices should be wired to the I/O racks and tested using the PLC/HMI network to verify that all field device outputs are compatible with the PLC system.

(4) *Total system*. After the above tests have been completed successfully and the lock machinery is ready to be moved, the entire system should be checked for proper operation. All systems should be checked via:

(a) Water level sensing system. Since it is used as a safety interlock in PLC control systems, the water level sensing system should be tested before operation of any lock machinery. Each water level sensor first should be checked for a proper and accurate level, as displayed on the HMI operating screen. Since the transducer has been tested, this test should concentrate more on the decoding in the ladder logic.

(b) Water level changes. Verify that the level displayed corresponds to water level changes. In the case of a submersible pressure transducer, raise each unit exactly 1 ft and verify that the level displayed responds accordingly. Repeat this step for several feet and back down again. While not the most accurate test, this will give a good indication that the unit and programming are responding correctly. Fine tuning the calibration can be done when the lock chamber is filled and emptied and large changes in water level can be tested.

(c) Lock gates. Motor rotation always should be checked before movement of any equipment. When all limit switches and safety interlocks have been tested and verified for proper operation, the contractor should begin moving each lock gate one at a time in slow speed. Immediately check to ensure that the position displayed on the HMI screen is responding correctly. The contractor should stop and restart the gate from several different positions to ensure the machinery starts in slow speed and changes speeds correctly.

(d) Limit switches. All limit switches, including overtravels, should be checked for proper operation and indication. Each gate should be run through a minimum of 10 cycles for testing purposes. Miter gates should be run together after it is shown that each leaf operates correctly. The position indication should be monitored continuously for glitches or spikes. End-of-travel limits should be checked for proper mitering and recessing of the gates. Bubbler system compressors and solenoids should be checked for proper operation and indication.

(e) Filling and emptying valves. The same basic procedure for the lock gates should be followed for startup and testing of the valves.

(f) Dam gates. After rotation has been checked, the dam gates should be operated individually through as much of their full range of travel as pool conditions will allow. If possible, placing stoplogs will provide the chance to test the full range of travel of the gates. All limit switches and overtravels should be checked for proper operation. Again, the position readout of the gate on the HMI should be monitored for proper response to the movement of the gate. Stop the gate periodically and verify the position against a known benchmark such as a staff gauge.

(g) Lock lighting. All PLC-run lighting systems should be checked for proper operation and indication. Feedback indication on the HMI screens should be from auxiliary contacts on the lighting contactors. Integrators often will use PLC output status as an indication of light operation, but this is not reliable feedback. Traffic lights also should be tested for proper operation.

(h) Alarms. All alarms such as transducer failure, fire and smoke detectors, motor overload, machinery overtravel, communications fault, power failure, etc., should be simulated and checked for proper indication on the HMI screens.

(i) Remote monitoring. Remote monitoring and troubleshooting capabilities of the system should be tested by the contractor for proper operation and security.

(j) Miscellaneous control features. Miscellaneous control features unique to each lock should be checked for proper operations. When all these systems have been verified to function properly, run the lock through at least five complete lockage cycles, using all the equipment mentioned above. Pay particular attention to the position indication of the gates and valves and to the level readouts for the pool, tailwater, and chamber water level sensors. Make sure that the pools equal interlock is functioning correctly at each end of the lock. It is usually better to specify requirements for extra testing rather than not enough.

(k) Testing requirements. It is highly recommended to clearly spell out all testing requirements and subsequent documentation with clearly defined schedules. The testing requirement could include performance requirements that are clearly articulated and measurable to verify the test was a success.

h. Documentation. The contractor should provide complete system documentation for all hardware and software used on the system.

(1) *Personal computer network*. The documentation should show all network and communication parameters and give detailed drawings showing the complete Ethernet network including all PCs, modems, routers, fiber optic equipment, communication cables, hubs, transceivers, network cards, video and sound cards, data storage devices, uninterruptible power supplies, etc. Manufacturer names and model numbers should be listed for all devices.

(2) *Programmable logic controller network*. The system integrator should provide drawings showing the complete PLC network with all I/O racks and cards, fiber optic converters and power supplies, lighting panels, AFDs, network communication

equipment, power supplies, uninterruptible power supplies, and other equipment. The drawings should show all manufacturer names and model numbers, how all devices are interconnected, and all PLC network addresses including addresses for each individual I/O rack slot. A list should be provided showing the location, address, type, designation, tag, and purpose of every I/O point in the system.

(3) *Ladder logic and human-machine interface applications*. The system documentation should include complete, up-to-date listings of the entire ladder logic program with all I/O points, cross referencing, and labels listed. The HMI software documentation should include a cross reference of every I/O point monitored, a list of all tags, showing type and designation, and a printed copy of every operating screen. All software configurations necessary to establish proper communications with the PLC processor should be in the documentation.

(4) *Field devices*. A complete listing of every field device, including transducers, encoders, limit switches, photocells, and motion detectors. The documentation should include manufacturer names and model numbers, voltages, input and/or output parameters (if selectable), dipswitch settings, wiring, power supplies, and all information relative to the job.

(5) *Input/output rack wiring*. The contractor should include as-built documentation of all equipment and wiring in each I/O rack enclosure. This information should be detailed enough to show point-to-point wiring, with terminal board designations for all connections.

Chapter 18
Remote Operation, Remote Control, and Automated Operation

18–1. Overview

This chapter discusses remote operation, remote control, and automation of locks, dams, spillways, and FRM facilities. There are several initiatives currently underway (at the publishing date of this manual) in USACE to implement remote operation at multiple lock sites. The guidance and requirements for remote operation and remote control are rapidly changing and evolving. The designer should work with the INDC to make sure they have all the current information and guidance. There are currently two USACE technical reports titled Remote Lock Operations. One is the National Assessment and Framework and the other is the National Implementation Plan.

a. General. While remote operation and automation may provide cost savings by allowing fewer operators to control multiple facilities, remote operation and automation require mitigation of increased occupational health and public safety risks. This chapter outlines a risk-based approach to mitigation of these risks. In addition to design criteria, this chapter also describes use and operating procedures of remote operation, remote control, and automation with separate discussions for navigation locks and spillway gates.

b. Definitions.

(1) *Automatic operation*. Predefined logic operates machinery without any direct input from personnel. For example, a PLC operates a dam gate after measuring the rate of reservoir rise and comparing it with a predefined threshold.

(2) *Remote control*. On-site personnel operate machinery from a control center, but the operating personnel are not at the water control structure. An example would be operating dam gates on site from the lock control house. Remote control is noted as Closed Campus Control in the National Framework and Assessment Study. For a lockage, the control center may or may not provide a direct line of sight to the lock chamber. Instead, operators use automated equipment, cameras, and sensors to monitor and control the lockage process.

(3) *Remote operation*. Off-site personnel operate gates and machinery, usually from a centralized location or Command Center. This is referred to as the Command Center concept in the National Framework and Assessment Study. Like the closed campus concept, lock operators use automated equipment control, cameras, and sensors to guide the lockage process. However, this is done without a direct line of sight. There are multiple lock sites operated from the same center.

c. References.

(1) ER 1110-2-1156. The USACE regulation provides risk-based policy for determining if a water control structure qualifies for remote operation, remote control, or automatic operation.

(2) PIANC WG 192 Report. This report provides guidance and considerations for remote operation based on recent developments and case studies from different countries.

(3) Remote Lock Operations National Assessment and Framework. The INDC is leading an effort to assess implementation of remote lock operations, improve resiliency, and maintain continuity of operations.

(4) Remote Lock Operations National Implementation Plan. Implementing remote operations at 85 locks.

(5) ANSI B11.0. This report provides guidance for safety of machinery.

(6) ANSI B11.26. This report provides guidance for functional safety for equipment and general principles for the design of safety control systems.

18–2. Case studies

a. At the time of this publication, USACE does not remotely operate any of their navigation locks, but remote lock operation is very prevalent in Europe. USACE personnel have made several site visits while participating in the PIANC 192 working group. Germany remotely operates the 16 locks on the Danube River and canal from four remote control centers. Germany also remotely operates its locks on the Upper Neckar and Rhine rivers and portions of the Bremerhaven Port system. The Belgium government remotely operates multiple locks.

b. The Canal Saint Denis in Paris, France, contains seven pairs of locks. Two control centers remotely operate the locks. Control consoles located at the Heel Lock in The Netherlands are used to remotely operate the Linne and Roermond Locks.

c. The SLS and Welland Canal in Canada use remote control extensively. Multiple hydropower dams also use remote control. See Figure 18–1 and Figure 18–2.

Figure 18–1. Remote operation center, Saint Lawrence Seaway, Canada

Figure 18–2. Welland Canal control room layout

d. Typically, remote capabilities are limited to RO gates. However, for the existing (legacy) remote operations and automation for the Willamette and Rogue dams, an automatic gate operation is enabled when the hydropower unit trips offline to maintain river flow. A Phase 1A study is being finalized to bring existing capabilities into compliance with industry standards, engineer regulations, and electrical reliability standards. Communication upgrades are also in progress.

e. The current control scheme for the Columbia and Snake River dams is local control and remote (on-site) control. There is a regional initiative to study the potential for increasing remote operation. Technical criteria are being developed to assist with gap analysis and define requirements. Risk-informed decision framework is to be developed to assess risks holistically.

18–3. Risk informed decision-making

a. Use the screening criteria and decision authorities described in ER 1110-2-1156 before implementing remote control, remote operation, or automatic operation of a water control structure. The designer must follow the general guidelines for risk-based decisions in ECB 2022-7.

b. During design and before construction and operation of these features, use a risk informed decision-making process to identify occupational health and safety risks for government personnel and the public; risk mitigations; and acceptance of residual risk. ANSI B11.0 provides an example risk assessment process that is summarized in ANSI B11.26. The District Chief of Operations has authority accept risks to government personnel, and the District Dam Safety Officer has authority to accept risks to public safety.

18–4. Remote operation of dams and gated spillways

Remote operation allows operating personnel to change their duty station and potentially operate multiple dams or gated spillways.

a. Qualifying spillways. When considering remote operation of a spillway, the structure type, downstream effects, and dam safety must be taken into consideration. These aspects of the spillway will determine the precautions that must be taken, the equipment to be installed, and the standard operating procedure required for a safe and useable system. See ER 1110-2-1156.

b. Gate capabilities. Tainter gates, vertical lift gates, and roller gates are the most common dam gates and have been discussed previously in this manual. These all are capable of remote operation, remote control, and automatic operation.

c. Outlet works. An outlet works spillway consists of an intake tower with a sluice tunnel or tunnels through the dam. The water is controlled in an outlet works by slide gates. These gates can be raised and lowered either by an electric motor or hydraulic cylinder. Also, many outlet works structures have low-flow valves. Low-flow valves can be operated by either an electric motor or by hand. The position of these valves is generally shown by a gear-driven indicator.

d. Lock and dam pool elevation and flood control. At a lock and dam structure, there is generally a spillway to control the pool elevation. In most situations, the spillway is a tainter gate spillway. The lock operator generally controls the flows from the tainter gates to regulate the navigation pool. Remote operation of the spillway in a lock and dam is beneficial because the lock operator can maintain the pool elevation from the control house at the lock.

e. Spillways with hydroelectric powerhouses. Spillways with powerhouses can be either outlet works type, roller gate type, tainter gate type, or any combination of these. In a powerhouse, pool elevations in normal situations are usually controlled by power generation activities. Powerhouse employees may or may not control spillway operations. It is critical that the powerhouse personnel and the spillway operator coordinate any releases with the generation schedule.

f. Downstream effects. The downstream effects of spilling water from a spillway will determine what is required when remotely operating the spillway. See ER 1110-2-1156.

g. Channel capacity. The capacity of a given channel will determine some precautions that must be taken when remotely operating a spillway. In many cases, more water can be released than the downstream channel can carry without overflowing. If the channel cannot carry the spillway release, a warning system must be in place to let the operator know if the level of the channel is reaching its maximum capacity.

18–5. Remote operation of locks

As discussed above, remote operation of locks is used extensively in Europe, Welland Canal, and SLS. These systems have been implemented successfully and are further discussed in the PIANC WG 192 Report. The designer should use the PIANC WG 192 Report for general design guidance on remote control implementation of locks.

a. Traffic management. One major advantage of remote operation is traffic management. Remote control helps to ensure an optimal utilization of the waterway network by all involved parties in the logistic chain. Both inland waterway traffic flows, as railway and road traffic can be organized in a smoother way, with shorter waiting periods. In other words, remote control and automation supports traffic management where different traffic flows are planned, monitored, and handled.

b. Increased availability. By performing operations from a remote location, it is possible to extend the operating hours at a lock site without great additional costs for operators.

c. Optimization of workforce. By controlling and monitoring locks from a central location, it is possible for a single operator or a small group of people to operate multiple infrastructures at the same time. This way, one can increase the operating time with the same or even a reduced workforce and therefore reduce the operational costs. Furthermore, working in a remote-control operation center is an opportunity to work collaboratively.

d. Accounting for failures. Remote operations technology is subject to failure and the designer must account for this. Failures include hardware, software, internet service, sensors, cameras, and other components critical to lock operation process. New protocols must be developed for unexpected failure.

e. Addressing issues. Some other issues to address with remote operation include no local presence at the lock site and safety concerns. There is no local operator to notice abnormal sounds, collisions, engine sounds, etc. Moreover, the absence of a local operator limits the possibility of direct intervention in case of accidents or malfunctions. Not all recreational crafts are equipped with the required communication tools to interact with the remote-control operation center. Locks with extensive recreational traffic may not be suitable for remote operation due to safety concerns.

f. Campaign Plan for Remote Lock Operations National Assessment and Framework. This report states that remote lock operations can enhance resiliency of the IMTS, ensure continuity of operations, and continued movement of cargo and commerce.

(1) Remote lock operation technology can ensure that USACE navigation locks continue to operate during a wide range of emergencies, including localized acts of nature, accidents, pandemics, and technological or attack-related incidents.

(2) Remote lock operations can modernize USACE navigation locks to gain operational efficiencies, improve traffic coordination, and integrate with other data information systems.

(3) Implementation of remote lock operations presents an opportunity to enhance traffic coordination.

g. Command center. In this concept, traffic is coordinated off site by operators for multiple locks. Deliberate communication protocol and information system with other locks. Coordinating traffic across multiple locks can increase efficiency of vessel movement, improve queue management, and reduce delays.

h. Campus control. Traffic is coordinated by on-site operator for each individual lock. No deliberate communication protocol or information sharing system with other locks.

i. Design requirements. Whether operators perform lockages from an on-site control tower (closed campus) or remote off-site command center, they might lose or have limited knowledge of the vessels and its surroundings. Design requirements must include cameras, sensors, two-way communications between vessel and lock operators, traffic coordination features, etc. Other design requirements include possible unassisted mooring and emergency-stop capabilities.

j. Operator responsibilities. The responsibilities of the operators in a remote operation center extend far beyond the responsibilities required for local lock operation. In a remote-control room, new and different tasks are required. These include lock operation, vessel traffic management, dam gate operations, incident response, etc.

18–6. Operating equipment

The discussion here applies to remote operation and remote control of both lock gates and dam gates. Specialized control equipment is required to remotely operate a lock or dam or spillway. This equipment consists of a backbone system with operating software, operating equipment to move the gates, and monitoring equipment to observe gate movement and see what is happening around the gate. All electronic equipment located on structures must be protected by surge/lightning protection devices.

a. Design reference. The designer should use and reference the PIANC WG 192 Report for the design of remote operation control rooms. This report specifically focused on locks and bridges, but the information directly applies to remote control of spillway gates. This includes layout considerations and ergonomics of the control room.

b. Backbone system with operating software. The backbone of a remote-control operating system can consist of either a PLC type system or a node-based digital control system. PLC systems are discussed in Chapter 17. Either technology has the capability to properly control gate operation. This backbone system will control all the other equipment required to remotely control the required gates.

c. Human-machine interface. The operating system must have an HMI allowing easy operation. The HMI must incorporate the complete monitoring system and the gate control equipment. The system must allow a remote restart of all computer equipment in the system. The on-site server must keep a log of all actions made in the system. The system must be password protected and time out/log off according to the cyber risk assessment.

d. Redundancies. The backbone controller must be redundant in nature. Document risks for the communication system and consider single points of failure and common cause failures. Risk mitigations may require physical separation and diversity of redundant communication pathways, for example.

e. Equipment reliability. At a minimum, follow Category B in ISO 13849-1. The equipment used must be proven to be reliable by previous applications. Equipment must have been used in previous applications for a minimum of three years or be verified to be suitable for safety-related applications. Choose a reliability specification commensurate to the identified risks and the desired risk reduction. ANSI B11.26 demonstrates how to apply ISO 13849-1 for this purpose.

f. Tainter gates. Tainter gates are generally raised and lowered by electric motors with large gear reducers. The operator must physically go to the gate control panel on the spillway and turn on the power supply feeder, press the raise or lower button, and then watch the gate position indicator to determine the position of the gate.

(1) *Local/off/remote switch*. To remotely operate a tainter gate safely, the first thing that must be accomplished is to install a keyed Local/Off/Remote control switch on the panel. This switch allows the local user to lock out the remote-control system to ensure that the gate is not remotely operated while maintenance or local operation is being performed. The switch disconnects the remote system in Local, disconnects the local control in Remote, and disconnects all control in Off.

(2) *Power source*. While in the remote control setting, the isolation switch for the power supply feeder must be locked on; do not defeat any automatic protective devices such as circuit breakers. The condition and operating status of each power supply must be monitored using potential transformers, current transformers, or both. At a minimum, this includes discrete annunciation of alarm status and of on-off or open-closed status. For example, monitor the auxiliary contacts of the supply feeder's breaker or use a current-sensing switch.

(3) *Gate control*. There are three buttons to move tainter gates at the local panel: Raise, Lower, and Stop. The raise and lower buttons are connected to a relay that is connected to the motor starter. The Stop button is connected to a normally closed relay connected to the control circuit that opens the circuit when pressed and allows the brake to set. With the remote control system, the gates are moved by the same control circuit except the buttons are paralleled with relays and switched by the Local/Off/Remote switch.

(4) *Gate operation*. The relays that control the gate operation are controlled by the backbone system. The gates are raised and lowered in approximately 6-in. increments with a command from the user for each increment. This method of operation is required because, in the case of a communication or remote system failure, the gate will move only to the next 6 in. increment and then stop. A rotary cam limit switch or programmable limit switch can provide the incremental stop signals. Resolvers or encoders can also be used. See Chapter 17 for more discussion.

g. Roller gates. Roller gates are operated in the same manner as tainter gates.

h. Slide gates. Slide gates are raised and lowered by either electric motors with gear reducers and cables or by hydraulic rams with electric hydraulic pumps. Slide gate hoist equipment can either be inside of a structure or on the deck of an intake tower.

(1) To operate a slide gate, the operator must go to the control panel and use the raise, lower, or stop buttons, like the tainter gate operation.

(2) Operation of electric motor-operated slide gates is very similar to the operation of electric motor-operated tainter gates. In this case, a Local/Off/Remote switch is required as well as a constant, clean, surge-protected power source.

i. Hydraulically operated slide gates. Hydraulically operated slide gates are slightly different than electric motor-operated slide gates. When operating a hydraulically operated slide gate, the raise/lower valve must be in the neutral position, the pump then started, and finally the valve moved to the raise or lower position until the gate reaches the proper position.

(1) Once the gate is in the proper position, the valve must be moved back to the neutral position and the pump stopped. With a remote-control system, the start and stop buttons for the pump must be paralleled with relays, and the valve must be replaced with an electric motor operated valve.

(2) This valve must be controlled not only by the remote-control system, but buttons must also be installed so that the valve can be controlled locally.

j. Low-flow valves. Low-flow valves are valves on conduits passing through a spillway to allow low flows to regulate downstream water quality. Low-flow valves are generally motor-operated butterfly or gate valves. Low-flow valves are generally monitored by percentage open and are controlled with Open, Close, and Stop buttons. To remotely operate a low-flow valve, a Local/Off/Remote keyed switch must be installed. Relays must be installed in parallel with the Open, Close, and Stop buttons.

k. Communication equipment. With a remote-control system, the communication equipment is what keeps the system running together. The use of fiber optic communication is highly recommended in the spillway structure and in the line from the structure to the commercial communication line access point. Radio communication is a less expensive method of communication but in many cases, it is less reliable. The landscape and terrain will influence the type of communication that is used.

l. Monitoring equipment. When operating a spillway remotely, the visual reference of having personnel on site is gone. Due to this, fixed cameras are required. The designer should try to analyze every situation that the on-site operator would need to look at available remotely via CCTV. To allow the best views, two types of cameras are required: pan/tilt/zoom and fixed cameras. The designer should incorporate each as needed.

(1) The minimum camera requirement is that directly upstream and downstream of all the gates can be seen. In a tainter gate situation, it is important to be able to see both sides of the tainter gates to see if debris or drift is collecting near or against the gates.

(2) Along with the CCTV system, an audio system should be in place so that the operator can hear the sounds of the spillway. One very important sound that must be heard is the downstream warning siren. Without the audio system the operator has no way to tell if the siren is functioning properly. The sounds made by the operating equipment is also important and should be monitored by the audio system.

m. Position monitoring equipment. The interlocking requirements of Chapter 17 emphasizes the importance of knowing if a navigation lock gate or valve is completely closed. Dam gates and valves have similar requirements to ensure safe and reliable operation. There are many different technologies that are commonly used to measure position. Mechanically actuated limit switches for example are commonly used in USACE.

(1) Mechanical-actuated limit switches can be prone to failure. To keep these types of switches operating in a reliable way requires significant maintenance to keep the moving parts free from obstruction and to ensure readings are accurate.

(2) Some of the problems associated with mechanical limit switches are overcome by using non-contact type switches. These sensors can be used to measure the full range of movement of a piece of moving equipment (as opposed to discrete positions within the full range of movement provided by limit switches). The advantage is that the position trigger points used by the system to sequentially execute the preprogrammed sequence of operation can be adjusted through the software. There are many technologies that fall into this category. The two common successfully used ones are magnetic-read switch type and proximity type (inductive or capacitive). These types of switches can give many years of reliable operation with a minimum amount of maintenance.

(3) Similarly, desired operating characteristics such as hysteresis and dead bands can be implemented using the control system operating software. Being able to measure the full operating range also provides other benefits. The control system can evaluate operating speed by constantly monitoring the position, which can be used to determine a fault with the equipment (obstruction or damaged equipment). This can be trended and is often used in a predictive maintenance system.

n. Assessing risk. When remotely operating or automatically operating a water control structure, use the following requirements or provide documentation of a “prevention through design” risk assessment process such as described in ANSI B11.26.

(1) To detect closure of a water control structure, use a well-tried (that is, widely used or safety-rated) and environmentally compatible discrete sensor with another brand or type of discrete sensor. For example, use two brands or types of limit switches. Diversity reduces the likelihood of both sensors failing concurrently.

(2) If used, limit switches must be positively driven, meaning the machinery drives the contacts open rather than depending on gravity or an internal spring. Limit switches with multiple contacts must be mechanically linked to ensure logical consistency between contacts.

(3) Install discrete sensors at different locations on the structure or its operating machinery, and route sensor signals in separate conduits to the safety controller.

(4) The safety controller should be non-programmable with automatic or remote reset. Programmable controllers are also acceptable but increase the cybersecurity level of effort. The output of the safety controller must indicate the structure is closed if, and only if, both discrete sensors agree. Provide a keyed selector switch that is hard-

wired to manually bypass the output of the safety controller. Initiate an alarm condition when operating with the bypass active.

(5) If other discrete positions of the water control structure pose a significant hazard, follow the requirements given above.

(6) To detect analog position of a water control structure, use a well-tried (that is, widely used or safety-rated) and environmentally compatible sensor (for example a draw wire encoder, resolver, or inclinometer) with another brand or type of sensor. Do not install draw wire encoders outdoors.

(7) Install analog sensors at different locations on the structure or its operating machinery, and route sensor signals in separate conduits to the controller. The controller must initiate an alarm condition if the position values differ from each other too much.

(8) Include overcurrent and surge protection for all electronic components. Shielded cables for sensor signals must be bonded to a grounding system only at the supply side.

(9) Verify the operating status of each drive motor with a current-sensing switch on at least one phase. Also include a current-sensing switch for each electrically controlled brake. The controller must initiate an alarm condition if the motor or brake operating status does not match the commanded status within a certain amount of time.

18–7. Operating requirements

a. Tainter gates. When a spillway with tainter gates is remote controlled, it is very important for the operator to know the exact position of each tainter gate. Due to the nature of a tainter gate, the position of the gate can be monitored with an inclinometer. An inclinometer is a device that determines the angle from level. When attached to the arm of a tainter gate, it can precisely determine the percentage or the distance the gate is opened.

(1) Inclinometers should be placed on each arm of the tainter gate to allow redundant measurements of the level of the gate and to also ensure that the gate is raised and lowered evenly. This can be useful if the cables are in poor condition or if the gate is binding. A second method of determining the level of the gate is to install a shaft encoder on the mechanical level indicator shaft.

(2) A current meter on the feeder conductors to the operating machinery should be provided. This meter allows the user to monitor the current drawn by the motor and should be programmed so that if an excessive amount of current is being drawn, it will shut down the operation. This will ensure that the motors and control equipment are not damaged.

b. Roller gates. The position and elevation of the roller gates must be monitored by an electronic elevation monitor or by a shaft encoder attached to the mechanical position indicator.

c. Slide gates. Knowing the accurate position of slide gates is required to operate a spillway remotely. To determine the position of a slide gate to an acceptable degree of accuracy, the position should be directly monitored with electronic equipment. If this is not possible, a shaft encoder attached to the mechanical position indicator is acceptable. On hydraulic systems, the spool valve position and hydraulic pressure must be monitored and relayed back to the user.

d. Low-flow valves. Low-flow valve position should be monitored as closely as slide gates and tainter gates. The operator should be able to read the percentage the low-flow valve is open on the remote-control system. A shaft encoder or other suitable measuring device must be placed on the valve to accurately determine the position of the valve.

e. Pool elevation. The operator must be able to see the pool elevation and the downstream elevation of the water with the remote-control system. In most cases, the pool elevation and downstream elevation is already transmitted electronically and can be brought directly into the remote-control system.

18–8. Operating procedures for spillway gates

The remote control system is intended to be operated during normal pool elevations. It should also be operated only by an individual with experience operating gates manually and with proper training using the remote control system. The system can be operated from any computer with the proper access and installed software. The remote control system will normally be operated from either the project office of the spillway, a nearby project office for a remote spillway, the hydroelectric powerplant control room, or the lock and dam control room.

a. Operating tainter gates remotely. To operate tainter gates remotely from a designated PC, the trained user will take all of the precautions an on-site user would take before moving the tainter gates. Before operating the gates remotely, the keyed switch on the gate control panel on the spillway must be set to remote and the power must be locked on. The following steps are required to make gate changes from the remote control station:

(1) Log in to remote control software.

(2) View cameras upstream and downstream to look for people, debris, or possible hazards.

(3) Check current level of tainter gate to be operated by looking at the inclinometer readings.

(4) Sound siren for prescribed amount of time. Listen to speakers to audibly confirm the siren.

(5) View cameras upstream and downstream to look for people, debris, or possible hazards.

(6) Use remote control system to move the tainter gate to the desired height. Some gates stop every 6 in. after started so they must be moved in 6 in. increments.

(7) View cameras upstream to look for people, debris, or possible hazards. View cameras downstream to look for hazards and flows.

(8) Once the gate is at the desired height, the user must move on to the next gate to be moved or log out of the system.

b. Operating roller gates remotely. To operate roller gates remotely from a designated PC, the trained user will take all the precautions an on-site user would take before moving the roller gates. Before operating the gates remotely, the keyed switch on the gate control panel on the spillway must be set to remote and the power must be locked on. The following steps are required to make gate changes from the remote control station:

(1) Log in to remote control software.

(2) View cameras upstream and downstream to look for people, debris, or possible hazards.

(3) Check current elevation of roller gate to be operated by looking at the indicator readings.

(4) Sound siren for prescribed amount of time. Listen to speakers to audibly confirm the siren.

(5) View cameras upstream and downstream to look for people, debris, or possible hazards.

(6) Use remote control system to move the roller gate to the desired height. Some gates stop every 6 in. after started so they must be moved in 6-in. increments.

(7) View cameras upstream to look for people, debris, or possible hazards. View cameras downstream to look for hazards and flows.

(8) Once the gate is at the desired height, the user must move on to the next gate to be moved or log out of the system.

c. Operating slide gates remotely. To operate slide gates remotely from a designated PC, the trained user will take all of the precautions an on-site user would take. Before operating the gates remotely, the keyed switch on the gate control panel on the spillway must be set to remote and the power must be locked on. The following steps are required to make gate changes from the remote control station.

d. Electric motor-operated slide gates.

(1) Log in to remote control software.

(2) View cameras upstream and downstream to look for people, debris, or possible hazards.

(3) Check current level of slide gate to be operated by looking at the level indicator readings.

(4) Sound siren for prescribed amount of time. Listen to speakers to audibly confirm the siren.

(5) View cameras upstream and downstream to look for people, debris, or possible hazards.

(6) Use remote control system to move the slide gate to the desired height. Some gates stop every 6 in. after started so they must be moved in 6-in. increments.

(7) View cameras upstream to look for people, debris, or possible hazards. View cameras downstream to look for hazards and flows.

(8) Once the gate is at the desired height, the user must move on to the next gate to be moved or log out of the system.

e. Hydraulically operated slide gates.

(1) Log in to remote control software.

(2) View cameras upstream and downstream to look for people, debris, or possible hazards.

(3) Check current level of slide gate to be operated by looking at the level indicator readings.

(4) Check position of the hydraulic spool valve. Ensure the valve is in the neutral position.

(5) Sound siren for prescribed amount of time. Listen to speakers to audibly confirm the siren.

(6) View cameras upstream and downstream to look for people, debris, or possible hazards.

(7) Start the hydraulic pump.

(8) Use remote control system to open the spool valve to move the gate to the desired height. Some gates stop every 6 in. after started so they must be moved in 6-in. increments.

(9) View cameras upstream to look for people, debris, or possible hazards. View cameras downstream to look for hazards and flows.

(10) Ensure the spool valve is in the neutral position after movements are made.

(11) Stop the hydraulic pump.

(12) Once the gate is at the desired height, the user must move on to the next gate to be moved or log out of the system.

f. Operating low-flow valves remotely. Operating low-flow valves remotely is similar to operating other gates remotely. The steps to be taken when opening low-flow valves remotely are as follows:

(1) Log in to remote control software.

(2) View cameras upstream and downstream to look for people, debris, or possible hazards.

(3) Check current percentage open of the low-flow valve to be operated by looking at the level indicator readings.

(4) Sound siren for prescribed amount of time. Listen to speakers to audibly confirm the siren.

(5) View cameras upstream and downstream to look for people, debris, or possible hazards.

(6) Use remote control system to move the low-flow valve to the desired percentage open.

(7) View cameras upstream to look for people, debris, or possible hazards. View cameras downstream to look for hazards and flows.

(8) Once the gate is at the desired opening, the user must move on to the next gate or valve to be moved or log out of the system.

18–9. Ice and debris flushing procedures

Spillways with tainter gates occasionally have issues with debris or ice buildup against the gates. The standard procedure to flush drift or ice from a tainter gate spillway is to evaluate the location of the tainter gates, close the gates that are away from the drift or ice buildup, and then fully open the gate or gates near the drift.

a. Once the debris is gone, the gates are all set back to the positions they were in prior to the flushing activity. It is important to keep the gates clear of ice or debris buildup because the ice or debris can affect the operation of the gates by jamming in the gate and not allowing it to fully close.

b. With the remote control system, it is important to be able to see the face and water level of each of the tainter gates on a spillway to determine if there is ice or debris buildup and to know when ice is flushed out.

18–10. Maintenance

a. Operating machinery and structures must be routinely inspected and maintained. If all the personnel are removed from the project site, a schedule of weekly site visits and inspections must be established and performed.

b. All electrical and mechanical systems require maintenance. The designer should reference Chapter 27 of this manual. The spillway remote control system is no different. The maintenance can either be completed by a service contract or by qualified in house personnel. Required maintenance is categorized as “as-needed maintenance” and “biannual preventative maintenance.”

c. The as-needed maintenance includes:

(1) Cleaning the camera housings and lenses.

(2) System reboots.

(3) Repair, if and when failures of equipment occur.

(4) Calibrating the sensors.

d. The biannual preventative maintenance includes:

(1) Visually inspect all remote equipment. This includes cameras, housings, sensors, servers, exposed communication lines, and conduits.

(2) Clean all components of the system. Clean camera housings.

(3) Provide and install any software upgrades that are necessary.

(4) Provide and install any hardware upgrades that are necessary.

(5) Test each component of the system by following the standard operating procedures.

(6) Repair or replace any damaged, worn, or failed equipment.

(7) File a written report stating every action taken. The system should have some commissioning done to ensure proper operation after hardware and software changes.

e. All electronic equipment has a useable lifespan. The maintenance and upgrades include replacing any failed equipment, monitoring equipment to find possible failures before they occur, and upgrading any equipment that is obsolete or worn.

18–11. Cyber Security

Cybersecurity is a critical component of remote operation and remote control. The designer should reference Chapter 19 of this manual and ECB 2022-2, ECB 2021-4, ECB 2020-10, and UFC 4-010-06. For CW projects, the Critical Infrastructure Cybersecurity Center or UCIC based in Little Rock District must be engaged.

Chapter 19
Cybersecurity and Communication Systems

19–1. General

One advantage of using a PLC system to operate and manage lock and dam equipment is the ability to provide remote monitoring and/or operation of the facility using Ethernet or other communication technology.

a. Remote does not necessarily refer to monitoring from a physically separate or disconnected site. It may refer to an adjacent control building, powerhouse control room, or administration building on the USACE project.

b. When using communication or information technology (IT), a cyberattack could damage equipment and harm infrastructure or the public. The risk must be assessed and, if too high, it must be mitigated to an acceptable level.

c. Mitigation may require additional technologies or changes to the system architecture, increasing the design or construction costs if performed too late in the life cycle. Cybersecurity of any system should be addressed early in the design process.

19–2. Publications

The concept and requirements of information assurance have evolved through several processes through the years. The documents below all relate to cybersecurity requirements for CW projects.

a. ER 25-1-113.

b. ECB 2022-2.

c. Department of Defense Instruction (DoDI) 8500.01 (2014).

d. Army Regulation 25-2.

e. DoDI 8510.01.

f. National Institute of Standards and Technology (NIST) Special Publication (SP) 800-37 Revision. 1.

g. NIST SP 800-37 Revision. 2.

h. NIST SP 800-53 Revision. 5.

i. NIST SP 800-60 Volume II Revision 1.

j. UFC 4-010-06.

19–3. Centers of expertise

When it relates to cybersecurity, USACE has established two CXs. While the CXs work with Headquarters to establish, refine, and enforce USACE cybersecurity policy, they are available as a resource.

a. Control Systems Cybersecurity Mandatory Center of Expertise. The Control System Cybersecurity MCX is in the Engineering and Support Center in Huntsville. The MCX leverages industrial control system (ICS) cybersecurity technical expertise from across USACE to ensure USACE delivers cyber-secure facilities to its military customers. Its focus is on facility-related control systems (FRCS) for military installations.

b. Critical Infrastructure Cybersecurity Mandatory Center of Expertise. The USACE UCIC-MCX was established in the Little Rock District to secure CW structures.

(1) These include hydropower plants, locks, and dams. The UCIC-MCX is led by the National Information Assurance Manager. The UCIC-MCX must “ensure all CW are logically and physically secure” and “ensure all CW control systems are assessed and authorized as described in current DoD and DA regulations.”

(2) The CX must be contacted when designing new CW control systems and prior to engaging any other outside entities regarding cybersecurity. The requirements for the UCIC-MCX and how operational technology (OT) is secured are defined in ER 25-1-113.

(3) *Regional Information System Security Manager*. The UCIC has appointed a Regional Information System Security Manager (ISSM-R) for each USACE Division. They are the primary point of contact to the MCX when beginning a new project.

(4) *Information System Security Officer*. During operation of the OT system, an Information System Security Officer (ISSO) will be appointed by the district. The district may have multiple ISSOs or a single individual appointed for the district. The designer should engage with the ISSO during the design process to ensure a successful system authorization in the future.

19–4. Cybersecurity

a. General. The designer must comply with the requirements of ECB 2022-2. This ECB provides direction and guidance for the mandate to use UFC 4-010-06 and UFGS 25 05 11 for all control systems designed or constructed by USACE, including those for USACE CW.

b. Risk Management Framework for DoD. For DoD, a key component of the cybersecurity program is the use of the Risk Management Framework (RMF) as required by DoDI 8510.01. The goal of the RMF is to authorize a system to operate after a system has been assessed and its risk evaluated and mitigated, if necessary. It is often assumed that control systems that are not connected to a network or the internet do not require RMF authorization. This is incorrect as all USACE-operated and maintained control systems must be authorized using RMF. The UCIC-MCX must be consulted as they have the responsibility to ensure the system is secure and can help navigate the RMF process.

c. Risk Management Framework.

(1) The RMF outlined in NIST SP 800-37 Rev. 2 provides a disciplined and structured process that combines information system security and risk management activities into the system development life cycle and authorizes their use within DoD.

(2) The RMF changes the traditional focus of certification and accreditation as a static, procedural activity to a more dynamic approach that provides the capability to manage information system-related security risks more effectively in diverse environments of complex and sophisticated cyber threats and ever-increasing system vulnerabilities. The seven-step process includes:

(a) Prepare to execute the RMF from an organization-level (and a system-level) perspective by establishing context and priorities for managing security and privacy risk.

(b) Categorize the information system and the information processed, stored, and transmitted by that system based on an impact analysis.

(c) Select an initial set of baseline security controls for the information system based on the security categorization; tailoring and supplementing the security control baseline as needed based on an organizational assessment of risk and local conditions.

(d) Implement the security controls and describe how the controls are employed within the information system and its environment of operation.

(e) Assess the security controls using appropriate assessment procedures to determine the extent to which the controls are implemented correctly, operating as intended, and producing the desired outcome with respect to meeting the security requirements for the system.

(f) Authorize information system operation based on a determination of the risk to organizational operations and assets, individuals, other organizations, and the nation resulting from the operation of the information system and the decision that this risk is acceptable.

d. Consistent monitoring. Monitor the security controls in the information system on an ongoing basis including assessing control effectiveness, documenting changes to the system or its environment of operation, conducting security impact analyses of the associated changes, and reporting the security state of the system to designated organizational officials.

Note. This document discusses the steps of the RMF process, as the control system's functional requirements and design will affect the outcome of these steps.

e. RMF Step 1: Prepare. Owners must identify personnel capable of executing the RMF. Personnel must have the necessary certifications for their roles.

f. RMF Step 2: Categorize. The architecture complexity of the control system will dictate some of the requirements of the RMF process.

(1) *Impact levels*. As part of categorizing a system, an impact level (low, moderate, or high) is identified for the security objectives of Confidentiality, Integrity, and Availability.

(2) Confidentiality is preserving authorized restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information (44 United States Code [USC] § 3542).

(3) Integrity is guarding against improper information modification or destruction and includes ensuring information non-repudiation and authenticity (44 USC § 3542).

(4) Availability is ensuring timely and reliable access to and use of information (44 USC § 3542).

g. Impact analysis. The results of the impact analysis help tailor the security controls to be implemented in the system. For CW FRM projects, the UCIC-MCX has identified initial provisional impact levels of low-moderate-moderate for confidentiality, integrity, and availability, respectively. The impact levels may be adjusted higher or lower based on the requirements or risks of the system. The UCIC-MCX must be consulted to determine the impact levels for a particular system and develop a baseline for approval.

h. Operational technology. The UCIC-MCX studied the OT systems (defined as platform information technology [PIT] in DoDI 8500.01). The MCX defined four main architecture types. The MCX must confirm the architecture type.

(1) *Operational technology product*. An OT product (formerly PIT product) is a small ICS consisting of a single PLC and an operator interface. The operator interface is using an embedded operating system, but only serial communications are used.

(2) *Operational technology subsystem*. The OT subsystem (formerly PIT subsystem) is comprised of one or more PLCs and a PC-based HMI. Devices are interconnected using an Ethernet network, a routable protocol. The system cannot provide remote access and it cannot include a routable connection to any external networks (outside the physical boundary).

(3) *Operational technology system closed restricted*. An OT closed, restricted system is a subsystem that is networked to another government-owned system within an identified boundary under the control of a single authority and security policy. The systems may be structured by physical proximity or by function, independent of location. A system is using encrypted virtual private network tunnels between sites to another

government-owned or operated subsystem. The system cannot include any routable connections outside the authorization boundary.

(4) *Operational technology system restricted interconnected*. An OT restricted, interconnected system, formerly known as a PIT system restricted interconnected, is an OT subsystem or an OT system that has interconnection capabilities with any external network. This interconnection is typically used for the transfer of data from one system to another government-owned, government-operated control system.

(5) *Scope limitations*. It is important to note that the architecture type is called “restricted interconnected” because the networking infrastructure is extremely limited in scope. Most frequently, these interconnections are meant for a single-directional data push and cannot reach out to the DoD information network.

i. RMF Step 3: Security controls. From the RMF Knowledge Service (https://rmfks.osd.mil), security controls are the safeguards/countermeasures prescribed for information systems or organizations that are designed to protect the confidentiality, integrity, and availability of information that is processed, stored, and transmitted by those systems/organizations and satisfy a set of defined security requirements.

(1) Security controls serve as a common management language for establishing cybersecurity needs. The security controls establish a common dialogue among information owners, PMs, outsourced service providers, enclave managers, assessing and authorizing authorities, and information system security engineers.

(2) They aid in the negotiation and allocation of cybersecurity requirements and capabilities, enable traceability to specific cybersecurity solutions, and provide a consistent reference for certification activities and findings.

(3) The NIST SP 800-53 set of security controls is organized into 18 subject families, indicating the major subject or focus areas to which an individual security control is assigned. The areas range from access control, contingency planning, and personnel security. NIST SP 800-53 identifies all the security control families.

j. RMF Step 4: Customization. The set of security controls to be evaluated for a control system is defined by the impact levels assigned to confidentiality, integrity, and availability during the categorization process. These impact levels and security controls can also be augmented or modified based on the functional requirements or risks inherent in the control system. The UCIC-MCX must be used to identify the security controls for the system.

k. RMF Steps 5 and 6: Assess and authorize. As step 5 of RMF process suggests, the security configuration of a control system must be assessed. In RMF, a Security Control Assessor (SCA) performs this assessment.

(1) The SCA analyzes the system and generates a report of their findings to be used by an Authorizing Official. The Authorizing Official must evaluate the risks to the

control system and its vulnerabilities and determine whether it can be authorized to operate.

(2) An Authorization to Operate is valid for three years, at which time the system must be reassessed and reauthorized. The UCIC has identified three types of assessments: Assess Only, Organizational Assess and Authorize, and Army Assess and Authorize. The UCIC-MCX will determine which assessment is required based on the system architecture, but other factors may affect their decision.

l. Assess only. For the smaller control system applications that can be classified as an OT product, an assessment of the system can be performed by the UCIC-MCX and will not require authorization. This will greatly reduce the cost of the RMF and cybersecurity process. An example is a sump pump system of two pumps controlled by a PLC. The PLC is wired only to pushbutton inputs to operate the pumps.

m. Organizational assess and authorize. All OT systems and some OT subsystems will require an assessment and authorization.

(1) The assessment must be performed by an SCA, but they can be part of the organization (USACE). The approval chain for the assessment remains in USACE. This type of an assessor is an SCA-O and is completed by the UCIC-MCX, as they are the organizational representative.

(2) Most of the UCIC-MCX activities as part of this process are funded by Headquarters, reducing the cost to the district for RMF. If the UCIC-MCX is engaged in implementing the security controls (RMF Step 4), their costs must be charged to the project. Due to complexities in the system, the UCIC may still require a third-party assessor.

n. Army assess and authorize. The Army must assess the larger, more complex OT systems.

(1) This assessor is a Security Control Assessor-Validator (SCA-V) and is typically an independent third party from the system and the owner’s organization. The Information Security Engineering Command and USACE’s ERDC – Information Technology Lab can provide the SCA-V capabilities.

(2) The use of an SCA-V may come at a significant cost to the project, as they must prepare for an assessment, make a site visit to inspect and assess the system, and develop documentation of their findings. Costs may range from $30k to $60k for an assessment that must be completed every three years. The approval chain for the assessment is also at the higher Army level.

o. RMF Step 7: Life cycle. As the seventh step of the RMF process suggests, RMF is a continuous process. System Owners must constantly monitor their systems and determine the impact of changes to the system and the environment. Documentation and annual reviews must be updated accordingly.

19–5. Remote monitoring and operation

The designer should reference Chapter 18 of this manual for more detailed discussion. The term “remote” refers to monitoring or controlling the lock or dam equipment physically separate from their immediate locations. Requirements for remote operation of spillways and other water release structures must follow the requirements in ER 1110-2-1156 (Chapter 20). Remote operation could be from a control building at a navigation lock, a powerhouse control room, or an operation center located miles away. Cybersecurity is a critical consideration for any remote operation.

19–6. Connectivity

Connectivity between the lock and dam equipment and the remote operation facility is necessary to implement remote monitoring or operation. The following technologies may be utilized in the system. Wireless networks should conform to IEEE 802.11ax.

a. Radio. Spread-spectrum radios can be used to provide connectivity between a remotely operated dam and a nearby facility. The technology often requires line-of-sight transmission and is used for shorter distances. Manufacturers should be consulted when considering a radio connection, as they can provide test equipment to evaluate its feasibility. Wireless transmissions must be encrypted using DoD-approved cryptography.

b. Fiber optic cable. Single-mode and multi-mode fiber optic cabling may be used to establish an Ethernet connection between locations. Industrial Ethernet switches with fiber optic ports should be managed switches to meet cybersecurity requirements. Defense Information Systems Agency maintains an approved products list (APL) at https://aplits.disa.mil. Industrial switches on the APL are limited, but approved products should be used when feasible.

c. Leased line. For locations without existing connectivity, a dedicated connection can be leased for a monthly cost. The costs are based on the physical distance between the locations and the bandwidth or speed required. T1 circuits typically provide a transmission of 1.544 Mbps and may be adequate for HMI data, but the use of video may require additional bandwidth. T3 and T4 lines may also be available for lease in some locations across the country.

d. Microwave. A microwave radio link can be more cost effective than leased lines and trenched fiber optic cable. It avoids the trenching and installation costs of fiber optic cable and the monthly recurring costs of leased lines. The microwave link can also prove more reliable than land-based technologies. The microwave link can be established faster than a cable connection, but transmission or “link” distances may be limited. Licensed and unlicensed bands are available between 2 and 42GHz. The microwave link must be properly designed to ensure topographic and atmospheric conditions do not interfere with the propagation of the radio signal.

e. Corporate network. Most USACE facilities have a connection to the corporate network, CorpsNet. While a designer might be able to leverage existing bandwidth, Army Corps of Engineers Information Technology requires a “SCADA Security Stack” between any ICS and CorpsNet. The security stack will be configured and managed by the USACE Information Technology contractor (currently known as CIO-G6), but it could have a significant first cost and its maintenance and upkeep must be considered in the system life cycle. CorpsNet should be used only as a last resort and must be coordinated with the UCIC.

Chapter 20
Electrical Support Systems

20–1. Support systems

This chapter addresses the electrical ancillary features of a navigation lock and dam. These include, but are not limited to, raceway systems, lighting, traffic signals, video systems, security systems, communication systems, and life safety systems. Detailed consideration of these systems in the early stages of the design can add to the successful operation of the facility.

a. It is recommended that the design engineer consult operations personnel regarding this ancillary equipment, especially locations of video cameras and monitors, communications systems, and the life safety systems.

b. It also is recommended that the design engineer work with the District Security Officer when planning the security system.

20–2. Types of raceway systems

a. Design of appropriate and sufficient raceway systems for lock and dam gate operating and control systems can facilitate control system installation and maintenance. Raceway materials include galvanized steel, rigid metal conduit (RMC), and polyvinyl chloride (PVC). Other materials include electric metallic tube (EMT) in interior, environmentally controlled areas, liquid-tight metal and non-metal conduits, stainless steel enclosures, cable tray, and other special raceway configurations that might be required by the equipment. Designer attention should be given to changes through the life of the plant. Generally, it is better to provide many relatively smaller conduits than a few large ones. Fewer, smaller conduits will facilitate replacement of cables/wiring, should it be needed during the life of the project.

b. Raceway size is primarily based on the volume of the cable(s) installed. However, in the case of conduit, it might be desirable to size the conduit to allow the installer to pull through connectors that can be attached to the equipment, in lieu of requiring tedious, final connections in the field.

c. The raceway system should be designed with utilization voltage levels in mind. For instance, all cables in a raceway must be insulated to the highest voltage level in the raceway (unless barriers, such as in cable trays, are used). In addition, it is desirable to separate low-voltage control wiring from instrumentation-type cables (4-20mA DC, RS232, RS485, RS422, etc.) to minimize noise on the communication lines. Raceway minimum size requirements can be found in NFPA 70. See Table 20–1.

Table 20–1
Recommended separation for copper communication cables from sources of electromagnetic interference exceeding 5 kVA in raceways

	Communication Lines in Metal Pathways	Communication Lines in Non-Metal Pathways
Unshielded Power Lines or Electrical Equipment in Metal Pathways	6 in.	12 in.
Unshielded Power Lines or Electrical Equipment in Non-Metal Pathways	12 in.	24 in.

20–3. Lock and dam lighting

a. Many types of lighting are provided for a navigation lock including building interior lighting, security lighting for parking lots and esplanades, roadway entrance lighting, and lock and dam lighting. Since the Illumination Engineering Society (IES) addresses building lighting, only lock and dam lighting is addressed in this manual including IES RP8. The UFGS 26 56 00 also specifies exterior lighting systems.

b. Lock lighting can be accomplished with either high-mast (HMST) poles (50 to 100 ft) or standard poles (typically 30 ft). Normally, the length and width of the lock chamber(s) will determine the best choice of fixture height. However, other factors such as boat height, maintainability, light trespass requirements, and architectural/aesthetic preferences should be considered when selecting fixture heights. Consult the customer at the beginning of the design phase. Additional lighting requirements on a lock include mooring bitt recesses, and navigation guard and traffic control lights. Regardless of which type is used, it is suggested that the poles be installed in a straight line, especially on approach walls, as this helps tow operators line up with the approach wall and is aesthetically more pleasing.

c. HMST lighting is typically employed where a large area of lighting is required. The use of HMST lighting reduces the need for many standard poles and provides better uniform lighting intensity. In the past, HMST lighting was usually provided with one of two types of high-intensity discharge (HID) lighting fixtures: high-pressure sodium (HPS) or metal halide (MH).

d. However, a sustainability and standardization study (INDC TR 2018-02) has determined that LED lighting fixtures provide equal or better lighting characteristics with high energy savings and lower usage costs over the component's life cycle at locks and dams (see https://www.wbdg.org/ffc/army-coe/technical-reports-tr/indc-tr-2018-02). New installations, retrofit, or replacements should apply LED lighting fixtures as applicable.

e. Computer programs that make the lighting design fast and economical are available. Often, the light fixture manufacturer is willing to provide a lighting layout based on input from the customer and may provide the software necessary to perform the lighting model. To provide an accurate design of exterior lighting for new or retrofit applications, designers should use an exterior lighting system modeling software to provide the point-by-point illumination. The software can also help the designer identify the necessary accessories (such as shields) to limit light trespass and the optics distribution classification.

f. HMST lighting poles are usually sectional, from 50 to 100 ft tall, galvanized, and provided with a luminaire ring that can be lowered to within 5 ft of the base of the pole for easy maintenance of the luminaires. The luminaire ring is lowered with a portable, heavy-duty drill that connects to an input shaft of a gearbox that is located inside the pole. The design of the pole, anchorage, and foundation must account for the equipment mounted on the pole and the wind conditions that will be experienced in geographical area of the project. If HMST poles are to be used in the project lighting, it is highly recommended that the engineer coordinate with the lock wall designers to ensure the walls allow the poles to be mounted as close as possible to the design location.

g. Lock lighting also can be accomplished using standard poles. The standard pole is typically 20 to 35 ft tall. Depending on the size of the lock, this approach might require more poles to be used, compared to lighting using HMST poles. In addition, compared to using HMST poles, lighting uniformity is typically not as high with standard poles.

h. Standard poles are typically used to illuminate the approach walls of a navigation lock, to fill in areas not illuminated by the HMST lighting, and for projects where the use of HMST lighting is not desirable (not cost effective, light trespass in residential areas, etc.).

(1) Poles are mostly galvanized, round, steel but might be aluminum, square, and sometimes concrete. If possible, hinge the standard poles for ease of maintenance of fixtures or other equipment installed on the pole. They may be either hinged at the base or at some point in the middle third of the pole.

(2) If access to the pole is limited, which is usually the case on an approach wall, a base hinge point is not desirable. There are lowering devices the designer may consider for fixtures when access is limited. When using a hinged pole, the designer should specify the orientation of the pole on the drawings to ensure the installed pole will hinge in the direction desired.

i. The lock and dam exterior lighting study performed by the INDC recommends a 5-foot-candle (fc) average illumination along the top of lock walls with a maximum to minimum (Max:Min) ratio of 5:1. The recommendation for the lowest tailwater illumination is 2 fc with a Max:Min ratio of 5:1. The lighting intensity requirements vary to some degree from district to district, even project to project. Some projects are illuminated to the same intensity all the time. Some projects illuminate to a security level (lower intensity level) when not locking, and switch on additional lighting (higher intensity level) during the lockage.

j. The designer should consider lighting intensities at other locks in the district when deciding what level will be used, to ensure uniformity throughout the district. This is important because it gives a tow operator uniformity from project to project, lowering the chance of an accident caused by sufficiently different lighting.

k. The following suggestions are for areas bounded by the lock miter gates and the outside walls of the lock chambers; all intensities are average maintained foot-candle values. It is suggested that top-of-wall lighting levels be designed for approximately 2.0 fc, average maintained; and that a lock chamber at lower pool be designed for approximately 1.25 fc, average maintained, with uniformity of at least 70 to 80%. When a lockage is not being made, the low-level (or security) lighting intensity may be chosen. It is suggested that low-level mode lighting intensities for areas outside the lock chamber be designed for 0.5 to 1.0 fc. This can be accomplished with fewer energized fixtures on the HMST poles, or fewer energized standard pole fixtures.

l. Lower values of lighting uniformity will result when using the standard poles but might not be important during low-level or security mode. Lighting fixture types used for lock lighting are HPS (yellowish, more foot-candles per watt than MH); MH (better color rendition, whiter light, fewer foot-candles per watt than HPS); and LED (better color rendition, whiter light, and greater foot-candles per watt than both MH and HPS).

m. Luminaires on HMST poles are usually like Holophane, refractor-type HMST type. Luminaires on standard poles are usually the cobra-head type with wide distribution. With lock lifts greater than 30 ft, the designer might want to consider using floodlight-type fixtures with a narrower distribution than the HMST-type fixtures. In that case, additional poles/fixtures might be needed for lighting on top of the lock wall. For extreme high-lift locks, such as the Wilson Lock with an approximate 93-ft lift, findings have shown that HPS light fixtures may distribute lighting further than LED fixtures and should be analyzed to determine the best lighting technology for the application.

20–4. Traffic signals

Traffic signals are required, as applicable by 33 CFR Part 207, at navigation projects to communicate to the tow operator that the lock is ready to enter. The traffic signal lights are provided on the land wall of the landward lock and middle wall of the riverward lock, just upstream of the upper miter gates. Mounting height of the signal lights is 10 to 15 ft and might vary, depending on the tows entering the lock.

a. The navigation lights typically are provided in a street traffic light configuration, with red conveying that tow should not enter the chamber and an amber-green combination allowing the tow to enter the chamber with caution.

b. The traffic signal lights must flash in a duty cycle as specified in the 33 CFR Part 207 and the applicable U.S. Coast Guard regulations. Mechanically driven flashers have traditionally been used to generate the flash duty cycle, but these are slowly giving way to PLC logic and discrete, solid-state timers to provide the timing.

20–5. Navigation and spillway signals

The lock and dam should be marked according to Coast Guard requirements or with those of the entity responsible for defining the marking requirements of the project.

a. The designer should refer to 33 CFR Part 207 for USACE regulations.

b. Locks are typically marked with a single red light on each end of the land guide wall, three green lights on the upstream end of the river wall or intermediate wall, whichever extends further upstream, and two green lights on the downstream end of the river wall or intermediate wall, whichever extends further downstream.

c. The specific configuration of the lock and dam structure might necessitate a modified marking scheme, as determined by the correct sections within the 33 CFR Part 207, Coast Guard, or other appropriate entity. The dam should be illuminated with walk and security lighting across the bridge. Each pier should be provided with floodlight fixtures to illuminate at least the upstream portion of the gate bay.

20–6. Video systems

a. General. Video systems (formally CCTV) provide multiple functions in a lock and dam control system. A video system provides greater visibility of lock activities and can allow the operation of multiple locks from a single control room.

(1) Configure the video system with products that comply with the Open Network Video Interface Forum (ONVIF) standard to provide standard interfaces and interoperability of IP-based products. The design of video system components must deliver systems that comply with Federal Acquisition Regulation 52.204-25 Prohibition on Contracting for Certain Telecommunications and Video Surveillance Services or Equipment.

(2) Network video recorders (NVRs) store video system information. This information can be used for training purposes, forensic evidence in accident investigations, and other functions. With the appropriate cameras in place, the system can inform the lock operator of fisherman or other boats near discharges, dam spillways, or other hazardous areas. Video cameras also can be placed to provide additional security assessment for entrance gates, storage areas, and visitor access areas.

b. System purpose.

(1) Every lock and dam facility will place different requirements on the video system. The system designer must identify the requirements and determine all the roles of the video system to provide a suitable design. The risk level as given by the Security Officer against requirements by Army Regulation (AR) 190-51 must be reviewed. To begin the design, ask:

(a) Will the system be used to provide better visibility for operators in control rooms at both ends of the lock?

(b) Is the system supposed to provide a means of operating a single lock or multiple locks from only one central control room?

(c) Do the lock operators need to watch the dam or spillway gates?

(d) Does the system provide security assessment for the facility?

(e) Will remote monitoring or control be a possibility?

(2) Answers to these questions can help identify where video monitors and cameras are needed. Refer to UFC 4-021-02 for detailed application guidelines. Consideration for adding operator safety and efficiency into the process must be included.

c. Views. This list is not exhaustive of views that might be designed into the operator monitor(s) for locking:

(1) Behind the gates to verify they are clear of debris and vessels.

(2) Miter blocks for miter gates to ensure that the gates are fully closed.

(3) Tie off mooring bits to verify vessels are secured in locks.

(4) Approaches with vessel views.

(5) Discharge and other areas of turbulence to understand they are clear of vessels.

(6) Damming surfaces intake and discharge areas.

(7) Access gates with views sufficient for overnight, as the operators may be the only staff.

d. Integration. The PLC/SCADA system can be designed in parallel with the viewing system to augment the operator’s viewing and reduce the number of glass panels required for operation. This should be done at a low-level using relay outputs from the PLC and interrogation of those by the camera system to automate views. This will keep the accreditation boundary of these two systems separate and in compliance with requirements (site).

20–7. Lock control room video system

For surveillance of the project during operation, control rooms equipped with monitoring stations will be required. See Figure 20–1. On facilities requiring a complete video system, lock operations will be conducted from a single control room. However, even on these facilities, there might be other viewing station control locations, as described herein.

Figure 20–1. Lock control room

a. Single lock, multiple operators. In this method of lock operation, a control room usually is positioned at each end of the lock. Each control room should be equipped with a video client. A video server is the NVR and software to support the system. A video client is a PC configured to access the video files on the NVR. The video clients can have multiple monitors, and these monitors can be split into four or more views to provide a look at each side of the lock gates, an upstream (or downstream) view of the lock approach, and a general view of the lock. Views can be added as required by the facility for viewing the security cameras, coverage of the dam, discharges, etc. The views should be selected to support the operator in achieving mission outcomes.

b. Single lock, centrally operated. A central control room should be equipped with at least six views: each side of the gates, upstream and downstream, the upstream and downstream approaches. Views can be added as required by the facility for viewing the security cameras, coverage of the dam, discharges, etc.

c. Multiple locks, centrally operated. A central control room should be equipped with at least one video client, with a monitor split into multiple views, for the operation of each lock. Most central control rooms have separate control consoles for each lock. Placing a video system monitor at each console reduces operator movement between the consoles.

(1) There may be room for multiple monitors. These can be located above the viewshed so as not to impede the operator's view of the surroundings if desktop space

is at a premium. Placing more than one monitor has advantages of having a larger or call-up view in addition to other needed views.

(2) The call-up view may be a good candidate for automation with the PLC/SCADA system. The six views per lock provide a view of each side of the gates, upstream and downstream, and the upstream and downstream approaches. Views, and monitors, if necessary, should be added as required by the facility for viewing the security cameras, coverage of the dam, discharges, etc.

d. Lockmaster office. The lockmaster might require a video client in their office. This provides a means to monitor the lock activities at the site. The ability to control PTZ including pan, tilt, and zoom cameras can be accomplished via this client if not restricted by programming. An alternative might be to remote the views from the control room to the Lockmaster Office by sending video signals over copper and fiber using HDBaseT to convert high-definition multimedia interface (HDMI) signals to deliver them in full uncompressed quality such 4K, 18GB/S data.

e. Visitor center. A visitor center could be equipped with one or more glass panels to afford visitors views that are designated appropriate. These views should be vetted and provided via HDBaseT. There should not be a client located in the visitor center connected to the video system that could possibly be accessed by the general public.

f. Lock electrician office. Consideration for providing a separate video client for the lock electrician should be evaluated so they can troubleshoot system problems or test the cameras without disturbing operations in the main control room. This workstation can serve as a redundant machine that can be quickly repositioned into the control room if a workstation goes down, adding to the business continuity plan. This workstation can be used in a pseudo-sandbox to provision cameras with network addresses and test that they are live on arrival before they are deployed into the production environment.

g. Remote operations. Remote operations require camera views described for multiple locks and centrally operated described above. In addition, the camera views need to provide the views the local operator would receive from looking out the window.

20–8. Camera requirements

The views described above require the appropriate camera to obtain the scene with the necessary fidelity to promote decision-making. UFC 4-021-02 will guide the designer in the selection of cameras and lenses.

a. Security views. In addition to the operational views described herein, the following should be considered by the designer for security cameras:

(1) Entrances to the lock and dam.

(2) High-value assets.

(3) Gates on land-side approaches.

(4) Controlled portals.

(5) Approaches to operator locations for visibility in dark hours.

(6) Views of promenades to facilitate safety surveillance of maintenance personnel.

(7) Machine-house doors when an intrusion detection system (IDS) is installed, or when visibility is limited.

b. Network cameras. Network IP camera sales surpassed traditional analog cameras sales before 2014 and account for most new cameras purchased in the United States.[1] Since they use Ethernet, the designer can use the same design principles as for other forms of OT in design. Copper distances are limited to 100 meters with standard solutions. A hybrid fiber optic cable with 57VDC centralized power can power fixed cameras at distances that exceed the allowable link length of 1,800 ft for OM3 multimode fiber (Table 20–2). For PTZ cameras, the designer is cautioned to calculate the voltage loss by lengths. Centralized DC allows the designer to centralize UPS/batteries and not have separate raceways with AC power and DC conversion at the utilization appliance.

Table 20–2
Composite cable distances

Example Composite Cable Distances (1 Pair)

	30 Watts	**60 Watts**	**75 Watts**
20 AWG	590 ft	295 ft	235 ft
18 AWG	940 ft	470 ft	375 ft
16 AWG	1,500 ft	750 ft	600 ft
14 AWG	>2,000 ft	1,190 ft	950 ft
12 AWG	>2,000 ft	1,895 ft	1,500 ft

c. Pan, tilt, and zoom. The designer should use fixed cameras for all known views. A PTZ camera can focus on nearly limitless objects besides the desired view, increasing the probability that an event can occur without being observed by the PTZ. The designer can improve this probability with integration into the PLC/SCADA and access control system (ACS) to position and focus the PTZ when events occur. Sound design is to specify fixed cameras for necessary views and PTZ for ancillary and patrol functions. The ability to follow an object (including watercraft) may require a PTZ.

d. Panoramic. Panoramic cameras provide the designer wide-area coverage with just one camera. They can monitor activities and detect incidents in large areas and track the flow of people, vehicles, or vessels. Specifying one camera in place of several

[1] Statista 2022 “Analogue and IP camera market size worldwide from 2011 to 2017”

reduces the installation cost and complexity. These cameras can be specified with 180° or 360° of view. The prices are between fixed cameras and PTZ cameras. These units will not have optical zoom, so resolution will need to be considered to provide the needed pixels in the range to use digital zoom.

e. Edge storage. Many network cameras can store video at the edge, meaning on the appliance. These cameras may have software options available at the edge for additional features. The ability to store video at the edge gives the system some capacity for an interruption of Ethernet link to the system without the system permanently losing the data. When the link that is interrupted is power over Ethernet (PoE), the link furnishing power to the camera is defeated.

f. Resolution. Traditional analog National Television Standards Committee signal and phase alternating line standard of 720 x 480 pixels has a resolution of .4 megapixels (MP). Network cameras can be specified 1 megapixel through 33 megapixel for an 8K camera. Typical resolutions are 2 MP, 5 MP, and 8 MP for a 4K camera. UFC 4-021-02 will guide the designer through the proper selection of the minimum resolution. Resolution beyond what is needed adds to expense for equipment and added storage space.

g. Environment. CW projects have notoriously harsh environments with high humidity and temperature variations. The designer should consider the need for heaters and the associated power penalties along with other elements, including pressurization with inert gas such as nitrogen. The additional maintenance associated with these items should be considered in the life cycle cost analysis.

h. Camera mounting. Manufacturers providing equipment to wall-mount, corner-mount, parapet-mount, and pole-mount camera equipment should be consulted. The designer must ensure that the hole pattern in the mounting equipment is compatible with the camera housing chosen. In a lock and dam application, pole mounting is often deployed. Pole mounting provides the heights needed to obtain a good view in the lock chamber. Parapet mounting may be used on a dam structure to provide camera coverage of either the lock or dam.

i. Prohibited. The NDAA, in part, restricts the use, procurement, or sale of certain brands of surveillance equipment for federal agencies. The designer must include information sufficient in the project to prevent the inclusion of prohibited surveillance equipment including cameras.

j. Lighting conditions. For cameras to work properly, adequate lighting must be provided. The sensitivity of a camera refers to its ability to produce a usable image given a minimum lighting level. The designer must specify cameras for the lighting conditions that exist or add lighting. Infrared illuminators can be selected illuminate scenes with good success. The designer must specify cameras that are designer to work with infrared (IR) illumination.

20–9. Monitors

a. Resolution. Ultra-high definition (UHD) monitors have a resolution 3840 x 2160 and sized in the 24-in. to 32-in. size are commonly used on video workstations. Larger format displays and video walls should be designed not to block the operator viewshed. The video card and CPU need to be specified by the designer to handle video workloads without latency. Specialized appliances should be considered for video walls. Commercial monitors are required for the 24/7 utilization of these systems. Monitors with tuners and other ancillary electronics should be avoided.

b. High-definition multimedia interface. Connection between the video workstation and the monitors should be specified as an HDMI connection. The distance of this connection should not exceed 15 ft without the designer specifying a solution. Solutions should be specified to deliver uncompressed video at the resolution of the monitor. An HDBaseT Spec 3 receiver can be specified to mount behind the monitor on the bracket and shielded or screen category 6A structured cable used to deliver 4:4:4 60@4K for up to 100 meters along with gigabit Ethernet and USB 2.0.

c. Mounting. Mounting of the monitors should minimize the strain on the lock operators. Commercial enclosures with many different configurations are available. Usually, it is more cost effective to use commercially available consoles and avoid specially constructed consoles. A modular approach also reduces impacts from upgrades and equipment repair. The designer must determine the size and mounting of the video monitors, in addition to the number required. Modern video monitor sizes differ from traditional 24-in. bays in consoles that are designed for 19 in. Telecommunications Industry Association (TIA) mounting configurations inside of the rails.

d. Keyboards. Operator video workstations that have PTZ cameras require a joystick in addition to a traditional keyboard. Working space needs to allow for keyboards and joystick control in planning the workspace. Operator ergonomics should be considered as well.

20–10. Network video recorder

An NVR records digital video from multiple IP cameras and video encoders to one or more internal hard drives or external storage systems.

a. Software. NVRs can be purpose-built appliances or use commercial off-the-shelf servers with software. The designer should work closely with manufacturers that have proven integration with ACS from the General Services Administration (GSA) schedule in selecting the appropriate hardware and software specifications. The designer should align redundant power supplies when specified with redundant power sources and redundant UPS capacity to provide availability results desired.

b. Storage. NVRs can have as little as 1TB of storage to essentially limitless capacity. The designer should work with the system owner to determine availability needs in specifying storage. The appropriate capacity along with the redundancy requirements will need to be addressed. Redundant arrays of independent disks (RAID) allow the designer to specify fault tolerance and performance into a system. RAID 1 is a mirrored solution that requires 100% excess disk capacity, but additional RAID modes reduce this by striping volumes and including parity bits so an out-of-service drive does not remove availability.

c. Integration. The NVR is required to be integrated with the IDS and ACS to provide the best capabilities. AR 190-51 requires that any video system be fully integrated into the project's IDS and ACS systems. By specifying ONVIF, the designer creates a standard for how IP products within video surveillance and other physical security areas communicate with each other that is independent of the manufacturer.

d. Analytics. The operator's primary duty is not surveillance observance. The designer should consider video analytics to offload some of this workload from the operator to the system to multiply capabilities. These can be performed at the edge by smart appliances or by the NVR. The designer can specify rules than display notices on the monitor or integrate the rules into the IDS. Proper scene selection and equipment coordination, along with successful commissioning, will be required for positive outcomes.

e. Time server. The system should have Network Time Services (NTS) available to ensure that all the sub-elements use the same time stamps. Forensics and the use of this information by other government agencies (if required) necessitate this time stamp. These closed restricted systems cannot connect to the internet to receive time services. The best solution is to install a global positioning system (GPS) receiver with an appliance to serve as an NTS and deliver this information to the electronic security system (ESS). This service can be provided to the NVR. All other elements of the ESS can be directed to point to the NVR for NTS.

f. Motion detection. Hardware motion detection such as radar, infrared, or ultrasonic detectors has become sophisticated enough that it should be considered when designing a video system. Detection also can be connected to audible alarms for immediate notification of a security problem. Motion detection can also have application at low-volume locks to detect small vessels in the lock approaches.

20–11. Network

The designer must specify the network and the electronics used to connect the Ethernet and other components of the system into a cohesive system.

a. Chapter 19 includes physical layer information for the designer to use to interconnect all the electronics.

b. The designer must coordinate the electronics specified in UFGS 28 10 05 for electronic safety and security with UFGS 25 05 11 integrated automation requirements for those electronics. The cabling sections in UFGS 28 10 05 need to be deconflicted with UFGS 27 10 00 or need to direct readers to UFGS 27 10 00 for those requirements.

20–12. Lightning protection

Fiber optic communication and composite video signals are immune to problems caused by lightning when all dielectric cables are deployed. When composite fiber cables or copper cables are used, the designer needs to specify protection. Communications cables covered in other sections are covered by protected entrance terminals with gas tubes or electronic protection. Elements that leave the lightening protection envelope of the structure must be individually protected when they come into the building. Since the review of the lightening protection envelope is not always an easy exercise, any copper that leaves the exterior wall further than 4 ft can be used to determine when protection is needed. Any elements that extend above the envelope need protection even if they do not exceed 4 ft. Earthing of protection must be designed for it to function as designed.

20–13. Approved products list

The DoDIN APL has limited OT products designed with environmental hardening. The Common Access Card (CAC)-enabled web site to verify DoDIN APL listing is https://aplits.disa.mil/processAPList.action. Products on the DoDIN APL are sometimes at end of life or offer only a single vendor for a solution. The designer should work with centers of expertise in specifying products that will achieve operational goals and not have an end of life during the desired refresh cycle.

20–14. Throughput

Distances at CW projects often approach the limitations of multimode fiber. A 1 Gb network can be deployed up to 1,800 ft on OM3 fiber. If legacy OM1 (62.5/125) fiber is in place, this distance is reduced to 722 ft. At 10 Gb (the next Ethernet standard) this multimode distance is reduced to 984 ft for OM3. To future-proof projects, single mode fiber needs to be deployed. The designer is directed to ISO/IEC TR 24750 for copper cabling at 10 Gb. The cable that will permit this speed is category 6A balanced twisted pair cabling.

20–15. Endpoint connection

The uses of field-applied plugs on category cabling have high failures and are non-standards compliant. The proliferation of non-traditional appliances that require power and data from the horizontal equipment, combined with the development of the modular plug terminated link (MPTL), led to the inclusion and testing in the ANSI/TIA-568.2-D standard.

a. The designer must specify that MPTL connectors be used when a standard RJ45 jack and factory patch cord cannot be installed. The MPTL connectors are designed to be field applied to horizontal cable to allow the required quality needed for insertions over the life of the plant. The bodies have metal to assist with the dissipation of heat associated with PoE cabling. This application is useful for non-traditional IP, including cameras, wireless access points (WAPs), and Internet of Things (IoT) appliances. See Figure 20–2.

b. When end of support is reached, and the manufacturer no longer supports the product through software/firmware updates, the product should be planned for obsolescence.

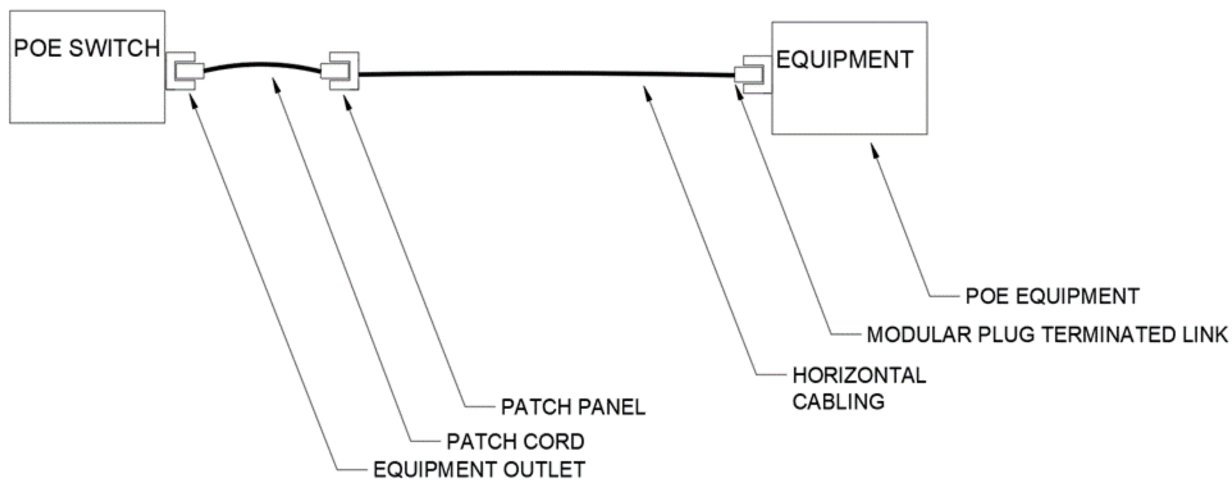


Figure 20–2. Modular plug terminated link

20–16. Security systems

a. Physical security. Physically limiting access to the navigation lock control spaces, electrical and mechanical rooms, and other critical areas is the most basic and effective security measure. Keep doors locked, keep areas well lit, and report anyone who looks suspicious. Maintain logs of access to spaces with critical assets. The use of electronic systems to maintain these logs can assist with record keeping and report generation.

b. Access control system.

(1) The function of an access control system (ACS) is to ensure only authorized personnel are permitted ingress and egress from a controlled area. The ACS should be able to log and archive all transactions and alert authorities of unauthorized entry attempts. ACS can be interfaced with the video surveillance system to assist security personnel in the assessment of unauthorized entry attempts. GSA maintains an APL for ACS. The APL is a list of Homeland Security Presidential Directive 12 (HSPD-12)-related products and services that have been tested per an approved NIST test procedure. The designer should limit the specifications to systems that reside on this APL.

(2) An ACS can have many elements, including electric locks, card readers, biometric readers (when required, but not always part of every system), alarms, and computer systems to monitor and control the ACS. An ACS generally includes some form of enrollment station used to assign and activate an access control device. This enrollment station must be equipped with a Personal Identity Verification (PIV)/CAC reader and keypad to enroll users in the system.

c. Federal bridge. The designer should work with the district security specialist to determine early if a connection with the federal bridge will be required for PIV card certificate verification. This connection will require additional hardware, to include identifying the server and firewall to allow the system to obtain the data. The accreditation boundary of the system will be larger to support this connection. The designer may need to specify a local certificate authority and a server depending on the selected configuration of the system.

d. Hardware. ACS hardware includes architectural door hardware in addition to electronic security elements. These can include, but are not limited to, electric transfer hinges and electrified locks. This specification requires coordination with the door and door hardware specifications to ensure the doors have pathways in the frames and connection boxes to allow passage of these cables. Careful coordination is essential for successful outcomes between specifiers of differing parts of the overall system. When the decision is made to deploy ACS later, the designer should consider specifying the frames and doors with necessary pathways along with concealed raceways to an accessible space to avoid having everything surface mounted on the secure side of the door in the future. This should be considered for all exterior doors and those interior doors that sperate some of the spaces delineated herein.

e. Spaces. The designer should consider the following spaces for inclusion in the ACS in consultation with division security specialist and the ESS-MCX and UCIC based on risk assessments according to AR 190-51:

(1) Electrical and control spaces, and control rooms building with high-value assets.

(2) Navigation lock control rooms, entrance into mechanical and electrical spaces, and/or gates accessing the navigation lock area are all suitable candidates for inclusion in an ACS. The designer should evaluate each location and determine the best way to incorporate it into existing systems or provide for future ACS. See UFC 4-021-02 for further electronic security design criteria.

(3) Telecommunication spaces are candidates for inclusion in the ACS to assist with logging access.

f. Intrusion detection system. The function of an intrusion detection system (IDS) is to record when unauthorized access is gained to facilities or spaces. The system may be integral to the ACS or a separate IDS system that is integrated with the ACS. The designer should consider an integrated system design.

g. Sensors. There are many sensor types, including door and hatch position switches, glass break sensors, motion sensors for indoor and outdoor, and others the designer should evaluate during design. See UFC 4-021-02 for further electronic security design criteria.

h. Remote monitoring. Many options exist for remote monitoring of IDS systems. Commercial alarm monitoring stations should be considered for sites that need remote monitoring. The designer must work with district security personnel and listed alarm monitoring services during design to ensure compatibility when this is used. This work may include provisions to extend the telephone demarcation facility with connectivity to the IDS panel and provisioning redundant cellular connections.

i. Integration. Integration with door hardware will be required for authorized entry and exit to provide signal to the IDS to not imitate an alarm. This may include specifying door hardware with Form C contacts and wiring to be connected to the IDS to indicate an authorized exit. The designer must further work with the architect to specify door hardware, including but not limited to, wiring harnesses and power transfer hinges to deploy successful electronic security.

20–17. Communication systems

a. General. While the power distribution and lock control systems are the key electrical systems for a navigation lock, designers must provide other communication systems for lock operators, maintenance personnel, and administration personnel. Designers should plan for raceways and other necessary infrastructure to support the following communication systems. Some of these systems will be used heavily by the lock operators and should be accounted for in the control house or control console designs.

b. Fiber optics. The fiber optic backbone is the heart of communications at a CW facility. Often, fiber optic cables are added ad hoc during the life of a project. This results in a myriad of fiber and connector types and limits the facilities ability to efficiently expand and change throughout its life. A holistic fiber backbone offers many advantages including EMI immunity and a reduction in lightning damage. The designer needs to be cognizant of the following subsystems when designing the communications systems cabling:

(1) *Industrial control systems* (includes PLCs, SCADA, and OT systems).

(2) Video systems.

(3) Security systems.

(4) Traditional IT Needs CIO-G6.

(5) Public address.

(6) Fire alarm/mass notification system.

(7) Building automation systems.

(8) Lighting controls.

c. Design considerations. The designer needs to select the center of operations and create a hierarchical star or a pathway for the facility to evolve to a hierarchal star. This will provide the facility with the best flexibility to deploy the various systems over a common backbone. An example is a device level ring for an ICS that can be deployed over a hierarchal star.

(1) When the ICS is upgraded, it can be repatched to a redundant Ethernet connection without replacing the fiber plant. Fibers should be planned for each FRCS as well as traditional IT. Single-mode fiber needs to be included in the backbone along with multimode if systems are identified that require multimode. The minimum fiber for multimode is OM3 50/125 micron cable. The single-mode fiber should be OS2 or OS1.

(2) The intrabuilding backbone count should include 24 single-mode fibers and if multimode is used, an additional 24 multimode fibers. The designer should use loose-tube OSP-type fiber optic jacketing for all fiber that leaves a building. The use of all-dielectric construction should be perused when more robust mechanical protection is not required. This alleviates the need to provide bonding and lightning protection at building entrances for these cables. Best practices are to start with fiber 1 and work up to accommodate IT systems and to start with the highest fiber and work down to accommodate OT systems. This avoids the comingling of patching and systems.

d. Telecommunications enclosure. Inside of buildings, a telecommunications enclosure (TE) must be designed to house electronics and to allow conversion from optical signals to electrical signals. A TE is defined as a case or housing for telecommunications equipment, cable terminations, and cross-connect cabling. For equipment that is not in a building, a field distribution box (FDB) will need to be designed.

(1) An FDB serves as a critical node for sensor processing, data transmission, and electrical power at exterior locations. The heat dissipation requirements need to be accounted for when environmentally hardened electronics are not deployed. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Datacom Series 2 IT Equipment Power Trends (third edition) provides the design information for traditional IT equipment heat and power loading. Power will be required to these enclosures.

(2) If redundant communications are planned, the designer should design redundant power to align the availability. If redundant power backed up by a separate reliable source such as a generator is not available, UPS power needs to be available to cover the anticipated outage.

e. Protected entrance terminals. When copper is required between structures, the designer must include space and bonding for protected entrance terminals (PETs) at each entrance. These should be designed as near the entrance to the facility as practicable to facilitate protecting building systems from exterior events.

f. Horizontal cabling. The designer must provision separate horizontal cabling for CorpsNet and FRCS, including OT and SCADA. The best practice is to deploy the category cable for CorpsNet into a locking enclosure and have it terminate on a separate patch panel.

(1) A fiber jumper from the backbone fiber termination cabinet into this enclosure will permit CIO-G6 to install electronics and provision them with horizontal and backbone services for traditional IT. All other horizontal drops will terminate on patch panel(s) in the OT enclosures.

(2) A separate color of cabling and jacks further delineates this separation. CIO-G6 can lock the enclosure with the equipment for which they are the system owner, and the site can lock the rest of the equipment. It is important that the fiber termination cabinets reside in the OT cabinet as CIO-G6 may be remote from the site and system testing and changes will be required through the life of the site.

g. Public address. The public address system at a CW site consists of internal and external notification appliances used to alert employees and other users of the site to changing conditions or announcements. These sites have damming surfaces that can exceed a mile wide and lock structures that exceed 2,000 ft with approach walls.

(1) The physical size and the probability of electrical events require the designer to design a distributed system. The designer should specify a standards-based audio over IP (AoIP) system that uses AES67/Dante to allow compatibility between differing equipment manufacturers. The designer can use hybrid systems that deliver traditional analog 70V signals to speakers and horns, or a self-powered AES67/Dante speaker can used.

(2) Interface between the voice over IP (VoIP) telephony equipment provided by CIO-G6 and the public address system needs to be coordinated by the designer. Provisions for an analog telephone adapter from CIO-G6, coupled with a telephone answering module in the paging, allows this interoperability without combining the accreditation boundaries. Fixed microphones should also be considered in the control room to facilitate system access.

h. Marine band radio. An operator will spend significant time on the marine radio arranging queues and acquiring vessel cargo information. Lock operators likely will move the radio to several different locations on the console while they are getting used to the new system. For this reason, it is probably not a good idea to provide a permanent location for mounting the radio. Instead, provide means to move the radio to any location on the console allowing the operators, after they are accustomed to the new control system, to station the radio where it is most convenient for them. Designers must plan for power supplies and antenna connections.

i. Wireless access points. Wireless access points (WAPs) are increasingly important in the O&M of facilities. The ability for maintenance personnel to access documents and checklists during maintenance and repairs is critical. CIO-G6 has provided wireless access to the networks, and the designer can work with them to determine scope. The industrial environments encountered in locks and dams require proper infrastructure be deployed outside of normal IT contracts to ensure successful installations.

(1) The MICE acronym stands for an environmental classification system for mechanical, ingress, climatic/chemical, and electromagnet. Cabling systems installed inside of galvanized rigid conduit are well protected from electromagnetic interference and mechanically well protected. The WAPs are furnished power and data using PoE. The designer should prepare routing to avoid transformers and large motors.

(2) IEEE defines PoE with 802.3bt delivering 100 watts of power at 52 volts over category cabling. The IEEE 802.11ax, Wi-Fi 6 by the Wi-Fi Alliance, is a 10 Gbps application necessitating a Category 6A cable for 100-meter reach. The current best practice and compliance with TIA Telecommunication Standardization Bureau (TSB)-162 recommends the use of two Category (CAT) 6A cables to each WAP. With the bandwidth available soon to most USACE structures, a single CAT 6A cable will suffice for WAP locations. Signal propagation best practice will require the use of predictive RF design software to produce heat maps to determine the best layout. If predictive RF design software is not available, the radius of the coverage area should not exceed 43 ft.

j. Vessel-logging personal computer. Major locks usually have a PC dedicated to logging vessel cargo and lockage information. Busy locks, such as key locks that are the first on a river to enter vessel data, require frequent monitoring and data entry. An operator will spend more time at this computer than at the lock operating workstations.

(1) Therefore, this PC should be located where the operator can conveniently sit down and log information (at the standard 760-mm [30-in.] desktop elevation with convenient keyboard and mouse, extra space for vessel lists and other paperwork, and a comfortable standard office chair). The Lock Performance Monitoring System (LPMS) will require access to the USACE corporate network. Lock operators may have restricted rights or capabilities on the logging PC and will require a separate PC for access to email and the Internet.

(2) With the vessel-logging PC requiring access to the corporate network, corporate IT will provision this PC. If real estate in the control room is at a premium, the designer should discuss the use of a keyboard, video, mouse, and Kernel-based Virtual Machine [KVM] switch to allow the operator to switch between the computers for checking email and LPMS duties.

k. Distributed antenna system. Emergency Responder Radio Systems are radio systems that are licensed by a licensing authority to a jurisdiction. Written approval must be obtained by the designer with the license holder. Design coverage and testing according to NFPA 1221 (Chapter 9). The use of predictive modeling software is the recommended method for design describe in NFPA 122.

(1) The Authorities Having Jurisdiction (AHJ) in the entity responsible for deeming areas as critical areas. Examples include fire command centers, fire pump rooms, exit

stairs, exit passageways, elevator lobbies, standpipe cabinets, and sprinkler sectional valve locations. These areas are required to have 99% floor area radio coverage. General building areas must be provided with 90% floor area radio coverage. NFPA 1221 defines the requirement to have minimum inbound signal strength sufficient to provide usable voice communications, as specified by the AHJ.

(2) As this is difficult to quantify for design, it is recommended that the International Fire Code Section 510 (a) 510.4.1.1 minimum signal strength of -95 dBm be used. The building is considered to have acceptable emergency responder radio coverage when signal strength measurements in 95% of all areas on each floor of the building meet the signal strength requirements of -95 dBm receivable and the agency's radio system can receive a signal strength of -95 dBm from transmissions inside the building. When a two-way radio communications enhancement system is installed, there are numerous supervisory and trouble notifications that must be reported to the fire alarm control panel.

20–18. Life safety systems

a. Personnel.

(1) Safety for lock personnel, commercial vessel crew members, pleasure craft occupants, and public visitors is the single most important consideration when designing a quality operating system for a lock and dam facility. This should be considered in every aspect of the electrical system design, including the features discussed below.

(2) It is strongly recommended that designers of such systems spend sufficient time observing the day-to-day operations at a lock and dam project. While this will not qualify a designer to operate a lock and dam, it might give the designer some safety concerns to consider when designing a replacement electrical system or one for a new lock and dam. There are numerous procedures (such as locking tows and ice maneuvers) at each lock that, while not obvious to the casual observer, can place the operators in serious danger if the equipment is not located strategically, fails to function properly, or interlocks and safety features do not operate in a timely and correct fashion. All must be considered at each step of the design.

b. Accessibility.

(1) All electrical and electronic equipment must be installed in a way that it is safely accessible by lock maintenance personnel. All equipment that has energized circuits must be marked properly. At times, it might be necessary to perform maintenance on this equipment in the energized state. At all times, proper arc flash protection and procedures must be followed per the operating district's policies.

(2) Equipment for which entry will cause a shutdown of the lock control system also should be marked with such a warning. All machinery and electrical gear that is controlled from a remote location should have warning labels and a means for disabling the remote control. Also, it is a good idea to provide a means for authorized personnel

to operate the machinery from local controls in the event of emergency or during routine maintenance.

c. Operating locations. When locating lock operating stations, designers must provide visibility to all aspects of the project as necessary to safely control the project. This can be done with direct visibility or with video cameras. Only experienced lock operators will be able to determine exactly what features of the project require constant, periodic, or occasional surveillance during a lockage. Other areas might require surveillance for security reasons.

d. Machinery safety interlocks. All operating machinery should offer safe access to the portions that require maintenance. In addition, interlocks should be in place to ensure that machinery cannot be started remotely while being serviced. Interlocks can consist of such things as machinery room door switches used as inputs to the PLC system. Auxiliary contacts on these switches can be used as hardwired interlocks. It is a good idea to have PLC inputs from these switches because of the flexibility and remote indication that can be provided.

e. Emergency stop/hardwired backup.

(1) All lock control systems should have emergency stop pushbuttons at various points around the lock. These areas can include, but are not limited to, all lock control consoles, each gate machinery area, along the lock walls in areas frequented by lock personnel, at MCCs and switchgear locations, and in all galleries where electrical and mechanical machinery are located. The emergency stop pushbuttons should be large, red, mushroom-head type, clearly marked, and hardwired directly to motor starters.

(2) Using illuminated emergency stop buttons, wired such that they light when activated, should be considered because they provide visual indication to the operator that an emergency stop has been pressed. Consider an auxiliary MCC starter bucket with relays for use in each gate and valve starter circuit. Auxiliary contacts on the emergency stop buttons should be wired to PLC system inputs for indication only.

f. Motion detectors. Some locks have submersible walkway bridges, walkways across miter gates, or other traffic areas that can be compromised by operation of lock equipment. In these locations, particularly if the lock is automated or remotely operated, motion detectors can provide important safety interlocks to prevent movement of machinery when lock personnel are passing through these areas. It is also a good idea to have some type of visual and/or audio indication prior to actual movement of lock equipment to allow personnel to stay clear of these areas. Muster stations can be added to the ACS system and personnel trained to procedurally credential in when they enter and leave these spaces so safety personnel can be alerted of failure to exit.

g. Distributed antenna system. See paragraph 20–17k regarding communications on radio systems for life safety. These systems can be designed to provide radio coverage in frequencies beyond those used by Emergency Responder Radio Systems.

The designer can specify systems with frequencies that correspond with operations frequencies and cellular frequencies.

h. Duress systems. Person-down duress systems can be designed by providing coverage in unlicensed frequencies used by these systems and providing duress appliances to be worn by personnel in these spaces. The designer should use predictive RF software in the designing of these solutions combined with robust commissioning specifications to ensure proper operation.

Chapter 21
Firefighting Systems

21–1. Introduction

This chapter provides engineering design guidance for firefighting systems specifically for the lock structure. The fire hazards addressed herein are those presented by commercial vessels, tows, and recreational craft. The protection to be provided is solely for lock appurtenances, such as miter gates, operating machinery, and bridges. Any benefit afforded vessels and other watercraft is considered incidental.

21–2. Firefighting systems

Firefighting or fire protection systems provide the capability to protect vital components such as miter gates. Firefighting systems could also provide capability to fight a fire within the lock chamber, such as a fire on a barge or tow. However, it should be noted that the operating staff at many lock sites do not have the capability or training to fight fires in the lock chamber, whether on a tow, barge, or recreational vessel.

a. Lock protection system design must comply with UFC 3-600-01. UFC 1-200-01 and UFC 3-600-01 also mandate requirements for lock buildings, control stations, control towers, and any outbuildings that are outside the scope of this manual. UFC 3-601-02 can be used as a guideline for establishing maintenance and inspection requirements of fire protection systems.

b. All sources of ignition should be prohibited on lock structures within 50 ft (15.24 m) of vessels where flammable and combustible materials are handled. Suitable NO SMOKING or OPEN FLAME signs should be posted.

c. Fire protection requirements for petroleum-based hydraulic power units and hydraulic power systems must comply with UFC 3-600-01.

d. The intent of this chapter, including the use of all referenced codes and publications, is to provide for practical and economic fire protection for government property at navigation locks without exposing project personnel to undue risk. It is not the intent to provide a fire-fighting service to the navigation industry nor is it an intent to create that appearance.

e. A policy of coordination with local fire departments should be established to effectively use their firefighting capabilities, provided that such services are available. Coordinate with any local fire protection officials during the fire protection system design process. Comply with UFC 3-600-01.

f. Professional firefighting services should be relied on to control and extinguish fires at the facilities. The initial response to a fire emergency should follow a written procedure as required by EM 385-1-1, agreed to by the local fire departments, the Coast Guard, and the operating district. This procedure should include hardware requirements, method of communications, equipment access, response times, etc. Fire drills should be conducted periodically.

g. Districts should establish emergency response procedures and training suitable to the level of firefighting equipment and services available, and the ease of accessibility to same, for each of its locks.

h. Miter gate spray sprinkler systems must comply with the requirements in UFC 3-600-01. The determination to provide a miter gate spray system must be risk-based and fully documented in the project Design Documentation Report. An example only of risk-based guidelines is included in ECB 2019-15. It is up to the District and PDT to determine the level of effort needed for the risk analysis. Factors that should be considered include the lift of the lock, number of lockages, red flag barges, gate height, project remoteness, etc. The risk analysis should also be done in coordination with the local fire department.

i. A miter gate spray system will help to protect the miter gates from heat damage during a fire (Figure 21–1). A water spray system should be activated as quickly as possible to cool and help wash flammable liquids away from the miter gates. In operation, the miter gate spray system provides a dense spray of water on the miter gate surface between the gate and barges that might be on fire in the lock chamber. This spray helps keep the gates cool and minimizes distortion during a fire.

j. At many locks, the downstream side of the gates are not covered with a skin plate. Therefore, water sprayed onto the downstream side of the gate may pool in horizontal girders instead of flowing down a skin plate to cool the whole exposed surface, as would occur on the upstream face of the downstream gates. The designer must evaluate this potential condition as part of the risk analysis and determine whether both sides of the miter gate need a spray system. The upstream gates may also be cooled by the upper pool.

k. Filling the lock chamber will provide additional protection for the miter gates and lock walls. This is an effective procedure only when it does not expose important buildings and equipment on the lock walls to danger. Flushing a burning vessel out of a lock chamber is another alternative when it can be accomplished quickly enough to prevent damage and it does not endanger other vessels or river facilities. It also could require the installation of an oil boom downstream for liquid containment.

l. The burning vessel’s crew and lock personnel should be evacuated as required by the situation. Ambulances and police should be called in to assist. Suitable access for fire trucks and other emergency vehicles should be provided where physically possible.

Figure 21–1. Miter gate spray system, Bonneville Lock

m. A fire alarm system should be provided according to UFC 3-600-01 to alert personnel quickly to a lock chamber fire.

n. Fire extinguishers should be located, inspected, and tested in conformance with UFC 3-600-01.

o. The fire protection water supply system should be tested yearly for leaks, pump performance, and overall system readiness.

p. Fire pumps must conform to UFC 3-600-01. The location of fire pumps will be site specific.

q. At some lock sites, it may be impractical to install vertical turbine fire pumps because of flooding concerns. Many lock sites are submerged for long periods of time during flood events. In those cases, submersible turbine pumps that do not comply with NFPA 20 may be used as permitted by UFC 3-600-01. Refer to EM 1110-2-3105 for additional guidance. Some lock sites may allow pumps to be installed in the culvert valve recess and draw water from the lock culvert.

r. Hose stations must conform to UFC 3-600-01. Hose stations can also be retrofitted to existing locks and can be used for cleaning off the lock walls in addition to fire protection, as noted by UFC 3-600-01. See Figure 21–2. The risk analysis for hose stations should be similar to that for the miter gate spray system and should be done in conjunction with and in coordination with the local fire department.

s. Above-ground and embedded pipe should conform to UFC 3-600-01. All aspects of the fire water-piping systems should comply with appropriate NFPA and AWWA standards and conform to UFC 3-600-01.


Figure 21–2. Hose station mounted on the lock

21–3. Advanced fire protection systems

Advanced fire protection systems incorporate PLC logic and remote operation for additional safety to operating staff. No USACE locks currently employ these systems. However, Figure 21–3 shows the remote-operated fire protection system at the Panama locks. This system can operate firefighting nozzles from the central control station through a PLC-based operating system. The system uses a joystick nozzle control that can provide water only, chemical injection, or both simultaneously.

Figure 21–3. Panama Canal fire protection systems

Chapter 22
Lock Dewatering Systems

22–1. Dewatering systems

A permanent lock dewatering system provides a means to quickly dewater a lock in lieu of using portable pumping and should be provided for new lock construction and major rehabilitation projects. Most locks in the Inland Navigation Waterway System (INWS) currently require floating plant and temporary dewatering pumps and dewatering infrastructure to dewater a lock. See Figure 22–1 and Figure 22–2. This method of dewatering requires mobilizing the floating plant and is both labor intensive and costly.

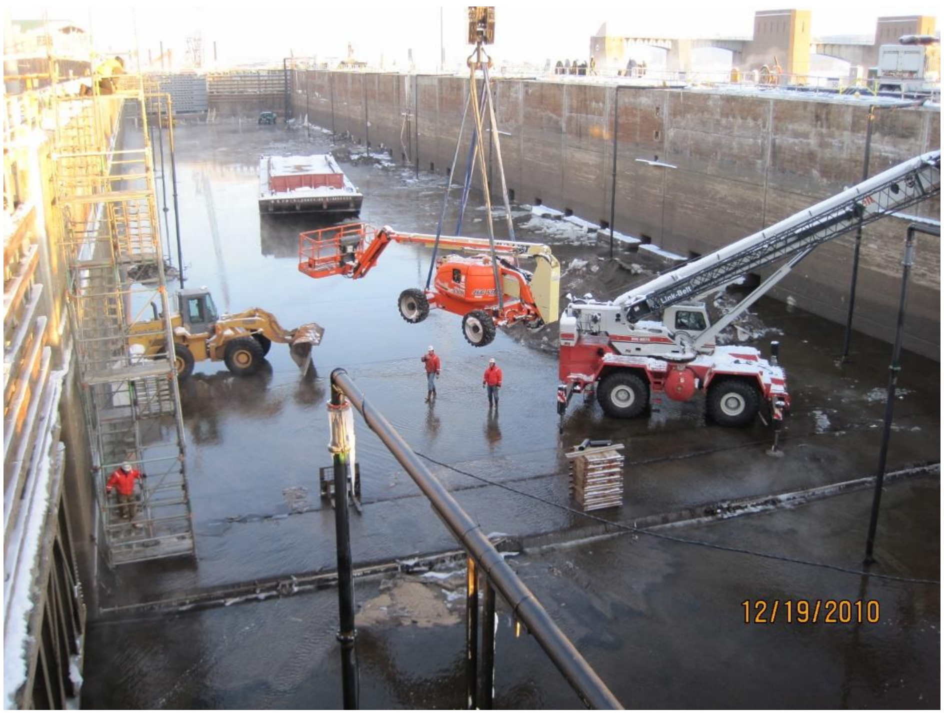


Figure 22–1. Lock 10 Mississippi River dewatering

a. The designer should reference and use EM 1110-2-3105 and Hydraulic Institute (HI) 9.8 Standard for the design of pumping plants and pump wells for lock structures.

b. There are only a few locks currently in USACE that use on-site pumping plants. This includes the Soo Locks, Chittenden Locks, and the Bonneville Lock. All the specifics of each are discussed further below.

c. Having an on-site pumping plant avoids the necessary mobilization work to bring in portable pumping equipment. The system can be used quickly, whether for planned or emergency work. In an emergency such as a miter gate failure, the lock can be quickly dewatered.

d. Another significant advantage of on-site pumping plants is the capability to draw down water below the lock chamber floor. This type of system is used at the Soo Locks.

e. On-site pumping plants have disadvantages. The pumps can be large, and maintenance requires specialized equipment. The pumping plant requires initial capital cost and can be maintenance intensive. Pumping sizes may require an increase in the overall electric service size to the lock site. Large pumping plants may dictate the size of the electric service to the site.

f. The common method of dewatering is using vertical mixed flow or turbine pumps or submersible centrifugal pumps. The primary components of vertical pumps consist of a motor, pump casing, shafting, and the impeller. Vertical pumps should use grease bearings and not product-lubricated bearings. Water in the lock chamber will contain sand, silt, and debris, and pumps need to be designed for this. Submersible pumps should be rail mounted for removal. See EM 1110-2-3105. Regardless of whether submersible pumps or vertical pumps are used, the system should be accessible for O&M.

Figure 22–2. Lock 8 Mississippi River dewatering

22–2. Soo Locks pumping plant

The Soo Locks likely has the most extensive pumping plant for dewatering in USACE. There are currently two functioning locks at the site, including the Poe Lock and MacArthur Lock. A new pumping plant will be constructed as part of the new lock construction at the Soo Locks starting in 2022. The current pumping plant and pumping system dates to the 1890s. The locks at the Soo are dewatered every winter.

a. The current dewatering system at the Soo Locks consist of the Davis pump well and Poe pump well, which, at the writing of this manual, both have greatly exceeded their design life. Many components of the Davis Well are still original from 1914. The two pump systems work together to dewater either the Poe or MacArthur lock, however, only the Davis pump well system can completely dewater the locks due to the lower pump intake elevations (Figure 22–4 and Figure 22–6).

b. Rapid drawdown times at the Soo Locks are needed to prevent ice formation when the locks are dewatered. Dewatering starts typically in mid-January. There is then a 10-week winter shutdown from mid-January through March. See Figure 22–3. A drawdown under 12 hours, and preferably 8 hours, is optimal.

Figure 22–3. Soo Locks, Poe Lock dewatering

c. The Davis Well system currently consists of three, 30-in., double-suction, centrifugal pumps, plus a maintenance dewatering pump (Figure 22–4 and Figure 22–5). The Davis pump well dates to 1914 with the construction of the Davis and Sabin Locks. The pumps in the Davis Well are original from 1914 as is all the discharge piping, including the main header pipe. All three Davis Well pumps combine the discharge pipes into a common 60-in. steel header pipe.

d. The current Davis Well configuration is typically the primary well system used for dewatering the Poe Lock and the MacArthur Lock and is critical to sufficiently pump out either lock chamber and keep it dewatered. If the Davis Well is out of service, the only pumping capacity will be from the Poe Well. The original Davis pump well curves from 1914 show a design condition of the 30-in. centrifugal pumps as approximately 18,000 gallons per minute (gpm) at 40-ft head. Nominal capacity is approximately 22,500 gpm each, for a total capacity of 67,500 gpm.

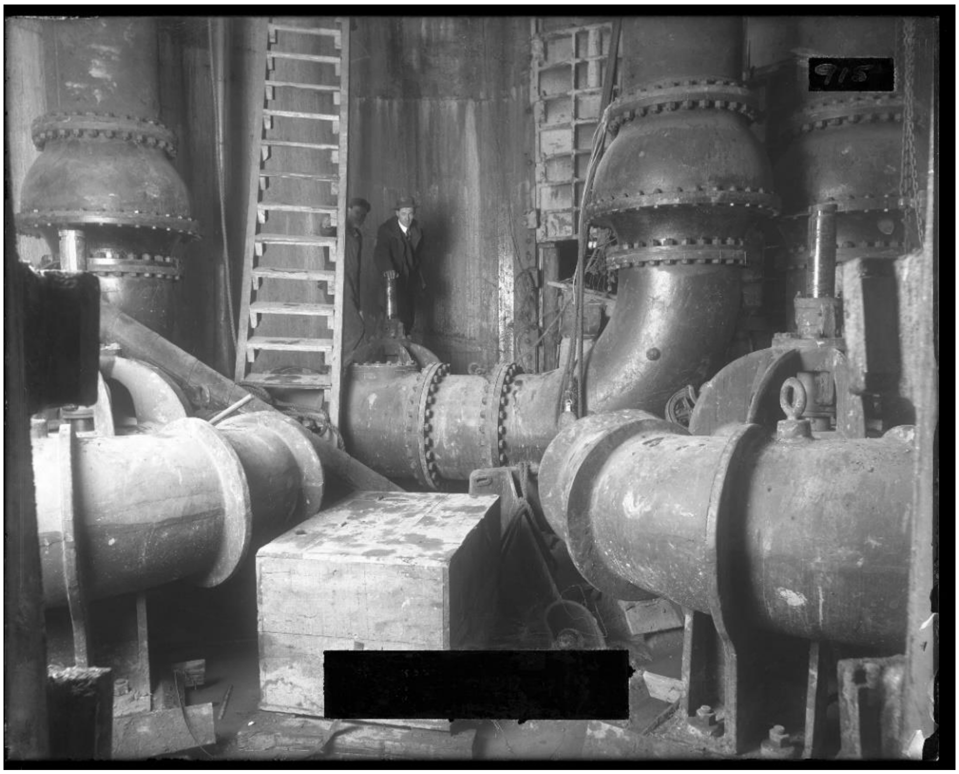


Figure 22–4. Davis Well double-suction centrifugal pumps from 1914

Figure 22–5. Davis Well pump motors on operating deck

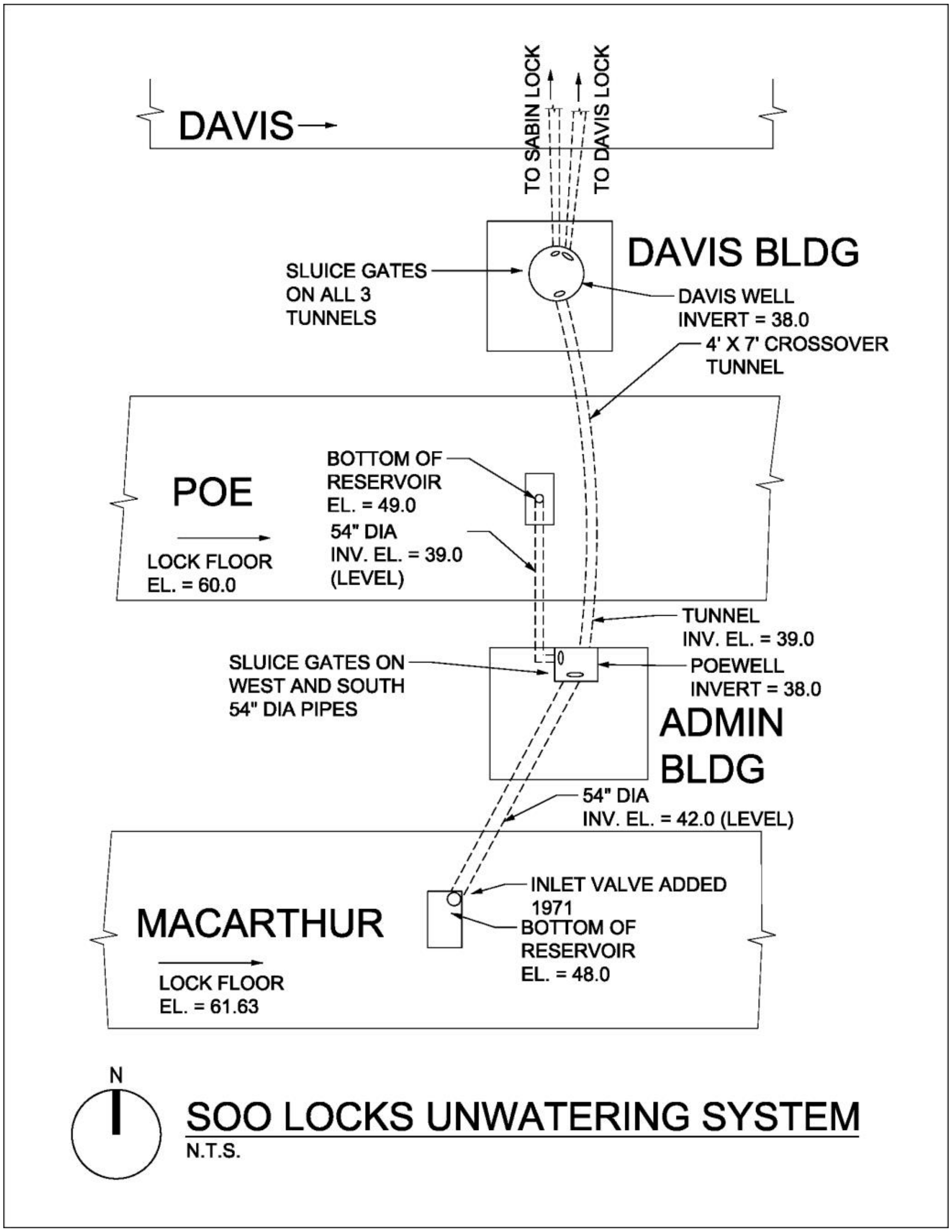


Figure 22–6. Plan view of Soo Locks dewatering system

e. The Poe pump well dates to the 1890s and was deepened in 1943 with the construction of the MacArthur Lock. The pumps in the Poe Well are original from 1943. The two dewatering wells are connected by a rock tunnel, called the crossover tunnel, which was constructed in the 1940s, as shown above in Figure 22–6.

f. The Poe Well has two 30-in. vertical pumps and a maintenance dewatering pump. The Poe Well pumps are rated at 25,000 gpm each. The goal is to pump any of the lock chambers (MacArthur Lock, Poe Lock, or New Lock) down in approximately 12 hours or less, with 8 hours being ideal. This dewatering time has been determined to be optimal by the Soo Area Office as a fast enough dewatering time to minimize ice formation and minimize personnel effort.

g. The new design and new pump well provide 120,000 gpm nominal capacity, which matches the capacity of the existing Davis and Poe pump wells (Figure 22–7). Construction started in 2022, and the new pump well construction will take place in the existing Davis Lock. This lock will be decommissioned. New vertical mixed-flow pumps will be installed in new pump well (3 total). The new design has sufficient depth to allow all the water in the locks to be pulled down below the underflow drainage system.

h. New pumps will be nominally rated at 600 hp and 40,000 gpm at 40 ft of total dynamic head (TDH). Vertical pumps are 42 in. in diameter. New pumps and motors will operate using a VFD. This allows pump capacity to match the inflow to the extent possible. The VFD will slow the pumps down as the well approaches shutoff. Model testing of the pump well also will be done as part of the contract.

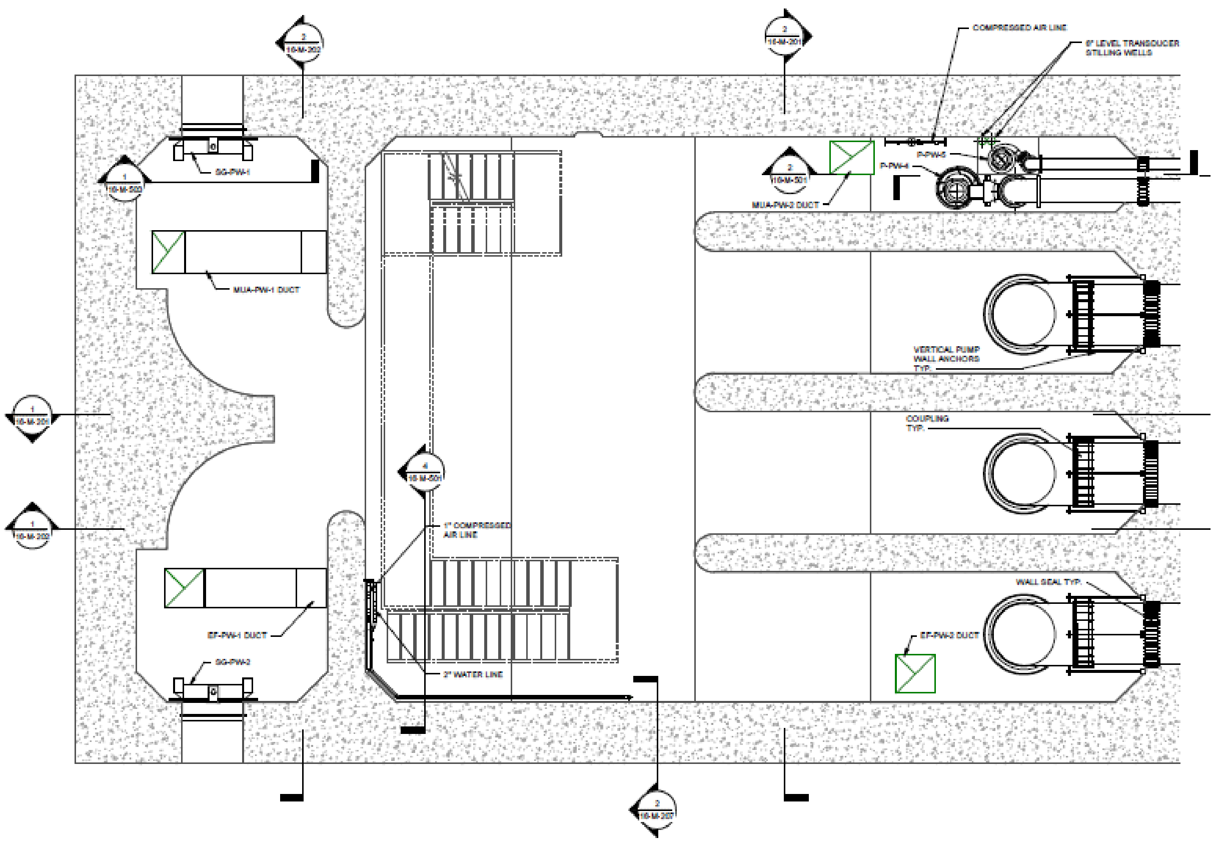


Figure 22–7. Soo Locks new pump well plan view

i. The new vertical pumps will need to operate with a large range of head conditions. As noted, the design point will be 40,000 gpm at 40 ft TDH. However, the pumps will need to be capable of pumping against 55 ft TDH at shutoff. The shut-off point will have the largest static head. On the other side of the pump curve during pump startup, there will be no static head on the pumps. This brings the total head to less than

5 ft and will likely cause the pump to become unstable because of the low head condition. As such, knife gate valves were added into the discharge pipelines to add more pumping head at start up.

j. New maintenance pumps and slurry pumps were also included in the new pump well and installed in a separate bay, as shown in Figure 22–7. These pumps will pull water down in the pump well to the floor elevation.

22–3. Chittenden Locks pumping plant

The Hiram M. Chittenden Locks are in the Lake Washington Ship Canal (LWSC) approximately one mile southeast of Shilshole Bay in Puget Sound. The LWSC is an 8-mile-long man-made waterway connecting Lake Washington to Puget Sound. The pumping plant at this lock was originally constructed in 1917. The pumping plant was replaced in 2016. The plant can also be exposed to brackish water.

a. The original 1917 pumping plant used two 300-hp, double-suction, centrifugal pumps like the Soo Locks Davis well and one 75-hp centrifugal, double-suction pump (Figure 22–8). The larger pumps were rated at 40,000 gpm and the smaller pump at 2400 gpm. Much of the design matched the Davis Well since both pump wells were constructed at the same time. Motors were installed on the top operating deck like the Davis Well. The dewatering system was operational until replacement in 2016.

Figure 22–8. Original dewatering pumps and valves, Chittenden Locks, Seattle, Washington

b. The new pumping plant installed in 2016 used submersible centrifugal pumps (Figure 22–9 and Figure 22–10). Two larger centrifugal pumps were rated at 27,000 gpm and 400 hp (Figure 22–9). The overall capacity was designed to match the original pumping plant. The existing structure was used, and the existing pumping plant was removed.

Figure 22–9. New pumps for Chittenden pumping plant 2016

c. The new pumping plant work included new discharge piping and valving. The existing piping was severely corroded after 100 years of service. The new submersible pumps in the well, however, were not designed to be removed using guiderails. Therefore, pump maintenance must be done within the well. Any removal of the pumps will require removal of the operating deck and a rigging system within the well.

d. The Chittenden Locks are typically dewatered yearly, usually in November, for maintenance. The Chittenden Locks have the most traffic of any lock in USACE, so the maintenance dewatering is typically limited to 30 days or less. The drawdown time is not as critical as the Soo Locks since icing is not a concern. The drawdown time is typically 2 days.

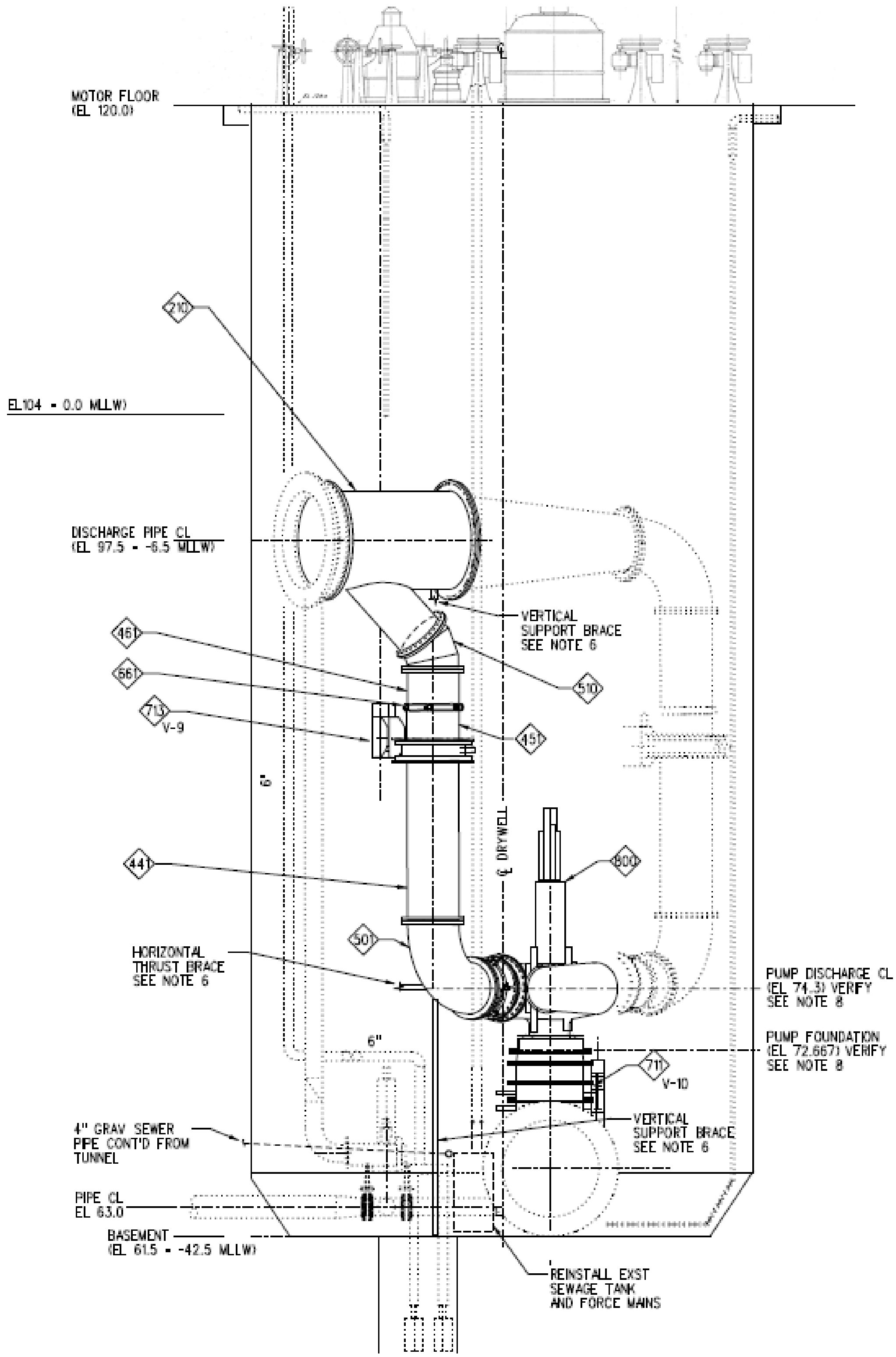


Figure 22–10. Chittenden Locks new pumping plant installation

22–4. Bonneville Lock pumping plant

The new lock at Bonneville was constructed in 1993 and includes an on-site pumping plant (Figure 22–11).

Figure 22–11. Bonneville Lock pump

a. The Bonneville pumping plant consists of six multi-stage pumps manufactured by Interstate Pump. The navigation locks are dewatered every three years on a preventative maintenance schedule that coincides with all locks on the Columbia and Snake River systems.

b. Pumps 1 and 2 are 5,800 gallons each and dewater the upstream tainter valve chamber. Pumps 3 and 4 are 1,200 gallon each and dewater the bubbler pit into the discharge piping of the downstream tainter valve dewatering pump. Pumps 5 and 6 are 7,000 gallon each and dewater the downstream tainter valve chamber.

c. The lock staff determined it is impractical and expensive to carry spare and on-hand replacements for all dewatering pumps the project uses. Critical pumps and motors are planned to be replaced with at anticipated half-life for reliability purposes.

22–5. Lessons learned

The lessons learned of on-site pumping plants are provided below. They include the following:

a. Design the system for an 8- to 10-hour dewatering time in northern climates. This will minimize ice formation in locks in northern climates.

b. Use at least three pumps, preferably four. Providing additional pumps minimizes the size of each pump. This reduces the weight of the pump and affects the crane size for removal. Multiple pumps also provide redundancy in the event of a pump failure.

c. Provide a dewatering pump chamber or pump well.

d. Provide VFD control to modulate flow rates.

e. Provide vertical pumps with reverse-ratchet mechanism to prevent rotation of the impeller in opposite direction. This could damage the pump and could cause the impeller to unscrew. Provide means for impeller adjustment at the top of the motor for vertical pumps.

f. Use stainless steel impeller shafting.

g. Periodically exercise and rotate the pump shaft every six months or less. This prevents bearings from seizing on the pump.

h. Use grease-lubricated pump and line-shaft bearings and not product-lubricated bearings.

i. Conduct vibration analysis on the intermediate bearings on a regular basis. This can prevent catastrophic failures.

j. Select appropriate pump materials. Material selection is critical. In saltwater, brackish, or corrosive environments, appropriate stainless steel components should be selected. Work with the pump manufacturer to select correct components.

k. Vertical pumps or submersible centrifugal pumps can be used.

l. Submersible pumps should be designed for removal with a crane and mounted on guide rails.

m. Include a pump-removal system as part of any design. Pumps need to be accessible for operation, maintenance, and removal.

Chapter 23
Ship Arrestors

23–1. Ship arrestors

Ship arrestors are devices that prevent ships and vessels from impacting lock operating gates. The most common ship arrestors are composed of large steel wire rope cables extending across the lock chamber. Steel booms are often used in conjunction with the cables (Figure 23–1). The boom assists in setting the cable and can either remain in place or be retracted. If the boom remains in place, it becomes sacrificial in the event of a ship impact.

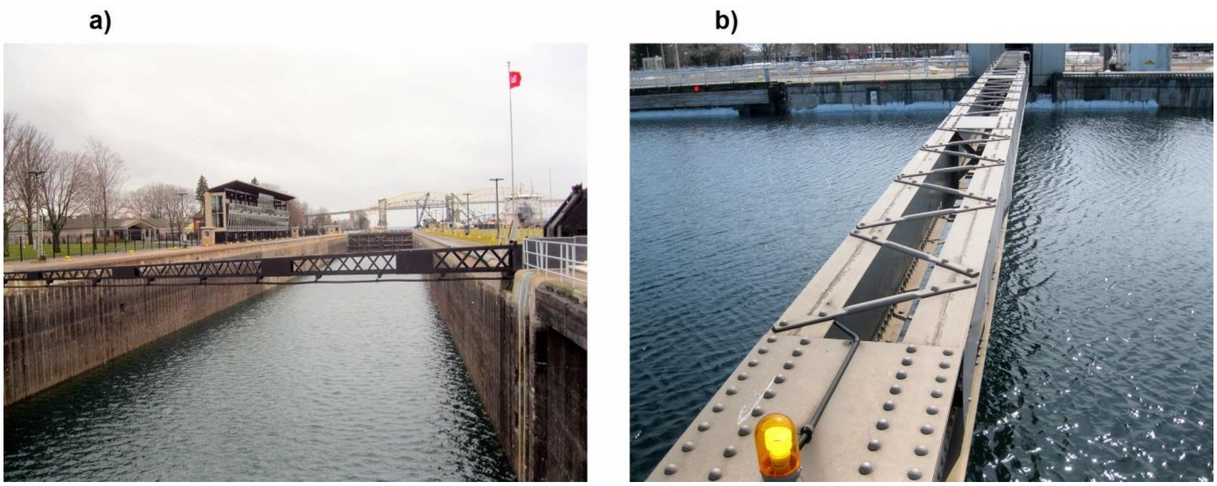


Figure 23–1. Soo Locks ship arrestors:
a) MacArthur Lock, general view; b) Poe Lock, top view of ship arrestor

a. Ship arrestors have been provided at locations where damage to gates or loss of a gate would result in catastrophic consequences. Ship arrestor systems are used primarily for deep-draft locks such as the SLS, Welland Canal (Canada), and the Soo Locks (United States) on the Great Lakes. They are also used on multiple deep-draft locks on European waterways.

b. The Soo Locks comprise two navigation locks, both of which use ship arrestors. This includes the MacArthur Lock (constructed in 1943) shown in photo (a) and the Poe Lock (constructed in 1968) shown in photo (b) in Figure 23–1. A new lock is under construction currently at the Soo Locks and will also use ship arrestors. More details on that system are provided below.

c. In the United States, no feasible arrestor system has been developed for shallow-draft locks typical on inland waterways. Such systems are, however, used in Europe. An example is the Netherlands’ Born Locks on the Meuse River that employ a fixed arrestor system to protect a miter gate. This lock has a 12-m lift. The fixed arrestor runs across the chamber at the downstream gate side. At the lower tailwater elevation, ships pass under the arrestor. The PIANC WG 138 Report discusses this system in more depth.

d. Design references for ship arrestors include the textbook “Lock Gates and Other Closures in Hydraulic Projects” (Paulus and Daniel 2018), the Saint Lawrence Seaway Management Corporation (SLSMC) study from March 2012, USACE HY-N-1.4, and the PIANC WG 138 Report. The design documentation for the new lock at the Soo Locks also provides design computations.

e. The ship arrestor should be located to mitigate the most frequent and costly accidents. The predominant location of ship arrestors is on the upstream side of the downstream gates within the lock chamber. They can also be located upstream of upstream gates, downstream of upstream gates, or downstream of downstream gates. However, the upstream side on downstream gates usually represents highest risk in terms of probability of occurrence and the highest potential for damage, as these gates are closed when ships heading downstream come into the lock chamber.

f. Another consideration in ship arrestor design is to determine if the variable pool elevations require an adjustment of the arrestor elevation for most effective response to the approaching vessel. In the case of a relatively fixed pool elevation, a stationary elevation for the arrestor is suitable. Otherwise, the arrestor should be capable of floating with the pool elevation or be equipped with operating machinery that can winch it into the proper position.

23–2. Ship arrestor design and classifications

The actual structural component that is impacted by the approach vessel can be one of several shapes. One type is a rigid beam (concrete or steel). This type of arrestor, however, can transfer significant forces into the lock walls and likely will cause damage to the ship. The most widely used arrestor type, a flexible cable, is effective on vessels with a V-shaped bow.

a. Ship arrestors can be classified according to function, location, structure or shape, method of moving the arresting medium into and from vessel passage, installation relative to pool elevation, and energy dissipation criteria. Unless the system is capable of being activated on short notice, the operation of the ship arrestor must take place during all ship locking. This is the case on the Welland Canal, SLS, and the Soo Locks. Common ship arrestor designs include the following:

(1) Boom and cable.

(2) Flexible net or dual cables.

(3) Dynamic bar.

(4) Rigid beam with or without shock absorbers.

b. The fender boom on arrestors is typically constructed of welded-plate girder made of aluminum or steel. The ship arrestor boom can be driven via a mechanical drive or hydraulic drive, as shown below in Figure 23–2. The mechanical drive uses a drive gear system with shafting that connects worm gears to a bascule portion of the base of the boom and drives the boom up and down. The hydraulic drive uses cylinders and consists of the boom, hydraulic cylinder, wire rope brake, receiving socket cylinders, and various associated machinery components.

a)

b)

Figure 23–2. Drive systems of arrestor booms: a) Welland Canal Lock 4E; b) Poe Lock

c. A means to transfer the energy from the ship collision needs to be provided. The most frequently used designs incorporate either hydraulic shock absorbers or brake drums to dissipate the collision energy. The Soo Locks use both types. The load analysis of a ship arrestor differs from the analysis of ship collision into a gate. This is primarily because most ship arrestors are not rigid and allow a great deal of deformation like the cable systems.

d. The SLS and Welland Canal in Canada have the most extensive ship arrestor systems in the world. Their ship arrestor systems were documented in the SLSMC report from 2012. Boom and cable systems are used, but the method of braking varies between the regions. The SLSMC also classifies these waterways as the Maisonneuve Region (MR) and the Niagara Region (NR). The Welland Canal is in the Niagara Region and the SLS in the Maisonneuve Region. There are 8 locks in the Niagara Region (Locks 4, 5, and 6 are double locks) and 7 locks in the Maisonneuve Region. All the locks throughout the Seaway are equipped with at least one ship arrestor. All locks always have one ship arrestor located upstream of the downstream lock gate.

e. The Welland Canal and SLS ship arrestors are either the fixed boom type or the free boom type (Figure 23–3). For the fixed boom type, the boom stays in place after placement. For the free boom type, the boom is retracted after placing the cable. Each SLSMC ship arrestor, whether in the MR or the NR, is based on the concept of using a wire rope cable connected to an energy absorption system. The fixed boom structure spans the lock with a wire rope attached to a braking bollard system and remains in that position when the vessel is in the lock. The free boom drops the wire rope into position and is lifted out of the channel until it is time to remove the rope and allow the vessel passage.

Figure 23–3. Saint Lawrence Seaway Management Corporation fixed boom a) and free rope; b) arrestors in Welland Canal, Niagara Region

f. Maintenance of any new ship arrestor system should be a consideration. Some older systems are maintenance intensive, including setting of clutches and brakes and replacement of the boom and cable. Ice loading of the arrestor boom is an issue at locks in northern climates, such as the SLS, Welland Canal, and the Soo Locks. Extensive ice buildup on the boom can significantly increase the operating load for the boom drive. From the PIANC WG 138 Report and discussions with the Soo Locks, Welland Canal, and the SLS, some O&M considerations that can be applied to all types of arrestors were noted as follows:

(1) The operation time of the fender boom machinery should be approximately 90 seconds.

(2) Account for ice loading on the fender boom. Assume the fender boom is loaded with ice across the full width of lock chamber. Waves from ships also will create ice on the boom.

(3) Operator errors can bring the arrestor boom down on top of a ship. This has happened several times at the Soo Locks. Incorporate interlocks and electric eyes similar to a garage door.

(4) The arrestor system needs to be tested periodically to verify the operational capability.

23–3. Ship arrestor loads and theory

The types of ship arrestors in use at navigation locks are diverse in scope and design. Each has been constructed for a specific set of design criteria related to the types of ships passing through the lock chamber. For a ship impacting the arrestor, regardless of the severity of the collision, the impact energy to be absorbed is given by the kinetic energy of the ship.

a. The energy absorption is a function of the mass and velocity and is limited by the ship size and lock dimensions. The kinetic energy of a ship is the energy it possesses due to its motion. It is defined as the work needed to accelerate a body of a given mass from rest to its stated velocity. Having gained this energy during its acceleration, the ship maintains this kinetic energy unless its speed changes by impacting the ship arrestor. Kinetic energy is defined by equation 23–1 as:

$$E_k = \frac{1}{2} mv^2 \tag{23–1}$$

where:

E_k = kinetic energy
m = mass
v = velocity

b. In SI units, mass is measured in kilograms, speed in meters per second, and the resulting kinetic energy is in joules. For the large forces involved in ship arrestors, the kinetic energy is often stated in KiloJoules (KJ) or MegaJoules (MJ). In English units, this energy can be stated in ft-lbs of force. The ship speed is a critical consideration. Since the kinetic energy increases with the square of the speed, a ship doubling its speed, for example, has four times as much kinetic energy. In specific cases, energy analysis also accounts for the shape of the vessel and the angle of its entry. The 2012 SLSMC study for ship arrestors assumed a vessel speed of 3 mph (2.61 knots or 1.34 m/s).

c. According to the SLSMC study, once a maximum vessel mass has been established, this mass should be increased by 10% to 15% to account for the translation wave that precedes the vessel entering the lock. This resulted in 40.1 MJ for the Niagara Region and 30.1 MJ for the Maisonneuve Region. These values account for data sets collected per location, including:

(1) Characteristic vessel traffic.

(2) Maximum possible vessel speeds limited by ship hydrodynamics within a lock.

(3) Representative vessel size and velocity.

d. The energy absorption capacities of the arrestors are based on:

(1) Design of the braking system, including the brake force and related frictional forces used to absorb energy.

(2) Capacity limits, including arrestor system component strength.

(3) Serviceability limits, including allowable stopping distance before gate contact or limits on the arrestor system displacement.

e. The SLSMC study accounts for the hydrodynamics of a ship transiting a lock and provides a detailed analysis for calculating the kinetic energy of a ship, as shown below in equation 23–2. As a large ship enters a channel or a lock, its hydrodynamics differ significantly from those in open water. The SLSMC report has calculated maximum possible collision energies based on ship hydrodynamics within a lock and on the specific geometry at each lock. Equation 23–2 indicates that it is the longest ships, not necessarily the heaviest ships, that result in the highest kinetic energies.

$$E_k = \frac{1}{2}\left(\rho \cdot L \cdot C_p \cdot A_m\right)v^2 \tag{23–2}$$

where A_m is the submerged midship section area, defined in equation 23–3 as:

$$A_m = B \cdot T \cdot C_m \tag{23–3}$$

where:

B = overall beam length
T = mean draft
C_m = midship section coefficient
ρ = density of water
L = vessel length overall
C_p = prismatic coefficient
v = velocity

f. For the Seaway ship arrestors in both regions, the primary energy absorption mechanism is friction. In the Niagara Region, a rotating bollard or drum is resisted by the friction between the bollard plates using compression springs (Figure 23–9). In Maisonneuve Region, the rotation of the wire drum is resisted by the friction of the brake shoes acting on brake drums (Figure 23–10). Table 23–1 lists the vessel design parameters used originally for the ship arrestors and calculation of the kinetic energy to be absorbed.

Table 23–1
Original ship arrestor design parameters from the 2012 Saint Lawrence Seaway Management Corporation report

Parameter	Niagara Region	Maisonneuve Region
Design vessel displacement	40 642 tonnes	30 481 tonnes
Design vessel speed	1.34 m/s	1.34 m/s
Kinetic energy of vessel	36.5 MJ	27.4 MJ
Reported original factor of safety	1.70 at full extension	1.62 at full extension for a full-size vessel with fine prow
Kinetic energy of vessel plus 10% mass of water moving with the vessel	40.1 MJ	30.1 MJ

g. The SLSMC conducted an extensive study to determine actual operating forces for the ship arrestors. In many cases, the speed at the arrestor exceeded the value of 1.34 m/s as originally designed. In part, this is due to the original design not considering the full range of ship sizes. Further, the study was based on the worst-case scenario in which the vessel continues through the lock and runs into the ship arrestor at full speed.

h. The study indicated that the maximum possible velocity of a ship at the arrestor (assuming continuing full thrust) decreases with increasing ship size for a fixed size of lock. Therefore, it is possible that the maximum kinetic energy for design may correspond to a smaller ship traveling at a higher speed. This results from reduced midship section area relative to the lock dimensions.

i. The design basis for the impact loads of the Poe Lock ship arrestors at the Soo Locks is shown in Figure 23–4. This figure was extracted from the original design and construction drawings from 1968. The ship arrestor at the Poe Lock is used for all ship locking and uses 3-1/2-in. diameter wire rope. The design is graphed with retarding force plotted against the distance the ship travels after impact. The design basis for ship velocity at the Poe Lock was taken at 4.6 mph (2 m/s). A 40,000-tonne ship traveling at 5 mph (2.2 m/s) would exceed the capacity of the arrestor system.

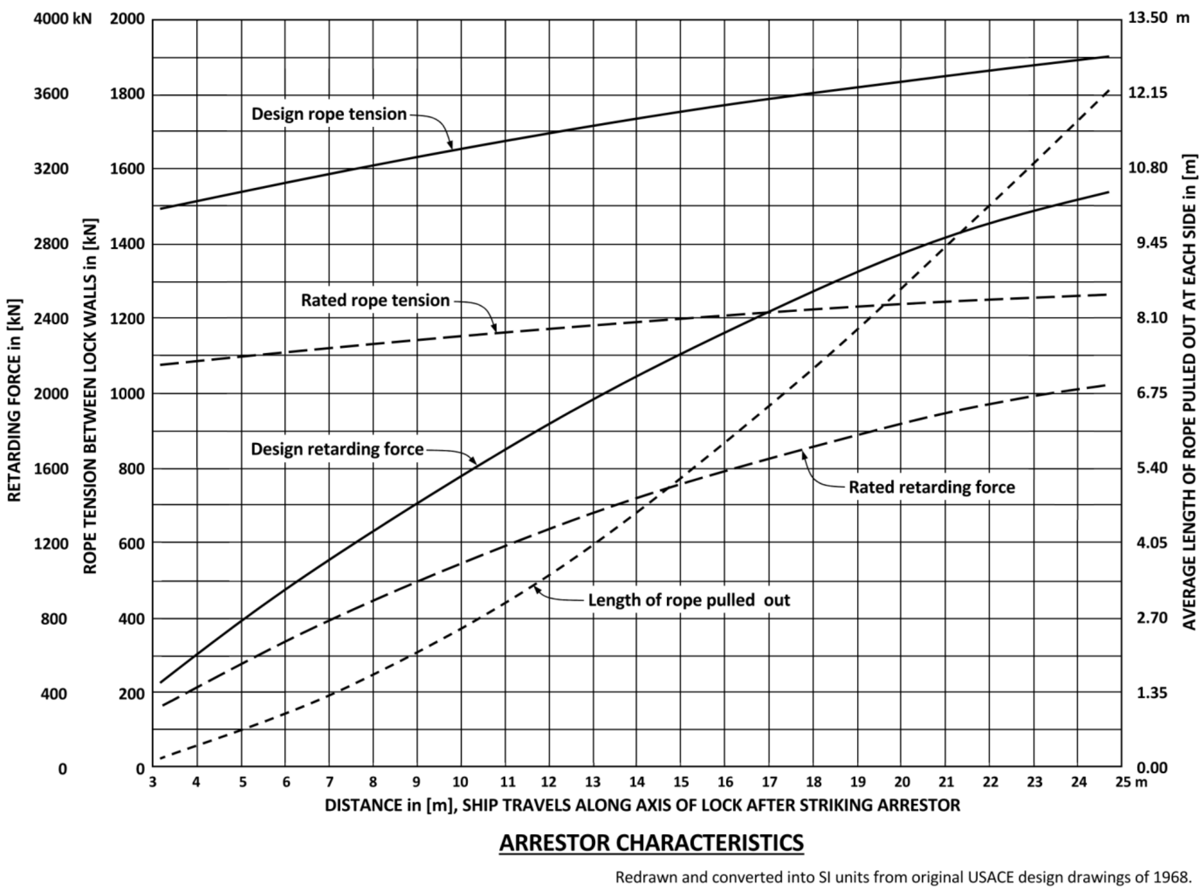


Figure 23–4. Poe Lock ship arrestor design basis

23–4. New Soo Locks arrestor design

Ship arrestors will be included for the new lock at the Soo Locks. A boom and cable system will be used like the other locks, but the arresting and braking system is a different design. Instead of using large hydraulic cylinders or mechanical brakes to provide the braking force, the new system will use more compact winch-type units with hydraulic motors to provide the braking force. The design requirements for the ship arrestors were also revised from the Poe and MacArthur Lock arrestor design.

a. The new ship arrestor braking machinery will consist of a spiral plate bolted between two gears with resistance provided by two hydraulic motors (Figure 23–5 and Figure 23–6). One side of each gear in contact with the spiral plate is flat to retain the wire rope as it winds on itself. The end of the new arrestor rope will be fitted with a special rope socket and contained within the spiral plate and gear assembly. Gears were used to help reduce the size of the hydraulic motor required. This drum arrangement is like the spiral drum gate hoists using hydraulic motors used in USACE for operating tainter gates.

b. The spiral plate and gear assembly will be mounted on a shaft supported by plain greased bearings. The gears for this assembly will mate with pinions integral with a common shaft and are connected to the two low-speed, high-torque hydraulic motors. Resistance to the drum turning is provided by a pressure relief valve in the motor hydraulic circuit.

c. The braking units do not see any use except in case of a ship impact. The braking units are supplied with their own compact hydraulic power units (Figure 23–6) to rewind the wire rope onto the spiral drum. Figure 23–6 shows the unit mounted on a test rig in the contractor shop. The arrestor rope is 3 ½-in. diameter, 6 x 36 IWRC rope with a minimum breaking strength of 1,128,000 lbs. The rope has a minimum factor of safety of 1.86 based on the peak arrestor rope load. The individual wires in the strands are galvanized.

d. The new design accounts for larger ships transiting the lock. The increase in the displacement of the ships transiting the Poe Lock has rendered the existing ship arrestor incapable of stopping these larger ships in the original designed stopping distance before impact with the miter gates. For this reason, an effort to increase the capacity of the ship arrestors was undertaken.

e. It was determined that design of the ship arrestor would be based on a circular- or parabolic-bow ship displacing 100,000 short tons traveling 2.5 mph with the capability of stopping within 81 ft. It is expected that this design of the ship arrestor will not stop a pointed-bow ship displacing 100,000 short tons in 81 ft. Consequently, the maximum displacement of a pointed-bow ship that could be stopped in 81 ft was determined to be 76,000 short tons. This was compared to the Great Lakes fleet transiting the Poe Locks and it was found that there was no ship displacing more than 76,000 short tons.

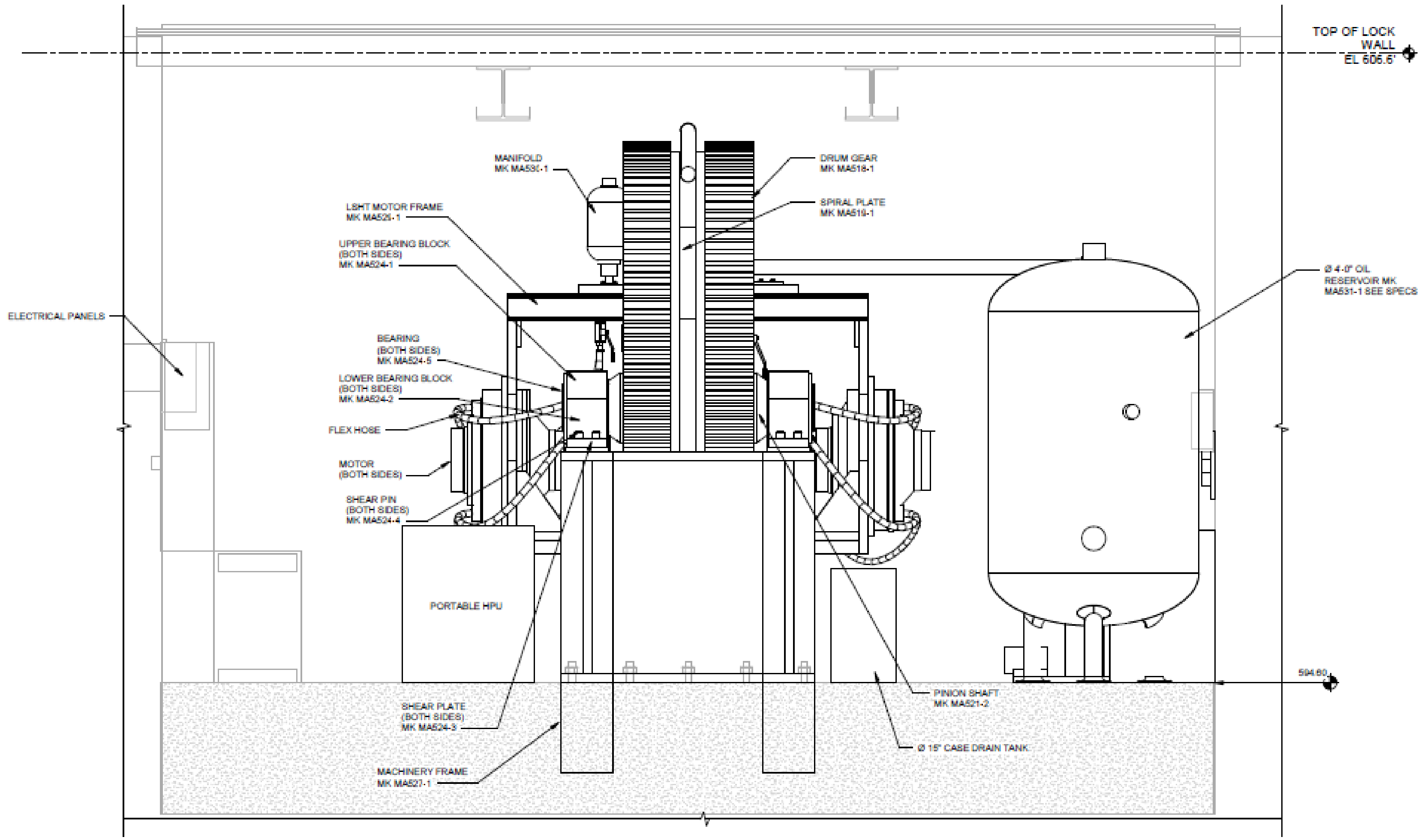


Figure 23–5. New Soo Locks arrestor design

Figure 23–6. New Poe ship arrestor mounted on test rig

23–5. Boom, cable, and brake systems

The means of arresting the cable can vary as discussed above. One end of the cable can rigidly be fixed to the chamber wall, causing the energy to be absorbed by a hydraulic cylinders or brakes located in the other lock wall. This is the system used at the Soo Lock MacArthur Lock and the Maisonneuve Region arrestors.

a. More common are arresting systems on both sides of the lock wall, which splits the forces imparted into the arrestor (Figure 23–6). This system is used at the Poe Lock and all the SLSMC ship arrestors in the Niagara Region (Welland Canal). The arrestor cable can be removed from the vessel path by means of a boom that lowers to catch the cable and either raises to an upright position or swings horizontally to the side. Figure 23–7 schematically shows the energy resisted by the span cable as a function of displacement δ of the vessel bow in contact with the cable. With increasing displacement, the cable angle θ also increases, causing growth of the retarding component of cable tension $\boldsymbol{T}$. This can also be observed in the graph for the Poe Lock ship arrestor in Figure 23–4.

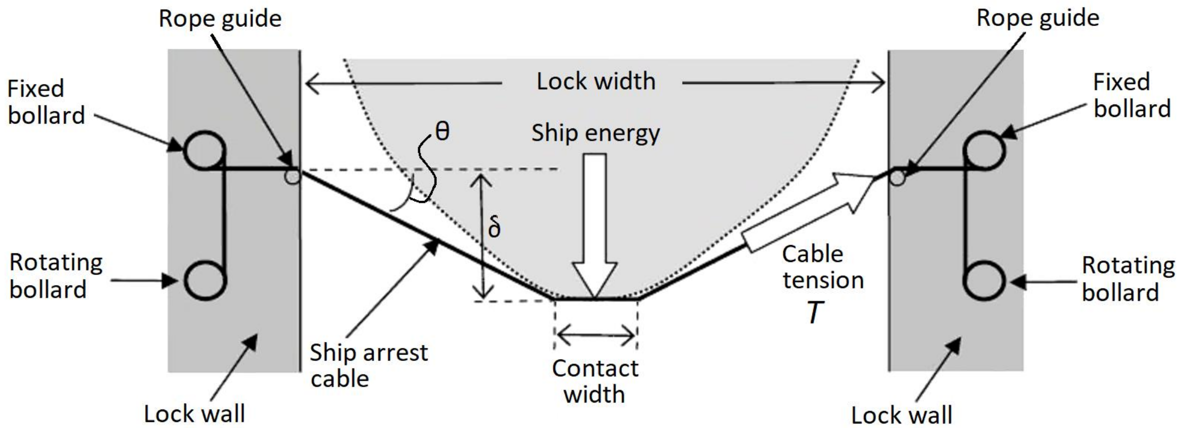


Figure 23–7. Load scheme for Saint Lawrence Seaway Management Corporation ship arrestor (from Saint Lawrence Seaway Management Corporation Report)

b. The SLSMC uses both mechanical drives and hydraulic drives to move the boom as discussed above. As of 2009, all arrestors in the Niagara Region (Welland Canal) have been converted from mechanical to hydraulic drives as shown in photo a) in Figure 23–2. The arrestor booms in the Maisonneuve Region still use a mechanical drive system that drives a trunnion and gear assembly on a rolling bascule track. These systems were installed in the mid-1950s and modified in 1965. The Soo Locks use hydraulic drives to move the boom for both the Poe and MacArthur Locks. Figure 23–8 shows the drive wheel and cog of the Poe Lock boom.

Figure 23–8. Poe Lock boom drive

c. At the Soo Locks, Welland Canal, and SLS, both mechanical and hydraulic systems are used for the braking. Hydraulic braking systems employ hydraulic cylinders with piston rods fixed to the ends of the wire rope. If run into by a ship, the wire rope extends a piston rod, which, in turn, provides the resisting force. In the United States, a hydraulic brake system is used for the Poe Lock, while a mechanical brake system is used for the MacArthur Lock.

d. The arresting portion of the ship arrestor system at the Poe Lock is substantially different than the MacArthur Lock. Schematics of this system are shown in Figure 23–9. There are arresting cylinders or brake cylinders on each side of the lock (both upstream and downstream).

(1) The project plans call these cylinders “brake cylinders.” There are three key components here including: brake cylinder, cross head, and the wire rope sheave. All of this equipment is located in what is called the brake cylinder recess on the plan sheets. The recess is just a deep rectangular pit located in the gallery area of the Poe Lock.

(2) The cross head is a structural steel fabrication that rides up and down on tracks in the cylinder recess. The brake cylinders are pinned and connected to the cross head at the bottom of the cross-head unit. The wire rope goes around the large sheave, which is also connected to the cross head (near the top of the cross head). In the event of a ship impact, the wire rope and sheave pulls the cross head up in its track which, in turn, extends the cylinder.

(3) The arresting cylinders or brake cylinders do not use an HPU. Instead, there is simply a reservoir for the hydraulic fluid. As the cylinder is extended during a ship impact, the hydraulic fluid goes through an orifice, creating resistance, which acts to “arrest” the ship. Once the cylinder is retracted, the hydraulic fluid goes back to the reservoir.

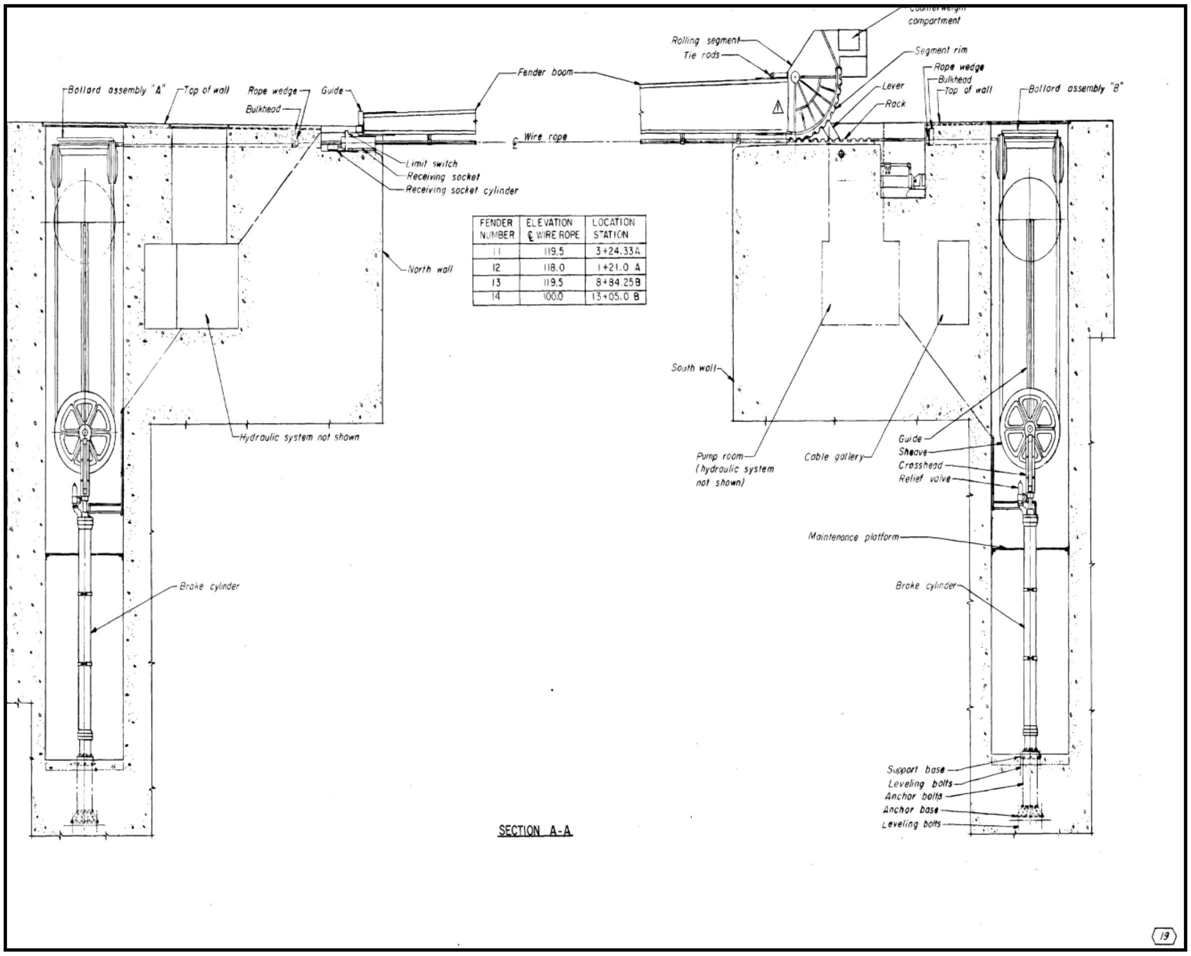


Figure 23–9. Poe Lock ship arrestor section view; note the sheave and cross head and arresting cylinder

e. In a mechanical braking system, the capacity of the energy absorption is provided at the lock wall by both the wire rope friction of the rotating bollard and the wire rope movement about the fixed bollard, as schematically shown in Figure 23–7. This is the system used at the MacArthur Lock and the Welland Canal Locks in Niagara Region. The SLSMC braking systems are designed to absorb the energy and stop the ship within the maximum distance of 21.95 m, prior to contacting the miter gates.

f. The Welland Canal ship arrestors primarily use a rotating brake drum (Figure 23–10). For a rotating brake drum, the cable is spooled around a brake drum, which rotates to pay out the span cable. The rotation of the brake drum is resisted by the frictional forces created by the friction plates when compressed by the brake springs. The frictional force is multiplied by wrapping around the fixed bollard first. The cable wraps several turns around the rotating bollard drum and dead-ends on it. The brake drums are located on each side of lock to engage the ship arrestor symmetrically. At the Soo Locks, the MacArthur Lock ship arrestors are similar, but the brake drum is located on one side of the lock only. As such, the forces are not symmetrical when the arrestor is engaged.

Figure 23–10. Typical brake drum and compression springs, Niagara Region, Lock 6

g. For the Maisonneuve Region, energy absorption occurs on one side of the lock only, with the latched end of the span cable remaining fixed. The mechanical system consists of a retarding drum, brake shoes, clutch, motors, and link belts (Figure 23–11). The drums have two brakes at one torque setting, and two brakes set at 50% of that setting, causing their disengagement after 12.2 m of travel. So, the braking force is reduced (not ramped) at about the midpoint of the ship travel in a collision.

Figure 23–11. Brake drum at St. Lambert Lock, Maisonneuve Region

h. The wire rope latching system is also yet another consideration. As the boom is lowered and brings the span cable to the opposite lock wall, a latching mechanism engages the dropped end. This mechanism is either mechanical or hydraulic. The Poe

Lock uses a hydraulic latching system, and the MacArthur Lock uses a mechanical latching system. Wire ropes are 88.9 mm (3 ½ in.) in diameter at both locks.

23–6. Advantages and Disadvantages

Lessons learned from the Soo Locks, European Locks, and the SLSMC locks include the following:

a. Boom should be sacrificial. The intent is to save and prevent damage to the lock gate.

b. Hydraulic drive system is less maintenance intensive and preferred.

c. Elastomeric buffers and springs should be considered for fixed arrestors.

d. Absorption mechanism should be of hydraulic type, therefore minimizing maintenance.

e. Marine-rated LED warning light fixtures should be provided at each fender boom. These boom warning light fixtures should be illuminated at all times.

f. Greasing of the various fender boom bearing components should be done with an automated system.

g. The operation time of the fender boom machinery should be approximately 90 seconds.

h. Position sensing of the fender boom piston rod should be provided by a magnetostrictive, continuous, linear position-indicating system on the cylinder. This system provides appropriate slow-down points during opening and closing of the boom.

i. Account for ice loading on fender boom. Assume fender boom is loaded with ice across the full width of lock chamber. Waves from ships also will create ice on the boom.

j. Operator errors can bring arrestor boom down on top of the ship. This has happened several times at the Soo Locks. Incorporate interlocks and electric eye.

k. A vessel self-spotting system is used on the SLS. This could be combined with an arrestor system.

l. The drive system should match the system used to operate miter gates and culvert valves.

m. The arrestor system needs to be tested periodically to verify the operational capability.

Chapter 24
Wicket Gates

24–1. Wicket gates

Wicket gates are used in different applications, including for hydropower. In this manual, only the application of a wicket gate used to create a dam will be covered. A wicket gate, or wicket, as shown on Plate 70, is a structurally framed gate attached to the sill of a dam. Wicket gates allow open pass navigation on a waterway bypassing the lock.

a. Wicket gates are installed side by side and, when raised, create a wicket dam that restricts flow to increase the depth of the upstream pool. Wicket dams are used at USACE facilities to maintain required river navigation depths during periods of low river flow. Wicket gates are installed at several sites on the Illinois Waterway (Figure 24–1 and Figure 24–9). There are 109 wicket gates at LaGrange Dam and 108 wicket gates at Peoria Dam. They were used previously at Locks 52 and 53 on the Ohio River before their demolition when Olmsted came online. They are used at the new Olmsted dam on the Ohio River.

b. When river flows are high enough to maintain required pool levels without restricting flow, wicket dams are lowered so the wickets lay flat on the sill of the dam. When wickets are in the lowered position, vessel traffic can pass freely over the top. Most commonly, wicket gates are designed with a flat skin plate reinforced with structural members. Curved skin plate wickets also have been designed. However, curved skin plates are less common because they are more likely to develop low-pressure areas as flow passes around the wicket during raising and lowering, which can increase operating loads. In their raised position, wickets sit at a fixed inclined angle.

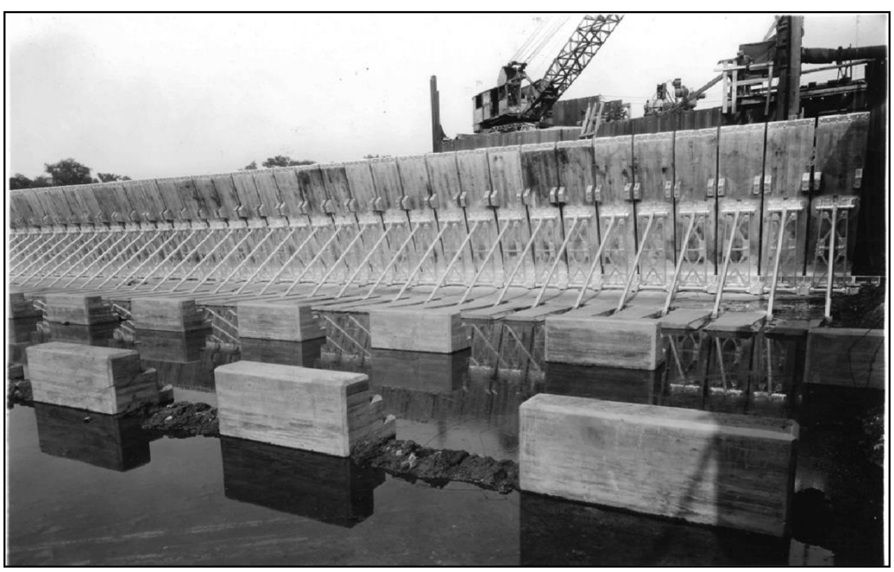


Figure 24–1. Manually operated wicket gates in the raised position (viewed from the downstream side)

24–2. General considerations

Manually setting wicket gates is extremely dangerous for lock personnel. The setting, maintenance, and operation of these gates have life safety implications. Any new wicket gate designs should be done to minimize life safety risks and minimize O&M. It typically takes a crew of 10 or more personnel to set wicket gates.

a. Operating machinery. Wicket gates are raised and lowered by mechanical means. There are multiple operating machinery types that are discussed in more detail below. The function of each machinery type is to raise a wicket gate against flow (no dewatering devices are installed for typical raising and lowering functions) and support the gate for the duration it is raised. Manually operated wickets are outfitted with a frame, called a horse, and a prop that support the wicket in the raised position.

b. Bearings. All bearings associated with wicket gates should be of the self-lubricated type as discussed in Chapter 2.

c. Operating system design. Specific design guidance for wicket gates is provided in the Fort Belvoir Engineer School Design Manual, Canalization of the Upper Mississippi River and Ohio River (USACE, The Engineer School 1939). Wicket gate designers also should reference USACE WES TR SL-97-12 (de Béjar 1997) for the hydraulic forces on a wicket gate. Wicket gates are considered a Type A hydraulic steel structure, per EM 1110-2-2107. The design of a wicket gate’s mechanical operating system must be coordinated with the appropriate structural designers.

d. Wicket gate types. Bebout and Chanoine wicket gates are the type used within USACE. A schematic overview is given in Figure 24–2. The earlier wicket gates had the rotation axis of their leaves at the bottom sill. Any adjustment for different levels was then particularly difficult because the gate movement under hydrostatic pressure required large forces. Such wickets could, therefore, be used only on the sites where no adjustments were required (for example in temporary cofferdams), and on relatively shallow rivers or rivers with small differential heads over the gate.

(1) This changed with the invention of Chanoine wickets, the leaves of which are hinged and supported to the structure behind them and at a higher level. That level is chosen to ensure the stability of the gate leaf, while the drive force to tilt that leaf is relatively small. This force was applied by chains hooked to both the upper and lower edge of the leaf and driven by winches located on a bridge at the upstream side of the dam.

(2) Bebout and Chanoine wickets are generally similar, and the design analysis as given for Chanoine wickets may be applied to those of the Bebout type. However, the hinged horse and pinned prop without hurter, which provide for the automatic tripping that characterizes the Bebout wicket, make the detail design somewhat different even though the stress analysis is the same. Also, the location of the wicket box becomes much more important. General rules that provide a large margin of safety against breeching, even with a considerable head over the tops of the wicket, are used to locate

the wicket box of a Chanoine wicket, but a more precise determination is necessary for the Bebout wicket if tripping is to occur at a certain point.

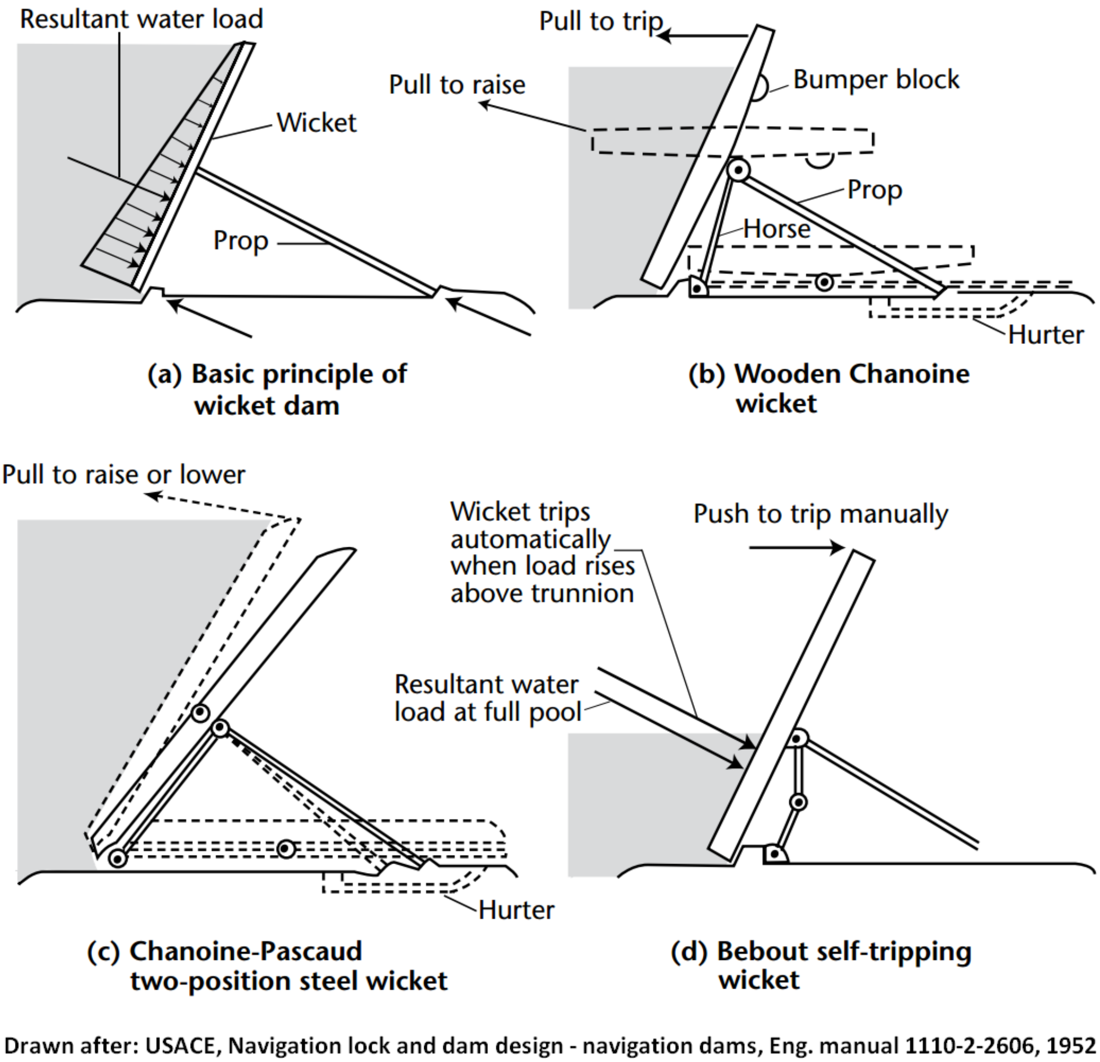


Figure 24–2. Common wicket gate systems and components

e. Manually operating wickets by floating vessel. Manually operated wickets are raised and lowered using equipment mounted on a floating vessel. The equipment, usually a crane or excavator with a custom-designed hook, raises each wicket individually as the vessel is maneuvered across the river. See Figure 24–3 and Figure 24–4. This equipment setup is currently used at projects such as Peoria Lock and Dam (L&D) and LaGrange L&D. A custom-designed wicket lifter is used at the Olmsted dam due to the larger steel design of the wicket gates (Figure 24–5). The wicket lifter uses a knuckle boom crane with GPS and a sonar camera system to locate the lifting pin of each wicket under water (Figure 24–6). Both vessel types are not self-propelled and require a tow boat to traverse the site.

Figure 24–3. Modified excavator for operating manual wicket gates

Figure 24–4. Another modified excavator for operating manual wicket gates

Figure 24–5. Wicket lifter vessel at Olmsted for operating manual wicket gates

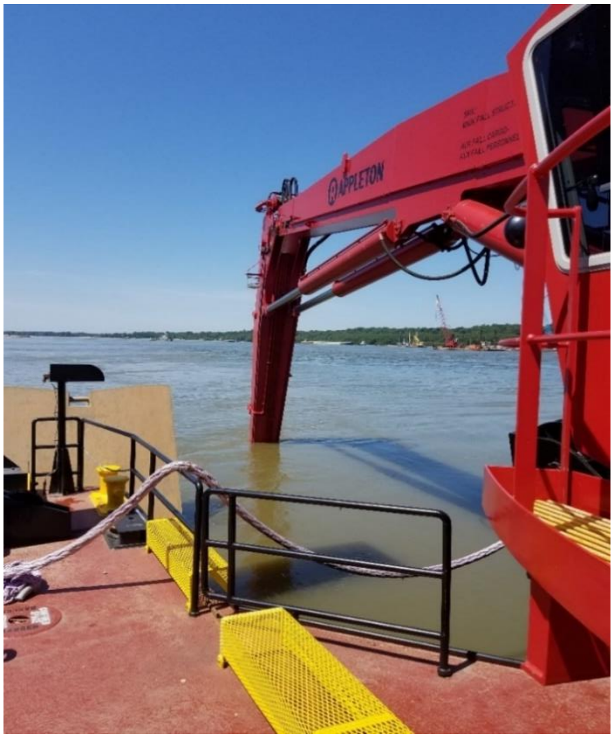


Figure 24–6. Wicket lifter crane at Olmsted raising manual wicket gate

f. Manually operating wickets by fixed overhead crane structure. The wicket lifting hoist at Amaropolis Dam in Brazil uses a fixed overhead crane structure that allows two maneuver cars, one for each side of the dam, to traverse by way of rails to each wicket to operate it. See Figure 24–7 and Figure 24–8.

(1) Each maneuver car contains one mobile electric hoist with a capacity of 50 kN. The maneuver cars are equipped with trolleys that have rack/pinion operated swing arms. There are movable coupling arms at the end of the swing arms that have hooks for connecting with each wicket gate. Each maneuver car uses motors to traverse the dam and to raise the wickets.

(2) The wickets can be set in the fully open and closed positions as well as five intermediate positions. There are limit switches present to assist in automatic operations to reduce the potential for impacts with the structure.

Figure 24–7. Wicket lifter overhead crane at Amaropolis Dam

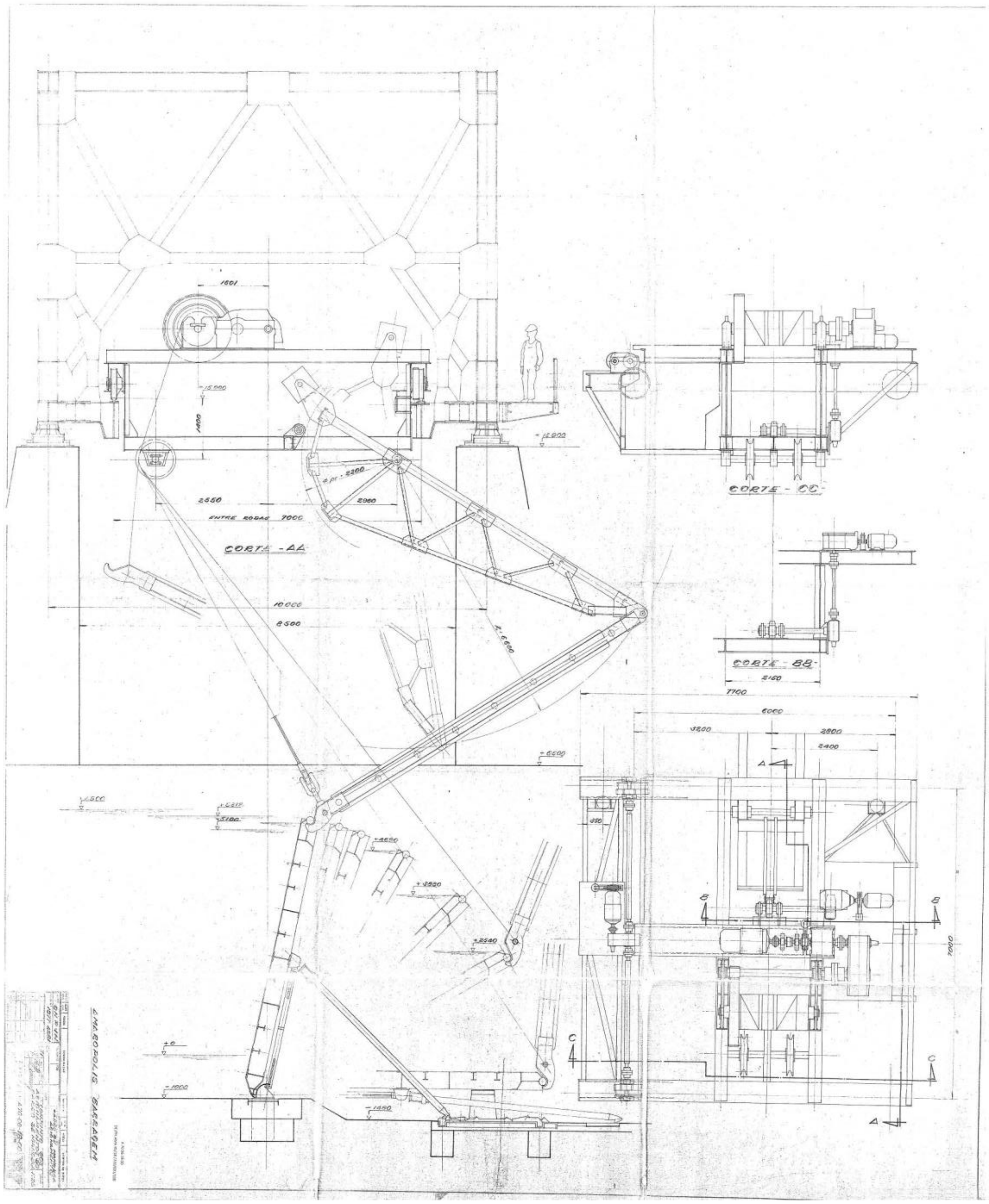


Figure 24–8. Wicket lifter overhead crane at Amaropolis Dam drawing

g. Raising. To raise a manually operated wicket gate, the floating vessel-mounted lifting equipment is manually hooked to an attachment point on the upstream end of the wicket. A pivoting frame, called a horse, is connected to the sill on one end and to the midsection of the wicket on the other end. See Plate 70. At Olmsted Dam, the wickets are raised by a pin on the downstream side of the wicket due to inadequate space for the geometry needed to raise from the upstream pin. This does increase the force needed to raise the wickets as water cannot easily flow under the wicket as it does when raising from the upstream side. Olmsted Dam does have a hydraulically operated tainter gate section of the dam that should be in the raised position to reduce the head pressure against the wicket section of the dam as it is raised.

(1) A prop is mounted on the bottom of the wicket at the horse, to the wicket pivot point. See Figure 24–9. As the wicket is lifted, the horse rotates forward, pulling the prop through a track assembly, called a hurter, which is mounted to the downstream sill (Figure 24–10 and Figure 24–11). As the wicket is lifted from the sill, the flowing water passes under the wicket and aids in lifting (the wicket stays relatively horizontal during lifting).

Figure 24–9. Lagrange wicket gates

(2) When the horse has reached a designated angle with the sill, the prop is designed to fall into a notch in the hurter. After the prop drops into the notch, the upstream lifting connection to the wicket is released and the current holds the wicket elevated horizontally from the sill. The wicket then is rotated into position by pushing the upstream end of the wicket down. As the upstream end of the wicket lowers, the force from the water current flowing past the wicket increases below the pivot point (fulcrum) at the midspan of the wicket.

(3) The wicket is pulled into contact with the sill as the moment from the forces below the fulcrum of the wicket overcomes the moment from the forces above. When the wicket is set in its raised position, the hydrodynamic and/or hydrostatic pressures (depending on the differential pool and flow past the gates) on the upstream face of the gate hold the wicket steady against the sill and wicket prop. Plate 70 shows the different stages of raising a manual wicket.

(4) Since the wickets at Olmsted Dam are raised from a downstream connection point, the wickets pivot at the pivot point but do not float in the horizontal position during raising. The horse and prop rotate with the wicket and the prop moves along the hurter and falls into the notch, just like raising a wicket from the upstream side. When the prop engages with the hurter, the wicket can be released from the wicket lifter. Since the wicket is already upright and not floating in the horizontal position, the wicket does not need to be pushed down into flow. Like the wickets raised by the upstream lift point, the hydrodynamic and/or hydrostatic pressures (depending on the differential pool and flow past the gates) on the upstream face of the gate hold the wicket steady against the sill and wicket prop.

h. Lowering. A connection point on the top of the inclined wicket is used to lower a manually operated wicket gate. The vessel-mounted equipment pulls the top of the wicket upstream, rotating the wicket about the sill into the flow of the river. As the wicket is rotated, the movement of the wicket pulls the prop out of the notch in the hurter.

(1) After the prop clears the notch, it falls into a different groove and does not reset into the notch as the wicket is lowered. Once the prop is clear, the wicket is released from the equipment and falls under the influence of gravity back to a flat position on the sill. The water under the wicket cushions the impact of the falling wicket. The hurter is designed to realign the prop for the next lifting operation of the wicket as the wicket moves to its lowered position.

(2) Due to the size and weight of the wickets at Olmsted, ERDC performed a study to determine whether lowering the wickets by gravity would be detrimental to their long-term durability. The result of the study was to manually lower the wickets to the sill using the wicket lifter to reduce the repeated impacts the wicket would experience if lowered by gravity.

24–3. Hurter design

Hurters are typically a fabricated steel weldment that is embedded in the concrete under the wicket gate (Figure 24–10 and Figure 24–11). When designing a wicket dam that uses a hurter and prop, the hurter should be designed so the movement of the prop through the hurter return guide is assisted by the river flow around the lowered wickets. For example, if the wicket dam is designed to be lowered from right to left, looking downstream, the hurter prop return guide should be located on the left, looking downstream. If the flow around lowered wickets are not taken into consideration when designing the hurter, lowering operations could be inhibited due to water flow preventing the prop from moving to the return guide in the hurter.

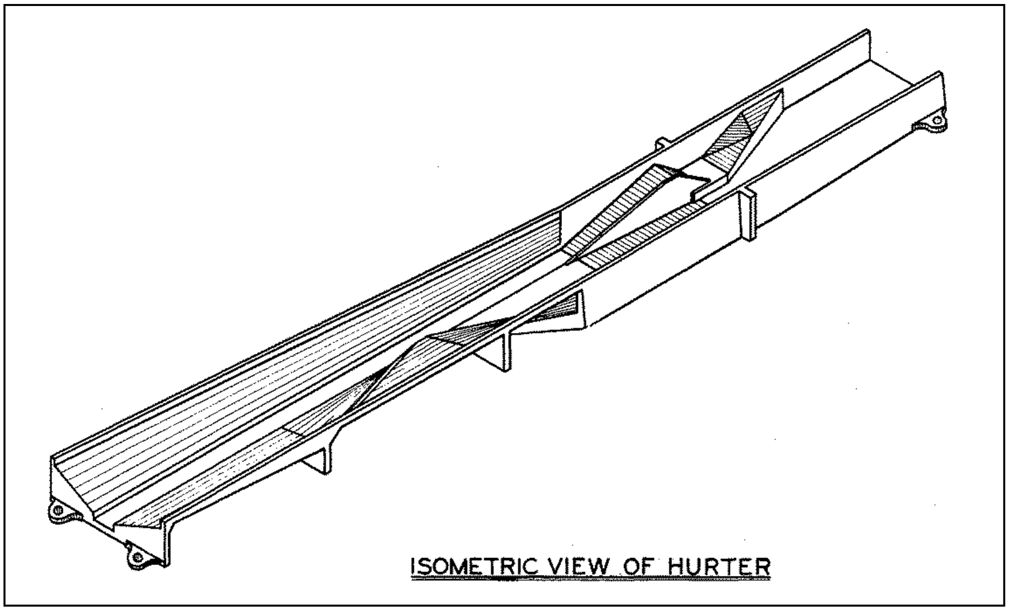


Figure 24–10. Hurter isometric sketch

Figure 24–11. Wicket gate hurter

24–4. Advantages

Manually operated wickets minimize the amount of submerged mechanical equipment. Operation of the gates does not rely on a dedicated hydraulic system that otherwise would have to operate in a submerged environment. The submerged mechanical equipment is limited to the horse-prop frame and hurter, which are relatively easy to design for a submerged environment.

24–5. Disadvantages

Manually operated wickets are labor intensive because raising and lowering a wicket dam require a team of people to operate the floating vessel and wicket-lifting equipment. Locks 52 and 53 on the Ohio River, which have been taken out of service and replaced by Olmsted L&D, required a crew of about 20 to set the wicket gates. Lifting a wicket requires connecting the lifting equipment to the wicket lifting point. The wicket lifting point cannot be seen from the floating vessel. The connection to the lifting point must be made by feel. The Olmsted wicket lifter vessel does have GPS and a sonar camera to aid in finding the lift locations. Both the excavator type and Olmsted wicket lifter vessel require a skilled operator to perform the lifting operations.

24–6. Dedicated operating system wickets

a. Two styles of dedicated wicket gate operating systems have been tested by USACE, Figure 24–12 and Figure 24–13. While neither have been selected for use at a USACE facility (to date only manual wickets are used), full-scale testing on each has proven the operating systems to be successful. The two types are a retractable hydraulic cylinder and a dedicated, direct-connected hydraulic cylinder.

b. These systems, along with manual wicket gates, were considered for installation during the planning stages of Olmsted Dam. The primary advantages of dedicated operating system wickets are there are significantly fewer operational safety risks and they take less time and labor to operate. However, manual wickets ultimately were chosen.

c. Olmsted Dam is on a wide stretch of river and required approximately 140 wicket gates. The dedicated operating systems have higher maintenance costs. There were also risk concerns with cylinder change-outs and during general maintenance efforts. Overall, the higher maintenance costs for so many wickets outweighed the lower amount of labor required to operate the wickets. While the dedicated operating system wickets were not feasible for such a large application, they are still a viable choice for narrow rivers.

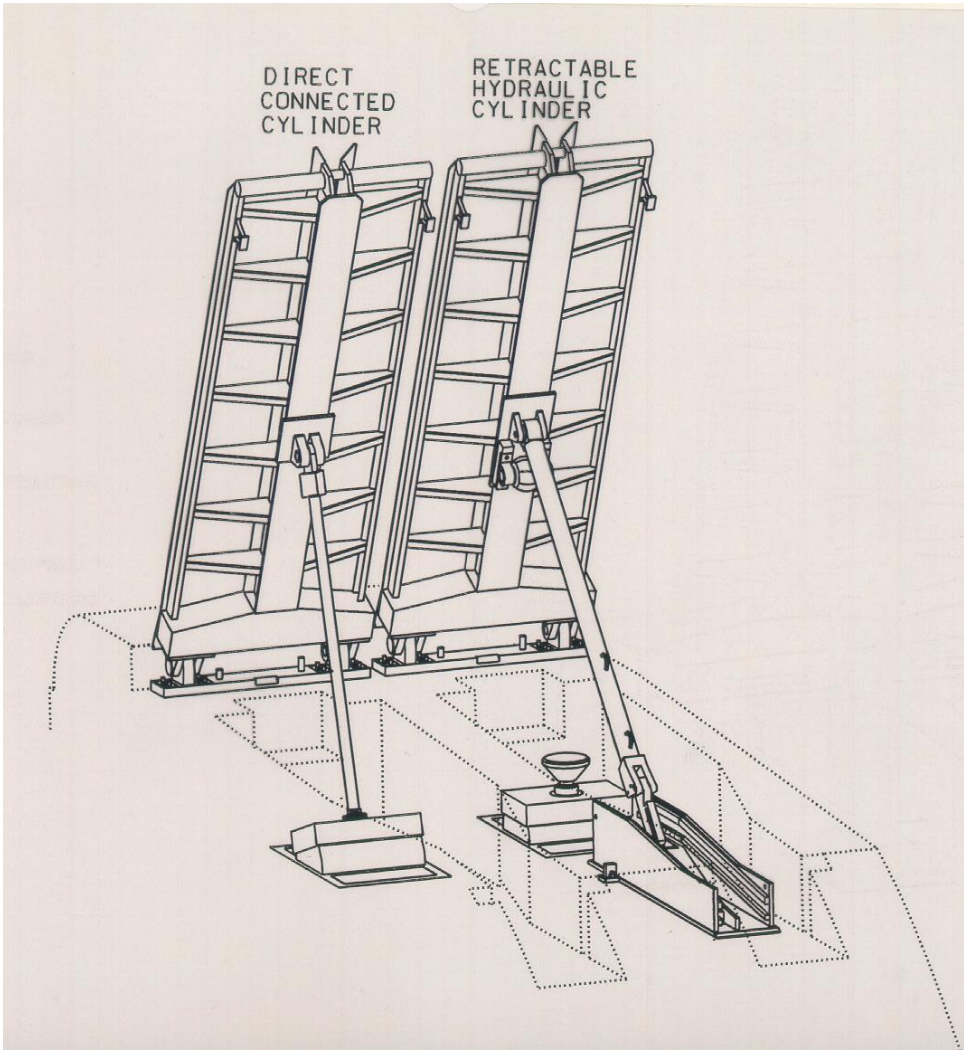


Figure 24–12. Retractable hydraulic cylinder and direct-connect cylinder wicket gate

Figure 24–13. Full-scale Olmsted Dam wicket gate prototypes (showing retractable hydraulic cylinder and direct-connect cylinder styles)

24–7. Retractable hydraulic cylinder wickets

The retractable hydraulic cylinder wicket, shown in Plate 71, uses the same principles as the manual wicket with a few modifications. Instead of using a vessel-mounted lifting device to operate the gate, a hydraulic cylinder with an HPU is used. The cylinder is under the lowered gate. The gate is hinged at the crest, and it pivots about the hinge as it operates. The retractable cylinder lifts the wicket until the prop engages the hurter to support the gate (like the manual wicket). The hydraulic power unit can be located on shore, above flood stage, or in a gallery beneath the wicket, depending on the size of the dam being built. The wicket is connected directly to the sill on the upstream end and does not use a horse frame.

a. Advantages. The advantage of the retractable hydraulic cylinder over the direct-connect cylinder is the use of a prop to support the gate while it is in the raised position. Leakage past the cylinder piston will not affect the incline position of the wicket over time.

b. Disadvantages. The retractable hydraulic cylinder system is more complex. A secondary cylinder is required to position the main lifting cylinder to perform the lowering operation.

c. Operating speed. A raising time of 12 minutes, lowering time of 3 minutes, and operating time of the secondary cylinder of 10 seconds was found to be successful for the Olmsted prototype testing.

d. Raising. The wicket is raised into position by rotating it from downstream to upstream about the hinge of the gate. The retractable design is made of two cylinders, one for raising and lowering the wicket and one for aligning the raising and lowering cylinder. The hydraulic cylinders are mounted under the wicket. The lifting cylinder's piston rod is mounted with a cup that engages a ball mounted on the downstream side of the wicket. The wicket is raised by extending the lifting cylinder, which engages the ball and rotates the wicket to a fixed angle where a prop engages a notch in the hurter in the same manner as the manually operated wicket design. Once the prop is set in the notch, the combination of current and gravity of the inclined wicket keep the prop securely fixed in the hurter. The piston rod is retracted to remove it from potential damage caused by debris.

e. Lowering. To lower the wicket, a second smaller alignment cylinder is used to align the larger lifting cylinder to the proper angle to contact the cup with the ball and the gate. The piston rod rotates the wicket forward until the prop clears the notch in the hurter and the flow of fluid out of the cylinder controls the speed at which the wicket lowers.

24–8. Direct-connected hydraulic cylinder wicket

The direct-connected cylinder design is very basic. One cylinder is connected directly to the back side of the wicket, as shown in Figure 24–12. The connection is made at the same location the prop is connected to in the retractable cylinder design. To raise the gate, the cylinder is pressurized and the piston rod extends, rotating the wicket to the inclined angle. The hydraulic cylinder valves hold the wicket in the raised position until the wicket is lowered.

a. Advantages. The main advantage of the direct-connect cylinder system is simplicity. It relies on only one cylinder for operation, eliminating the need for a prop-and-hurter system.

b. Disadvantages. The main disadvantage is that this system relies on the cylinder to support the wicket gate during the entire time the gate is raised. The cylinder valves must maintain hydraulic pressure in the cylinder to support the wicket. Leakage past the cylinder piston seal also could result in unintended lowering of the raised wicket over time.

c. Operating speed. A raising time of 12 minutes and lowering time of 3 minutes was found to be successful for the Olmsted prototype testing.

24–9. Composite wickets

Wicket gates have historically been constructed of wood, steel, or a combination of both. Fiber-reinforced plastic (FRP) composites are gaining interest and are being investigated for their feasibility of use. They are designed to be interchangeable with steel wickets and use the same steel horse and prop support as a traditional wood or steel wicket. The primary difference is that the wicket itself consists of an internal steel structure with a composite exterior. Testing of composite wicket performance has been conducted at various project sites as detailed below.

a. Experimental testing of a full-scale composite wicket for use at Olmsted was conducted at the Smithland Lock and Dam facility in the late 1990s. The results are detailed in “Performance Evaluation of Full-Scale Composite and Steel Wickets for Use at Olmsted Locks and Dam” (Chowdhury and Hall 1998). A single, full-scale composite wicket was placed at the test facility for direct comparison to a full-scale steel wicket in the same environmental conditions. After a simulated 25 years of operation (400 cycles) in a highly abrasive and corrosive environment, the composite gate performed well other than edge peel-off, while the steel wicket showed extensive corrosion.

b. Composite wickets were also tested in 2015 at Peoria Lock and Dam, as detailed in the PIANC WG 191 Report. Wicket gates can show extreme decay after only a few years of service, while composite gates made from UHMWPE can have a service life of 50 years or more. The composite wicket was tested in the Major Units laboratory, West Virginia University (WVU), Morgantown, West Virginia, for shear, bending, fatigue, and pushout, Figure 24–14. The composite wicket is shown in Figure 24–15.

Figure 24–14. Testing prototype composite wicket under bending

Figure 24–15. Composite prototype wicket

c. The tested composite wickets have performed well and are proving to be a viable solution for wicket gate material. They withstand abrasion from river debris and have better corrosion resistance. Composite wickets offer a longer service life and have a lower initial cost. Based on the full-scale performance testing, all the existing wicket gates at Peoria Lock and Dam and LaGrange Lock and Dam are planned to be replaced with composite wickets.

d. Several composite wicket gates were installed at Peoria Lock in 2017 and are currently being evaluated. This was a collaborative effort with ERDC and University of West Virginia. Thus far they have shown a much longer and reliable service life. As stated, replacement of all 217 wicket gates with composite gates at Peoria and LaGrange will take place incrementally during routine maintenance.

Chapter 25
Hands-Free Mooring Systems

25–1. Hands-free mooring

Hands-free mooring (HFM) is a new technology used on the locks in the SLS system and the Welland Canal. Both the Welland Canal and SLS locks have claimed improved safety and transit times with HFM technologies. The primary system being used currently is the vacuum grip system shown below in Figure 25–1. As of the date of this EM's publication, Cavotec® MoorMaster is the only known supplier world-wide that uses a vacuum system. Other manufacturers of the HFM technology use magnetic latching and grip-based latching. The HFM vacuum system is also being incorporated into the new lock at the Soo Locks. There is also an effort by ERDC to pilot test the HFM technology at several locks including McAlpine on the Ohio River.

Figure 25–1. Hands-free mooring at St. Lambert Lock, Saint Lawrence Seaway, and Snell Lock

a. The current construction project for the new 1,200-ft lock at the Soo Locks will incorporate HFM technology. The Soo Locks have predominately ship traffic and not barge traffic. The HFM systems have not yet been adopted for barge traffic on the Inland Waterway System in the United States.

b. The HFM system is like a floating mooring bitt. However, instead of tying off to the mooring bitt, the HFM system's vacuum pads attach to the side of the ship (Figure 25–1). The pads stay engaged to the ship using a vacuum system and vacuum pumps. It allows movement in the vertical, longitudinal, and lateral directions as the ship is raised and lowered. As noted, magnetic systems are also manufactured. The primary disadvantage with the HFM systems is the high initial cost, especially if they need to be retrofitted to an existing lock.

c. HFM is a concept that has been employed at ports throughout the world. The Port of Ngqura (South Africa), Port Hedland (Australia), the Port of Narvik (Norway), and the Port of Beirut (Lebanon) all have HFM systems. The locks on the SLS all experienced similar problems with conventional mooring methods. HFM systems have been in service on the SLS locks since 2014 and have increased the safety of vessel mooring during lock filling and emptying operations.

d. The USACE ERDC Laboratory is currently researching the HFM technology. In particular, the research is investigating whether the HFM technology can be adapted for barges used on the INWS. The research will also investigate other methods of accomplishing HFM for the INWS including magnetic latching and vacuum systems. The results will be documented in a Technical Note (TN) and a final TR. Neither of these are complete as of the publishing date of this ER.

e. The TN will include results and findings from site visits to the SLS locks, to include the Snell Lock and Eisenhower Lock. See Figure 25–2. It will also include site visits to numerous USACE inland waterway locks like Kentucky Locks, Montgomery Locks, and John Day Lock. The TR will detail the contracting processes and technical findings from the study. If an HFM system is determined to be feasible, it will be presented in the final ERDC TR.

Figure 25–2. Eisenhower Lock Cavotech system

f. The ERDC research will study the effectiveness and feasibility of currently installed SLS HFM technologies and possible alternative technologies that might be used in HFM systems. For example, the SLS HFM systems employ vacuum pads to securely attach to ships. The report will address whether these systems can be effective on typical inland waterway barges that are shaped differently, are often rustier, and have less freeboard than ocean-going ships. The report will investigate how might they be adapted for use on the inland waterways and what alternative technologies, such as magnetics, might be available or adaptable.

(1) A market study of HFM vendors to identify potential suppliers, technology types, and range of estimated costs will be conducted as part of the research. One or more contracts will be awarded to develop existing or new HFM concepts. If approved, a second contract will be awarded to complete concept development.

(2) A survey to identify the safety concerns while locking through a USACE lock will be conducted. This will help quantify the potential safety improvements from implementation of an HFM system. A survey of barge industry experts to identify any concerns that they might have with implementation of HFM technologies will be conducted as well. This survey would also include a study of the barge fleet inventory to identify barge shapes and configurations, if any, that might prove to be incompatible with HFM technologies.

(3) Other HFM technology is also being investigated by ERDC, including a magnetic system and a mechanical HFM system. These systems will be presented in the final TR.

25–2. Hands-free mooring systems

There are currently 15 locks on the SLS in the United States and Canada using the HFM system. The Canadian Locks on the Welland Canal also use the HFM technology (Figure 25–3). Vertical travel is approximately 39 ft to 49 ft. Transit times are typically reduced by 6 to 7 minutes. The HFM technology at the Canadian Locks is used in conjunction with a vessel self-spotting system (VSSS).

a. The vacuum pads are pressed against the ship hull, and once a seal around the pad has been established, a vacuum is created between the pad and the ship hull, which creates a strong connection. The articulating arms are connected to tracks located in vertical slots in the lock wall that allow the vacuum pads to travel vertically as the water level in the lock chamber rises or falls during lock filling and emptying operations.

b. At both Eisenhower and Snell Locks, three vacuum grip units have been installed on one of the lock walls. Most of the vessel traffic on the SLS locks consists of ships that have large, relatively clean, and undamaged hulls that serve as the connecting surfaces for the vacuum pads. This deep-draft ship traffic is significantly different from the typical shallow-draft navigation traffic that uses USACE inland locks.

Figure 25–3. Welland Canal Lock 7 hands-free mooring system

25–3. Hands-free mooring design

The vacuum grip system (Figure 25–4 and Figure 25–5) will be described here since it is the system currently in use on the SLS and Welland Canal. The vacuum grip system uses two vacuum pads per dynamic unit. These vacuum pads are not mechanically linked but work in unison with 15kW motors, each with VFDs. Each vacuum pad can produce 20 tons (200 kN) of vacuum coupling force. The size of the motor sometimes varies depending on the load requirement. A hydraulic power system is used to operate the vacuum pads. Some key parameters are noted below.

a. System pressure is 3,480 psig with an axial piston, pressure-compensated pump. Support frames are made of high-tensile steel to support the articulation mechanism and transfer mooring forces from the ship's hull into the lock structure.

b. In operation, vacuum pads are extended toward the ship, compressing the vacuum seals and controlling ship motions by counteracting any movement caused by external forces such as wind. The system provides continuous real-time load and motion monitoring.

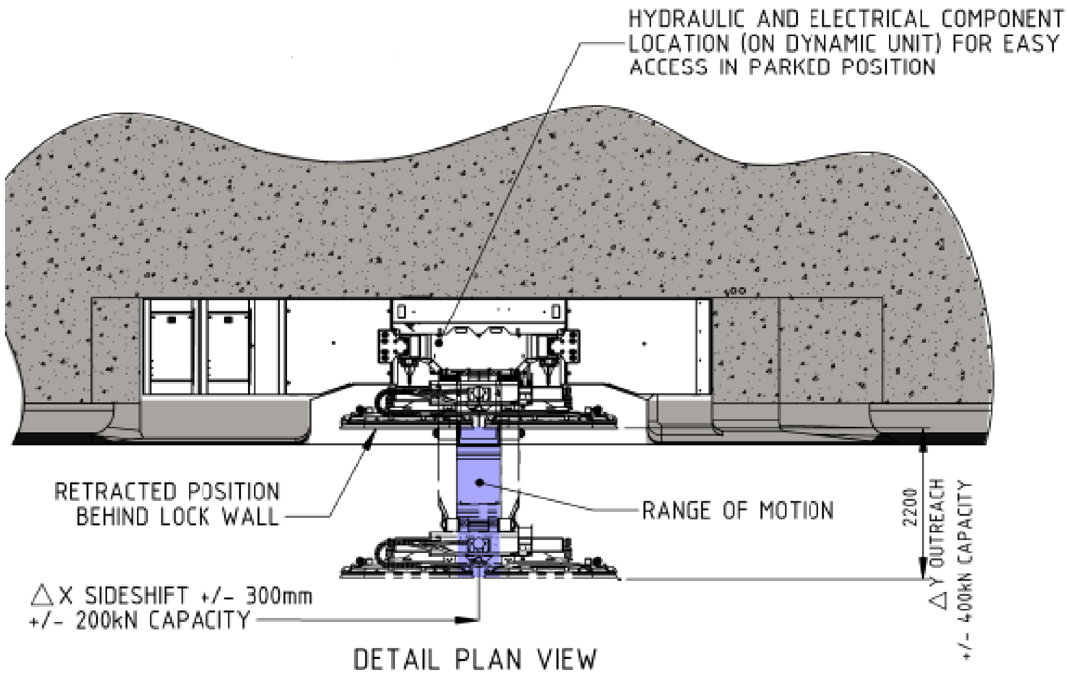


Figure 25–4. Hands-free mooring system detail (courtesy of Cavotec®)

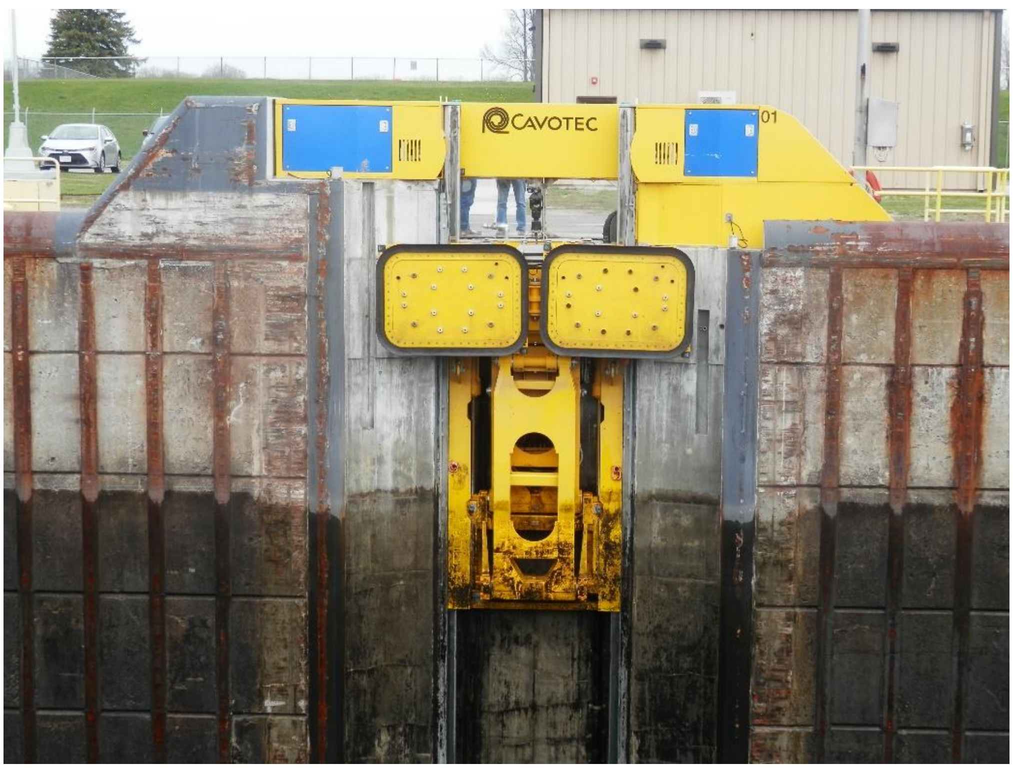


Figure 25–5. Hands-free mooring Eisenhower Lock elevation view

Chapter 26
Crane Systems

26–1. General

There are many types of cranes on USACE CW facilities, including fixed and mobile boom cranes, gantry cranes, jib cranes, and bridge cranes. Cranes installed on barges are used for maintenance and repair at navigation facilities. Cranes for setting bulkheads and emergency bulkheads are also discussed in this chapter. Some cranes have a unique configuration or application (like bulkheads) where USACE defines the complete crane specification. In some cases, it is not clear what crane or hoist category applies. No specific USACE crane design engineering manual has been developed; however, there are multiple industry standards and design guidelines.

a. Most cranes are considered commercially available products, with multiple nearly identical copies being produced. Commercially available products have reasonable product development with associated costs spread over the production run. Competition among multiple manufacturers also drives down the cost. But crane manufacturers, like other commercial product manufacturers, do not disclose their design criteria, which likely varies. This makes writing specifications for new cranes challenging.

b. Crane design assistance can be provided by the HDC and Marine Design Center (MDC). Crane design requirements for hydroelectric projects are provided in EM 1110-2-3006. Design of new cranes must include hydrodynamic loading when operating under flow.

c. There are several projects in Nashville District and TVA that use the same crane(s) to set the bulkheads for the dam spillways and the emergency gates and service gates at the intake of the powerplant (Figure 26–1 and Figure 26–2). Due to concern of the runway (generator) units, the generator units should not operate if the intake cranes are out of service. For this reason, some projects have two cranes as redundancy to set the bulkheads for the spillways and the emergency gates /service gates at the intake of the powerplant.

d. For small projects with only a few spillway gates, having two cranes to raise and lower bulkheads for the spillways may not be practical or feasible. At the minimum, projects should have the diesel generator as a backup in case that the primary power is out of service.

Figure 26–1. Kentucky powerplant intake/dam spillway cranes

Figure 26–2. Guntersville backup generator for powerplant intake/dam spillway crane

e. Mechanical parts of cranes and hoists should be designed for the rated capacity load with a minimum factor of safety (FS) of five based on the ultimate strength of the materials. In addition, mechanical components should be designed to withstand the forces produced by hoist motor-stalled torque, or maximum motor torque (MMT) as limited by VFD controls, with resultant stresses not to exceed 75% of yield point of the materials involved.

f. In determining the size of hoisting ropes, the maximum rope tension resulting from the rated capacity load should be used. It should also take into consideration the overall efficiency of the hoist tackle in the blocks and other parts. The resulting rope tension should not be greater than 20% of the nominal breaking strength of the rope.

g. In addition, the rope tension resulting from the maximum torque of the motor (locked rotor torque or MMT as limited by VFD controls) must not exceed 0.7 of the nominal breaking strength of the rope. Additional discussion on wire rope selection criteria is provided in EM 1110-2-3200 and the most recent edition of the Wire Rope User's Manual. ASME B30.30 includes provisions that apply to the construction, selection, installation, attachment, testing, inspection, maintenance, and replacement of wire rope, and should also be reviewed since the ASME B30 safety standards are updated more frequently than EMs.

h. The machinery efficiencies used for calculating the hoist and travel drive component sizing must not exceed the values provided in CMAA 70.

i. Electrical conduits for the cranes can be placed in a trench or the powered reel. For redundancy, two separate electrical feeders should be provided to power the cranes. The trench should be furnished with aluminum covering instead of grating to prevent snow getting into the trench. When using the powered reel, the cable is anchored in the concrete halfway through the gantry travel. An example is a Kellum® Device strain relief. The quick disconnect is then terminated into a junction box. Conductor bars should not be used for the spillway cranes due to high cost and high maintenance. See Figure 26–3, Figure 26–4, and Figure 26–5.

Figure 26–3. Guntersville Project, trench for electrical conduits of the powerplant intake/dam spillway crane

Figure 26–4. Barkley Project, electrical-powered reel for the powerplant intake/dam spillway crane

Figure 26–5. Barkley Project, anchored point for electrical conduit of the power reel for the powerplant intake/dam spillway crane

26–2. Specifications

It is critical that that the designers and builders of the crane (and any manufacturers) have experience in building cranes. This needs to be written into the specification. A request for proposal-type procurement is recommended for any crane purchases. That allows evaluation of the crane manufacturers experience and capability. The stability calculations and counterweight requirements for the crane should be done with the crane manufacturer.

a. The crane design and operation involve life safety, and this needs to be the overriding requirement in any design and procurement (Figure 26–6). The crane must be stable for all operations. The requirements in EM 385-1-1 must be followed. The manual requires that all cranes and hoists be classified by an ASME B30 standard, which helps with inspection and stability criteria but not design.

b. All cranes should be provided with safety features per EM 385-1-1, including load indication, load control, boom angle, anti-two block indication, and load-limiting devices. Other safety requirements are provided in ASME B30 and Naval Facilities Engineering Command (NAVFAC) documents noted below.

Figure 26–6. Barge-mounted crane for maintenance and repair

c. U.S. government centralized specialty groups can serve as a resource for crane planning, procurement, and ownership. These agencies or centers of expertise should have a large archive of previous procurements to help formulate the procurement documents. The USACE Marine Design Center is one crane resource. Its website is http://www.nap.usace.army.mil/Missions/MarineDesignCenter.aspx.

d. The HDC can be utilized as a resource for any non-marine crane applications.

e. The NAVFAC Navy Crane Center is another crane resource with several design documents that can be used. The NAVFAC website is https://portal.navfac.navy.mil/portal/page/portal/navfac/.

f. The NAVFAC document NAVFAC P-307 should be considered for crane specialists and crane design.

g. Several guide specifications are available for cranes. Also, in addition to the EM 385-1-1 safety manual, the OSHA manual for overhead and gantry cranes should be referenced as applicable. Available guide specifications include:

(1) OSHA 1910.179.

(2) UFGS 41 22 13.14.

(3) UFGS 41 22 13.15.

(4) UFGS 41 22 13.16.

(5) UFGS 41 22 13.33.

(6) UFGS 41 22 23.19.

h. ASME Standards (B30) provides specific design guidance for several crane types, including mobile cranes, portal cranes, and locomotive cranes. The ASME standards should be considered a starting point for specific crane design. Other industry crane publications include:

(1) American Petroleum Institute (API)-2C.

(2) ASME publications, including:

(a) ASME B30.2, Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist).

(b) ASME B30.4.

(c) ASME B30.5.

(d) ASME B30.6.

(e) ASME B30.8.

(f) ASME B30.9.

(g) ASME B30.22.

(3) CMAA publications, including:

(a) CMAA 70.

(b) CMAA 78.

26–3. Controls

The crane industry has shifted from DC drive and wound-rotor AC systems to AC VFD systems. VFD drives, in addition to being the standard design for crane manufacturers, provide safety features not available on previous generations of crane controls. Fail-safe VFD drive systems should be used on both crane rehabilitations and new installations. VFD drives for hoist applications should operate using closed loop, flux vector control scheme with encoder feedback to control and monitor hoist movement. For additional guidance on crane control design, see CMAA 70 and ASME B30.2.

a. Holding brakes should be either DC magnetic or AC thruster, spring set, shoe type (for hoists) or motor-mounted friction disc type (for travel functions).

b. Radio remote control is an option that is commercially available and should be considered to supplement cab controls.

c. Load cell feedback for hoists is recommended, with care to avoid nuisance trips triggered as the load cell undergoes hysteresis or goes out of calibration. For hoists with multiple parts of wire rope, sheave and wire rope friction may affect the accuracy of the load seen at the load cell location. Load cell readouts are required for trash raking hoists and auxiliary hoists that have inherent uncertainty and variation in loading. Load cell readouts are recommended.

26–4. Welding standards for crane fabrication

Industry standards for cranes, such as CMAA 70 and ASME Below-the-Hook (BTH)-1, call out AWS D14.1 for the required welding standard for cranes. AWS D1.1 can also be used as an acceptable (and in some cases preferrable) welding standard for cranes provided specific requirements of AWS D 14.1 are considered.

a. AWS D14.1 differentiates between primary and secondary welds. A weld is classified as a primary weld if the failure of the weld would result in a carried load being dropped more than 4 in. or an increase in stress beyond the allowable limit.

b. The HDC's crane specifications use AWS D1.1 as the welding standard and do not differentiate between primary and secondary welds in the same way that AWS D14.1 does. Instead, primary members are defined as those carrying principal loads such as the gantry frame and lifting beams, and all welds are required to be inspected with the percentages stated in the contract, no matter if the weld is on a primary member or not. This conservative approach does not require the engineer of record to identify all primary welds on the drawings for inspection purposes.

c. To ensure equivalence of welding acceptance criteria between AWS D1.1 to AWS D14.1, specifications state that any weld on a primary load-carrying member, weld connecting any ancillary item to a primary load-carrying member, or any weld on a lifting beam are to meet the cyclically loaded in-tension criteria in AWS D1.1. This is the same criteria that AWS D14.1 uses on primary weld connections. All welds not on primary load-carrying members are inspected to the static requirements within AWS D1.1.

26–5. Maintenance bulkheads

Maintenance gates and the associated crane systems for setting them have been used extensively on USACE navigation structures. Maintenance gates for locks and dams include bulkheads, stoplogs, and needle girder systems. Maintenance gates allow dewatering of a lock chamber or a dam gate bay to enable maintenance and inspection. Emergency gates or bulkheads provide a means for emergency closure of a lock or dam gate under differential head or conditions of flowing water. These are deployed in the event of a failure of the primary lock or dam gate. Figure 26–7 shows a maintenance crane for setting maintenance bulkheads on a dam. This includes a lifting beam, cable reel, and rail grabbers.

Figure 26–7. Bridge crane installed on an undercarriage

a. Maintenance bulkheads generally are installed and removed under balanced heads only and usually are handled by cranes with the help of lifting beams. See Figure 26–7 and Figure 26–8. Often at USACE navigation sites, maintenance bulkheads are set using barge-mounted cranes (Figure 26–8). Lifting-beam hooks should be designed for automatic or semiautomatic connection and release of the bulkhead. This eliminates the need for personnel to climb onto the bulkheads and manually release the lifting hook. Bulkheads may be made from steel, concrete, or timber.

b. The most common type of bulkheads at navigation projects are made of steel. Steel bulkheads typically consist of a skin plate supported by multiple steel girders and/or stiffeners. Structural steel guides are provided to limit the movement of the bulkhead horizontally, either in the direction of the flow or at right angles to the flow.

c. Maintenance bulkheads are extensively used for winter maintenance at locks. Figure 26–8 shows setting of maintenance bulkheads and Figure 26–9 shows the Soo Locks. The Soo Locks conduct a maintenance dewatering every year.

a) b)

Figure 26–8. Maintenance bulkheads installed by floating plant

d. Bulkheads can be provided in a single section or in multiple sections depending on clearance restrictions and handling equipment capacity limitations (Figure 26–9). For most navigation project sites, bulkheads are provided in multiple sections. Multiple-section bulkheads are sometimes called stoplogs. For multiple-section bulkheads, additional rubber seals should be provided between sections to seal the horizontal joint.

e. In general, there are one or two sets of bulkheads per project. When not in use, bulkheads should be stored in the bulkhead slots or on top of the wooden pallets or beams for corrosion protection. Bulkhead slots normally have dogging devices that can be used to keep the bulkheads above the water elevation.

a) b)

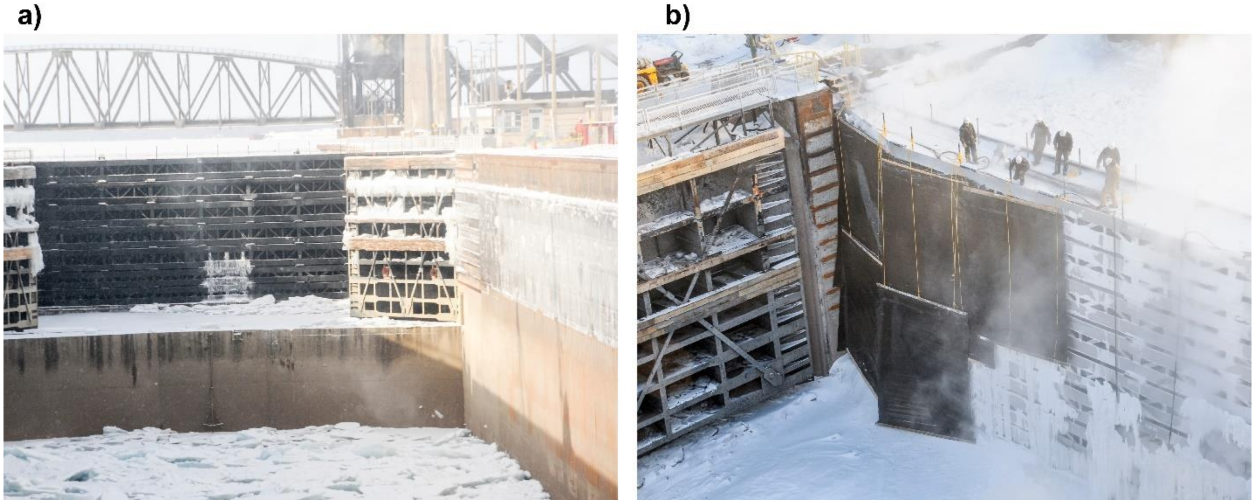


Figure 26–9. Soo Locks maintenance bulkheads

Figure 26–10. Old Hickory Dam, maintenance bulkheads for spillway gates

f. Floating cranes mounted on barges should be designed per ASME B30.8. Stability calculations need to be done for all load conditions, and all stability calculations should follow ASME B30.8. Load-monitoring, load-limit, and force-control switches should be provided on the crane.

g. Typically, on dam structures, cranes are mounted on an undercarriage assembly. The undercarriage is then installed on a rail system. This allows the crane to travel across the length of the dam. The design of this type of system should allow the undercarriage of the crane to incorporate the bulkhead lifting equipment rather than the crane.

(1) Rail grabbers should be used on the undercarriage to provide additional safety. This type of system design should follow ASME B30.5 for a locomotive-type crane. Stability calculations need to be done for all load conditions, and all stability calculations should follow ASME B30.5. Stability calculations need to be done for bulkhead placement and removal using the undercarriage.

(2) Counterweights should be added to the crane, rather than the undercarriage assembly. Cranes often use multipart wire-rope hoists. Fouling of the sheaves or ropes can lead to overloading of the ropes in either the raising or lowering direction. Load-monitoring equipment, load-limit switches, and force-control switches should be provided to avoid overload of wire ropes and the crane assembly.

26–6. Emergency bulkheads

Some lock sites have emergency bulkhead systems designed to be set under differential head and flowing water conditions such as the Old River Lock (Figure 26–11). These generally are provided on the upstream side of the lock. The system provides emergency closure so the navigation pool is not lost. They also are used for maintenance dewatering of the lock chamber.

a. At Chittenden Lock (Figure 26–12), the entire ship canal would be lost if the miter gate closure was lost. The bulkheads use rollers and/or lowering carriages to overcome the differential head of water. Port Allen Lock in New Orleans also uses an emergency bulkhead system. The emergency systems usually are confined to the lock at which the crane can be safely anchored. Typically, emergency bulkheads are not used on dam structures because the crane system usually cannot be secured safely to the dam.

Figure 26–11. Emergency bulkhead system, Old River Lock between Mississippi and Atchafalaya rivers

Figure 26–12. Emergency bulkhead crane system, Chittenden Lock, Lake Washington Ship Canal

b. In lieu of emergency bulkheads, other locks use an additional gate such as a vertical lift gate/upstream emergency gate to close off flow under emergency conditions. These types of systems are used on the Ohio River, Illinois River, Cumberland River, and Tennessee River. Emergency (vertical lift) gates are discussed in Chapter 9.

c. Emergency bulkheads are designed to be set under differential head and flowing water and are used as maintenance bulkheads. This eliminates the need to provide a floating plant for setting bulkheads. See Figure 26–11 at Old River Lock. The mechanical designer will need to work with the hydraulic engineer to determine the flow rates and head conditions under which the bulkheads will need to be set.

d. Emergency bulkheads typically require a lowering carriage, rollers, or some combination. It is also a labor-intensive process. At Chittenden Lock, it takes a crew of six to eight personnel approximately four hours to set all the bulkheads (Figure 26–12). The lowering carriage system is essentially a wire-rope hoist that forces the bulkheads down into the lock. The hoist machinery typically consists of an electric motor, gearbox, and open gearing. The carriage assembly and hoist machinery at Port Allen Lock is shown in Figure 26–13.

e. Without a carriage assembly, the emergency bulkheads will require rollers to help overcome the differential water head (Figure 26–14). The weight of each bulkhead will need to overcome any head difference plus the friction of the roller assemblies. It is recommended that rollers be designed with greaseless bearings. This will further reduce the coefficient of friction. It also will eliminate the requirement to manually grease all the roller units.

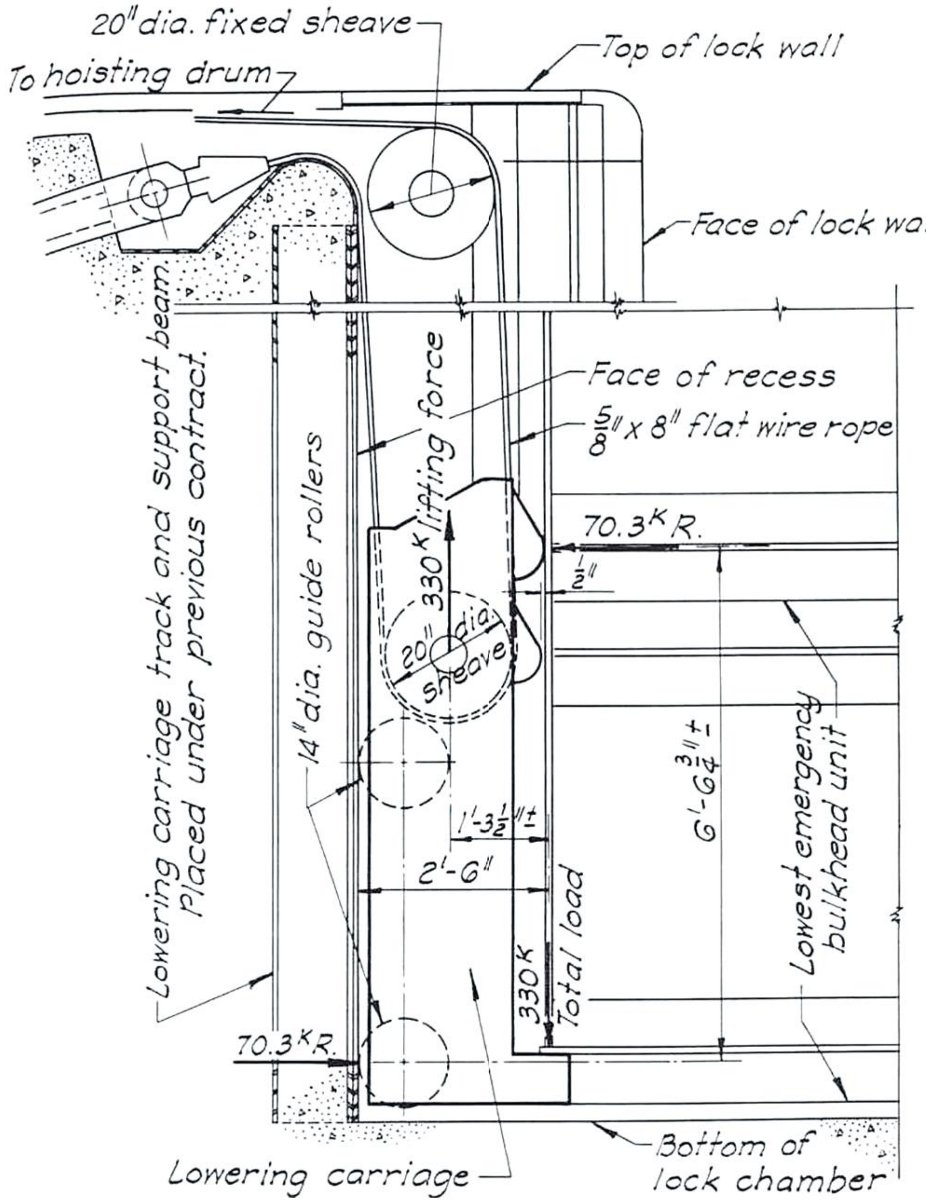


Figure 26–13. Lowering carriage assembly, Port Allen Lock

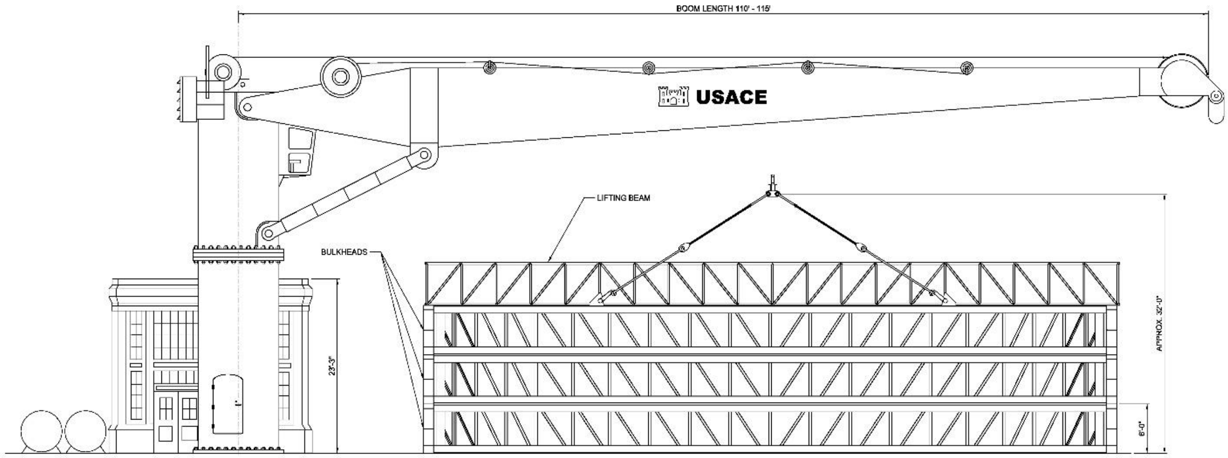


Figure 26–14. Emergency bulkhead lifting system, Chittenden Lock, Lake Washington Ship Canal

26–7. Lessons learned

New lock construction should incorporate either an emergency bulkhead system or emergency gates. Maintenance bulkheads on a waterway should be standardized. In that case, one set of bulkheads can be used to perform both scheduled and emergency maintenance on multiple locks across multiple USACE districts.

a. For new navigation dam construction, bulkheads should be designed to be set under flow conditions. This situation could occur after a barge impact to the dam gates.

b. For most lock and dam sites, water maintained on spillway gates year-round severely restricts gate inspection and maintenance. All gated spillway installations on dams should have bulkhead or stoplog capability. For existing projects, these will typically be maintenance bulkheads, not emergency bulkhead systems.

c. For new lock construction, provide a lowering carriage system in addition to rollers and bearings on the bulkheads. This will help ensure the bulkheads can be set properly.

d. Lowering carriages need to be inspected periodically. Also, inspect the wire rope system periodically and replace as necessary. See EM 1110-2-3200.

Chapter 27
Installation, Operation and Maintenance, and Inspection

27–1. General

The design engineer's responsibilities do not end with the preparation of quality plans and specifications. It is important that the design engineer remain involved in all phases of the project life cycle, from construction support during installation, to supporting O&M, to regular inspection of the project. Guidance in these areas is given below.

27–2. Installation

This section discusses some of the factors that affect the quality of construction during the manufacturing and installation of gate operating equipment for new construction, major rehabilitation, and major maintenance work. It discusses the gate operating equipment and does not include the gate itself, except when the operation of the gate (for example, misalignment of the rollers or adjustment of the gate seals) affects the operation of the gate operating equipment.

a. Designer involvement. It is important that the designer be involved with construction activities from shop drawing review through shop inspection to final field inspection. ER 1110-2-112 establishes policy that requires field construction participation by design personnel. The designer must maintain a good working relationship with the USACE construction office and must include engineering's involvement in the engineering considerations and instructions to field personnel, as provided in ER 1110-2-1150. ER 1110-2-8157 provides requirements for HSS.

b. Contract requirements. The contract specifications must require the contractor to perform all testing associated with the manufacturing and installation of equipment. The Contractor Quality Control (CQC) representative and a design representative should witness any testing. The contract documents should identify the test data that needs to be recorded, and the contractor should record all test data required by the contract. The contract documents should hold the contractor responsible for any retesting required due to the contractor's inability to fulfill the contract requirements.

(1) Each machinery unit should be fully assembled in the shop. Alignment of component parts, correctness of fabrication, and tolerances, as shown on the shop drawings, should be checked. Each machinery unit should be given a no-load operational test in the shop. In addition to the proper operation of the hoist assembly, items such as limit switches, the motor brake, torque switches, and the control panel should be checked for proper settings and operation, according to the manufacturer's recommendations. Gearbox efficiencies should be factory tested.

(2) The contractor should be required to submit a detailed installation procedure. The installation procedure should show items such as storage and handling requirements, installation sequence, alignment techniques and criteria, bolt torque requirements, anchorage requirements, fits and tolerances, lubrication requirements, fluid levels, inspection and testing requirements, and O&M information. The machinery

units should be shipped assembled, ready for field installation, according to the contractor's installation procedure.

(3) All installed equipment should undergo field testing. This assessment should include operational tests of the installed equipment with the gate in the dry and, if possible, at or near design head. The gate should be operated through several complete cycles in the dry to check the alignment of gate operating equipment and gate rollers and seals, and operation of the controls, limit switches, and brake. The gate operating system also should show that it can hold the gate in any position on demand. A load test then should be conducted at or near design head, if possible, with the measurements of the motor current, voltage, temperature, and vibration taken.

(4) For hydraulic operating systems, the pressure and leakage tests should be witnessed, and the operating pressures should be checked against the design pressures. Relief valve and torque switch settings should be checked.

(5) To ensure the parameters are met during testing, require a submittal within the specifications (a test report) that lists the parameters to be checked and the values obtained during testing, such as temperature, current, speed, vibration, performance, limits of travel, and interlocks.

(6) For the CQC/QA program to be effective, it must be enforced. The designer, as a member of the command's QA team, can assist the construction office in program enforcement.

(7) The designer should have the opportunity to review the CQC plan to ensure it includes the manufacturing and installation of the gate operating equipment. A preparatory inspection should be conducted for this phase of the contract work, and the designer should have the opportunity to attend the preparatory and initial inspections. The designer should also review follow-up inspection reports.

(8) Also, as part of the QA responsibilities, the designer should attend the shop inspection and test. To prepare, the designer should review the contractor's submittals and appropriate technical and non-technical parts of the contract documents. The designer should also review the referenced industry standards and shop drawings and check with the CQC representative to make sure the contractor is working from the same documents. Both CQC and QA should spot check to confirm the equipment is being manufactured according to the shop and manufacturing drawings.

(9) When multiple machinery units are being built, as is common to many USACE facilities, the designer should witness the shop and field assembly and testing of at least the first unit. The assembly and testing procedures should be reviewed with the contractor's CQC representative, and the calibration of the testing equipment should be checked by the CQC.

(10) For complicated machinery installations where field alignment is critical, an erecting engineer may be specified in the contract. Typical requirements of an erecting engineer's experience are 5–10 years of experience and holding professional

engineering licensure from a state or territory within the United States. A contract should require the erecting engineer be on site during field installation, oversee pre-construction installation plans, review and approve shop drawings, and attend shop visits. This adds cost to the contract but can drastically reduce risk during construction.

(11) During installation and prior to operation, the CQC representative should perform the following and the QA representative should spot check for compliance:

(a) Verify that an approved welding procedure has been submitted and qualified welders are on site when field welds are required.

(b) Witness the tensioning of the wire rope for multiple rope hoists.

(c) Witness dynamometer testing.

(d) Visually check alignment of shafts, couplings, gears, etc.

(e) Check operation of electrical components (motors, controls, limit switches, brakes, etc.).

(f) Verify that all fluid levels and lubrication of components are according to the manufacturer's recommendations.

(g) Check that the effects of corrosion have been minimized by a properly applied paint or coating system and that there is adequate drainage designed into the hoists to prevent water retention.

(h) Verify that all reporting requirements have been met.

c. Acceptance criteria. The designer should assure that the installation acceptance criteria are provided in the contract documents. When a performance specification is developed for contractor-designed equipment, the specification also should require the contractor to develop the acceptance criteria. The acceptance criteria should be based on USACE standards or applicable industry standards when such standards exist.

d. As-built drawings. The development of as-built drawings is a continuous process and must be a contract requirement. While the contractor is manufacturing and installing the equipment, the as-built drawings must be revised to reflect actual conditions. The CQC and QA representatives should monitor this process. All proposed changes should be coordinated with the designer. The as-built drawings, shop drawings, assembly drawings, and installation procedures should be revised as changes occur. The contractor should be required to furnish computer-aided design (CADD) drawing files on compact disc (CD), compatible with the customer's existing CADD system.

e. Operation and maintenance manual. Like the as-built drawings, the development of the O&M manual is a continuous process, and its development should be a contract responsibility. The manual is developed based on the equipment manufacturer's recommendations. It gives basic operating and maintenance procedures, guidelines for troubleshooting and repair procedures, and assembly/disassembly details.

(1) It should also include the procedure and frequency of the testing and inspection of components or systems. The contract specifications should list the items to be included in the O&M manual, and the designer should be involved in review and coordination with the contractor to ensure the inclusion of necessary information. Sufficient contract funds should be retained to ensure completion of O&M manuals. Since O&M manuals contain maintenance procedures that, in some cases, must be started immediately, consideration should be given to not starting to the warranty period until approved O&M manuals are received.

(2) The O&M manual should be considered a living document. This means that as the project ages and equipment is changed, the manual should be updated to reflect those changes. The O&M manual produced by the contractor will become part of the project O&M manual developed by the designers.

f. Submittal review. The designer should review and comment on the shop drawings, assembly drawings, installation drawings, installation procedure, O&M manual, and as-built drawings. The assembly drawings, installation drawings, and installation procedure can be submitted for information purposes only. Shop drawings that detail components specifically fabricated for the project should be submitted for approval. Shop drawings for purchased components should be submitted for approval. They should include catalog cuts and sufficient information to determine compliance with the specifications.

27–3. Operation and maintenance

The operation of a USACE lock and dam or FRM is the direct responsibility of the on-site lockmaster and FRM staff. However, everyone connected with the project has a responsibility to improve safety and increase efficiency. The design engineer must consider life cycle maintenance costs in all aspects of planning and design. This should include consideration of all costs to replace or rehabilitate gates or machinery.

a. Operation and maintenance manual. All projects should be operated within the guidelines provided in the project O&M manual. The manual should be updated to reflect all changes in operating procedures at the project. The manual should contain provisions to record equipment failures and to post maintenance records to enable operators to identify developing trends and avoid an unexpected failure.

b. Benefits of automation for improving operation and maintenance procedures.

(1) The level of automation of a lock and dam project can range from none to the simple manual start-auto stop of a single gate, or the complete lockage and recording of a vessel without operator intervention. The appropriate level of automation for a project is a judgment made by all involved with the project. To improve the effectiveness and safety of the project, the process of locking a boat and operating a dam can be examined for inherent inefficiencies or hazards.

(2) The PLC can be a tool for monitoring such parameters. The PLC never forgets to monitor and log movement and position of equipment, perform operations in a prescribed sequence, or record gate operating times and other parameters accurately. Inefficiencies will become evident when such data is monitored closely. Circumstances such as traffic-light signaling, traffic queuing, outdraft, operation of the dam, inefficiencies in direction change, operation of adjacent locks, pleasure craft, and visibility all might cause a traffic delay. Only careful monitoring of the process, along with these and other circumstances surrounding it, will present useful data to operations management.

27–4. Inspection and testing

Project-specific inspection requirements (such as items to be inspected, inspection procedure, and inspection frequency) should be included in the O&M manual. These inspections also are part of the Periodic Inspection and Periodic Assessment program, as defined in ER 1110-2-1156. Typical items include motors, brakes, gears, shafts, couplings, bearings, controls, limit and torque switches, hydraulic systems, wire rope, chain, structural base frames, emergency generators, and any other integral parts that transmit the power to operate a gate. Machinery should be inspected not only for its current condition, but also for its condition relative to the last inspection. The O&M procedures should be reviewed for adequacy. Operational tests should be performed on a regular basis.

a. System condition. The general condition and operation of the gate operating equipment should be observed. Operation should be smooth, and any abnormal performance should be noted. Noise and vibration should be noted, and the source determined. The inspector should report unsafe or detrimental procedures followed by the operator that could cause injury to personnel or damage to the equipment. The condition of the paint system also should be recorded. Maintenance procedures should be according to the O&M manual. Maintenance records should be reviewed with maintenance personnel. Maintenance procedures should include periodic operation of equipment that sits idle for long periods.

b. Inspection guidelines. The document Water Control Gates, Guidelines for Inspection and Evaluation is an excellent reference for inspection criteria. This document was published by ASCE. A current EC aimed at standardizing maintenance requirements for locks and dams is complete and awaiting release. The EC is not yet approved for publication; however, EC 1130-2-551 can be reviewed for some similar equipment. Below are some condensed guidelines for the major components of gate operating equipment:

(1) *Open gearing*. Open gearing should be inspected for alignment, including under/over-engagement, and wear patterns away from the gear pitch line. Alignment problem indicators can predict bent shafting, misaligned bearings, loose mounting bolts, improperly fitted keys, or eccentric loading. Excessive or abnormal wear of the tooth-mating surfaces should be noted, including pitting, scoring, spalling, and plastic flow.

Most tooth-wear problems are related to improper fabrication or lubrication, or misalignment.

(2) *Open gear surfaces*. Inspect gear teeth, spokes, and hubs for cracks, which might be the result of fabrication, heat treatment, or mishandling during installation. Cracks often are obscured by a coating of paint. Examine lubrication quality and quantity. Meshing gear surfaces that are scarred in the areas from slightly below the pitch line to the tooth tips is an indication of lubrication failure. Check gear teeth for excessive backlash, pitch line mesh, dirt, and corrosion. Inspect all keys, keyways, retainer caps, and bolting materials for proper fit, alignment, and tension.

(3) *Speed reducers*. Speed-reducer housings and mounting base should be inspected for cracks. All seals and gaskets should be inspected for lubricant leaks. All fasteners should be inspected for corrosion and proper tension. After removing the inspection cover, the interior should be examined for signs of condensation, corrosion, general condition of the gears (see “open gearing” above), and excessive shaft movement and backlash. The lubricant level should be checked weekly, and at least monthly for difficult-to-access equipment. Oil samples should be laboratory tested quarterly and examined for the presence of wear particles, contaminants, water, viscosity breakdown, and the verification of sufficient additives.

(4) *Shafts and couplings*. Shafting should be inspected for cracks, twist, bend, strain, and misalignment. Suspicion of cracking or excessive strain should be verified by dye penetrant testing. Bending can be estimated using dial indicators. Coupling components should be examined for adequate lubrication, proper fastener tension, damaged keys, and improper alignment.

(5) *Bearings*. Bearing housings, pedestals, and supports should be inspected for cracks and misalignment. Fasteners should be checked for tightness and corrosion. All bearings should be checked for condition and quantity of lubricant. Plain bearings (bushings) should be examined using feeler gauges for excessive wear, as well as the condition of any seals, as applicable.

(6) *Brakes*. All braking devices should be inspected for proper braking torque setting and complete release at actuation. On shoe brakes, check brake wheels and shoes for wear, corrosion, misalignment, and proper clearance at release. Linkages should be free but not loose. Ensure there is no leakage at connections or seals on enclosed hydraulic disc brakes. All limit switches should be tested for proper setting and actuation.

(7) *Motors*. Motors should be inspected to ensure nothing is interfering with the motor ventilation. Any unusual noise or odor, such as from scorched insulation varnish, requires a more detailed inspection. Bearings should be examined for adequate lubrication and for indications of wear (free movement), vibration, and seal leakage. The motor should be started several times to ensure that it comes up to proper operating speed. Operation of winding heaters should be verified. Fasteners should be tight and in good condition. Maintenance must include cleaning NEMA 4 drain fittings commonly

found in totally enclosed fan-cooled electric motors. These are typically located on the bottom of the end bell located at each end of the motor.

(8) *Motor electrical test*s. Follow ANSI/InterNational Electrical Testing Association (NETA) Maintenance Testing Specifications (MTS) for rotating AC induction motor testing requirements. 2019 was the last update as of the writing of this manual. General steps for this testing include the following (section references below are found in ANSI/NETA MTS-2019):

(a) Perform resistance measurements through bolted connections with a low-resistance ohmmeter according to, section 7.15.1.A.4.1.

(b) Perform insulation-resistance tests according to IEEE 43.

(c) Perform DC dielectric withstand voltage tests on machines rated at 2,300 volts or greater.

(d) Perform phase-to-phase stator resistance test on machines 2,300 volts or greater.

(e) Perform insulation-resistance test on insulated bearings according to manufacturer's published data.

(f) Test surge protection devices according to section 7.19 and section 7.20.

(g) Test motor starter according to section 7.16.

(h) Perform resistance tests on RTD circuits.

(i) Verify operation of machine space heater.

(9) *Hydraulic cylinders*. Inspect hydraulic cylinders regularly for misalignment, seal leakage, and piston rod coating deterioration. Personnel should review, at least quarterly, maintenance records for filter and fluid changes. All limit switches, speed-change switches, and pressure switches should be tested for proper function. Observe while operating regularly for irregular noises or vibration.

(10) *Hydraulic components*. Inspect hydraulic components for proper function of associated valves. Inspect for loose locknuts, damaged handles, stems, or wiring connections. All flexible hoses should be examined for deterioration, flaking, cracking, kinks, and wear. Hydraulic pumps should be checked for noise and vibration. All pressure relief valve settings should be verified annually by an independent, properly calibrated pressure gauge. All flow rate settings should be verified. Seasonal changes to pump, valve, or other equipment adjustable settings should be recorded.

(11) *Hydraulic fluid*. Hydraulic fluid should be tested quarterly for viscosity, moisture content, and other contamination. Filters, tank trappers, breathers, and other devices

should be examined for contaminants or replacement indication. Refer to EM 1110-2-1424.

(12) *Machinery supports*. Machinery support frames should be inspected for cracking in the steel, grout pad, and concrete. All welds should be examined for cracking. Any corrosion should be noted and scheduled for repair. Deformation of any steel members or anchor bolts should be cause for immediate analysis of the safety of continued operation. All drain holes should be clear so there is no standing water.

(13) *Wire rope, drums, and sheaves*. Wire rope, drums, and sheaves should be inspected according to EM 1110-2-3200 and Wire Rope User's Manual.

(14) *Interlocks and limit switches*. All safety interlocks should be tested regularly, along with periodic inspections. These include the miter gate to culvert valve, culvert valve to miter gate, and culvert valve to culvert valve interlocks. Also, the proper function of position limit switches should be tested regularly, along with periodic inspections when made possible by allowable gate opening.

(15) *Filling/emptying valve control*. The proper function of overfill and overempty and valve synchronization culvert valve controls should be tested.

c. Test operation of equipment. ER 1110-2-1156 requires "frequent observations of the dam and appurtenant structures." This includes all systems necessary for the project to serve its intended purpose in a safe and efficient manner. These components should be tested and operated using emergency power.

(1) The emergency power generator should be full load tested at more frequent intervals, such as every other month, to maintain its integrity.

(2) Full travel of dam gates should occur at least once every three years. Bulkheads or stoplogs might need to be installed at the times when pool levels prohibit the full opening of the gates. Partial opening of the gates does provide some test benefits, but it is essential that full travel tests be performed to verify non-binding operation at all gate positions and the proper function of travel limit switches. A partial opening test of each gate should be conducted at least yearly, except for the year that a full travel test is scheduled. The gate should be raised as high as pool conditions allow without the use of bulkheads or stoplogs.

27–5. Access for inspection and maintenance activities

Designers and reviewers should ensure that access has been provided to inspect and maintain equipment and components. Planning this access should happen early in the design phase of the project and must be coordinated with the structural engineer and others responsible for the design and layout of the equipment. The designer also needs to develop an inspection and maintenance plan and include that plan in the O&M manual. The details of the plan must be coordinated with those responsible to operate and maintain the project. Details should include locations of removable inspection covers, permanent or portable access platforms, etc. Provide proper lighting and a safe working environment to perform the inspection and maintenance procedures.

Chapter 28
Commissioning of Lock and Dam Mechanical and Electrical Systems

28–1. General

The design engineer has a responsibility to provide a quality product that is fully functional to meet the operational needs of the project and customer. This responsibility extends through the construction phase until final acceptance when the project is turned over to the end user for operation. Commissioning of lock and dam mechanical and electrical systems is the process to assure these requirements have been met prior to project completion. This applies to both electromechanical drives and hydraulic drive systems. Electric motors, for example, are common to both systems and should be part of the commissioning process. See Figure 28–1.

a. Commissioning of mechanical and electrical operating systems provides the verification process to ensure the design satisfies all performance and operational requirements. It also establishes the baseline for future reference when repairs or replacements are needed. Total project commissioning is a systematic, quality-focused process for enhancing the delivery of a project that focuses on verifying and documenting that all commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the project requirements. The purpose is to reduce the cost and performance risks associated with delivering facilities projects and to increase value to owners, occupants, and users.

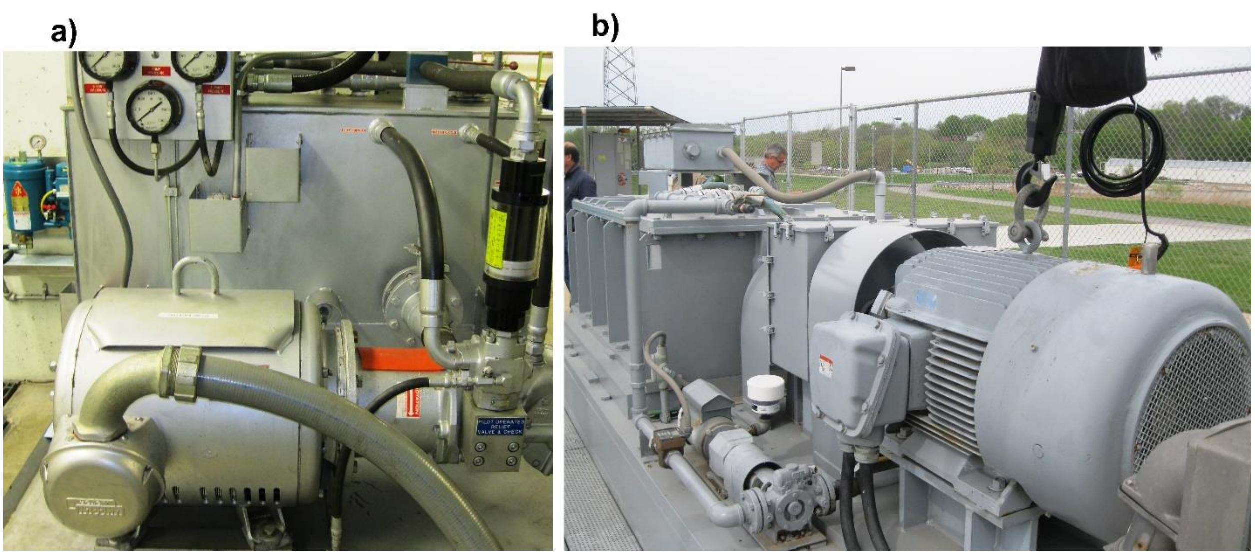


Figure 28–1. a) Electric motor and hydraulic drive, b) electric motor and mechanical drive

b. Commissioning has been a part of vertical construction projects in both the military and private sector for many years, with defined standards and references to meet project requirements. However, the commissioning standards and requirements for CW projects are often left to the individual designers to develop the technical specification requirements. These commissioning requirements are embedded in the technical specification sections and may not be comprehensive to the total project requirements. Total comprehensive commissioning is often needed to confirm operational performance of mechanical and electrical equipment.

c. On small projects, this can be completed with a set of well-written technical specifications and execution sections within the specifications. On large-scale projects with multiple construction activities involving numerous independent pieces of equipment or operating systems, the designers may wish to consider a larger comprehensive project commissioning specification that involves a third-party commissioning agent and commissioning process to ensure project success.

d. Commissioning involves the integration of all component mechanisms into a single system through adjustment of settings and other operating parameters. It also involves operational testing to ensure the equipment and operating systems are free of defects either inherent to the design or inadvertently incorporated during facility construction or manufacture of equipment. It is not always possible to foresee all issues during the design stage, and alterations during construction may produce unintended consequences.

e. Some level of troubleshooting and adjustment should be expected during the formal commissioning stage at completion of construction. Participation by the designers in the field during construction will help to clarify the design intent and address issues promptly when encountered.

f. Commissioning should not be viewed as strictly taking place at the end of construction, but as a process integral to both the design and construction stages of a project as well as the testing and acceptance period. It is a holistic quality control and quality assurance process applied to design through construction.

g. There are two key activities that take place during the design phase regarding commissioning a project. First, all the functions of the equipment and systems, along with their interactions with one another, must be planned out by the design team. Second, all testing and commissioning requirements for the project are specified during this stage. This tends to be the focus of design engineers. However, the functions of the systems and their interactions with each other are often overlooked. Sometimes this is covered by the inclusion of the standard language provided in guide specifications. The guide specifications, however, are tailored to address a specific piece of equipment and may not comprehensively include the interactions with other operating systems.

h. Guide specifications provide a good starting point. However, adequate attention should be spent developing practical testing and commissioning requirements to efficiently verify all project functions and design intents are achieved. Even the best design will not succeed if poorly executed with insufficient quality assurance requirements. Alternately, overly burdensome testing regimes may offset economic savings from time spent diligently optimizing project features.

i. Many of the issues that arise during the commissioning process occur at points of interaction between systems or across discipline lines. Most designers, tradesmen, and fabricators have some level of competency in their specific area of focus. This does not ensure that all their efforts will seamlessly integrate into a cohesive operating system.

j. Beyond preparing the portion of the design for which an individual is responsible, members of the design team should make a reasonable effort of familiarizing themselves with all aspects of the project to ensure the intents and assumptions of other team members are consistent with their own. Exercising effective communication practices and verifying references can also help ensure that contract documents do not provide inconsistent or conflicting instructions to the contractor. Such practices should, in turn, improve the coordination between constituent components and facilitate the successful commissioning of the project.

k. Commissioning of mechanical and electrical equipment ensures that all systems and components have been designed, fabricated, installed, and tested according to the contract requirements. It typically entails the following steps:

(1) Adjusting, integrating, fine tuning and initiating the operation.

(2) Dry testing—operating gates and valves without any pressure or head.

(3) Wet testing—operating gates and valves with pressure and head.

(4) Documenting and training.

(5) Handover and provisional acceptance.

(6) Final delivery to the client.

l. As stated earlier, the acceptance testing of mechanical and electrical equipment typically takes place at the end of the installation period. It is assumed that the equipment has been designed for reliable operation, achieves an acceptable level of safety, and uses appropriate technology.

28–2. Standard references

Standards and guidelines for successful implementation of a technical specification commissioning approach or comprehensive project commissioning approach are provided below. Many of these are building-related, but the designer can use these as a starting point. Specific mechanical and electrical CW commissioning specifications related to locks and dams have not been developed. However, at the writing of this manual, this effort has begun. The designer may reference the following documents as applicable to develop contract language or to use as the governing specification documents the contractors must adhere to for execution of project commissioning:

a. ASHRAE Standard 202.

b. Associated Air Balance Council (AABC) Commissioning Guideline (ACG).

c. NETA Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems, NETA Electrical Commissioning Specifications.

d. Whole Building Design Guide, UFGS 01 91 00.15.

28–3. Systems to be commissioned

Each mechanical and electrical design team member will likely have one or more technical specification sections in the design of each project that potentially require some level of commissioning be performed during construction and startup. All system and equipment types discussed in the chapters of this manual should be included in the commissioning requirements. Beyond the typical CW equipment identified within this document, other systems for commissioning consideration should include, but not be limited to, the following:

a. Building HVAC.

b. Lighting.

c. Fire suppression.

d. Security systems.

e. Fire alarms.

f. Electrical power distribution.

g. Underground electrical distribution.

h. Standby and uninterruptible power systems.

i. Electric motors.

j. Grounding systems.

k. Lightning protection systems.

l. Variable frequency drives.

m. PLC Controls and instruments.

n. Hard-wired and relay-based controls.

o. Pumps.

p. Lock machinery.

q. Dam machinery.

r. Sluice gates.

s. Valves.

t. Water distribution.

u. Sanitary sewer systems.

v. Compressed air systems.

w. Cranes.

28–4. Benefits of commissioning

Commissioning provides benefits to the overall project quality and delivery to achieve fully functional designs. It assures all parties involved with the commissioning sign-off process agree before for final completion of construction, startup and testing. Sign-off parties should include agents from the government (construction, engineering, operations), the Designer of Record, the contractor, subcontractors, Lead Commissioning Agent (as applicable) and Technical Commissioning Specialists.

a. It is the designer's responsibility to develop and define the requirements for commissioning such that contract language is incorporated to assure each system is fully functional, tested, and documented before delivery to the customer.

b. The risk of construction schedule slippage can be lowered by an effective commissioning plan that is fully understood by the contractor, the third-party lead commissioning agent and the technical commissioning specialists performing the pre-functional and functional checklists; start-up; testing, adjusting, balancing (TAB); and operation and testing. The owners and operators also benefit from well-documented commissioning through the data and documentation that is collected. This data serves as a baseline for historical reference in troubleshooting, maintenance, future repairs, and replacement of equipment.

28–5. Commissioning process

Effective communication will promote continuity of thought and allow early identification of points of concern that may require issue resolution. Similarly, coordination by the prime construction contractor should not be considered automatic and the project will benefit from input provided by the designer's involvement. It is not uncommon for sections of the design documents to be parceled out to individual subcontractors for preparation of bids. Parceling of work by the prime contractor to various individual subcontractors can lead to isolation of responsibilities and a breakdown in communication among the various subcontractors. This may limit their understanding of the complete project operational requirements.

a. The designers and customer should discuss and choose the most effective method to implement commissioning for the project early in the design process. A technical specification design approach will likely be the most economical for smaller projects with low technical complexity or limited equipment systems. A comprehensive project commissioning approach is appropriate for larger projects, projects with multiple systems, or projects where the highest quality assurance is necessary.

b. In building commissioning, pre-functional checklists are completed to verify the proper installation of new or relocated HVAC equipment as per typical industry practices. Their primary intention is to be instrumental in ensuring that equipment is suitably prepared for performance testing. In a similar manner, pre-functional checklists can also be used for mechanical and electrical equipment on locks and dams.

c. Also in building commissioning, functional checklists validate the performance of HVAC, pumping, piping, and lighting systems. In a similar manner, functional checklists can be extended to mechanical and electrical equipment on locks and dams.

d. Under the technical specification approach, the commissioning is executed through each technical specification and the requirements are usually mutually exclusive of other specification requirements unless specifically cross referenced in the specification language. There is no separate commissioning firm.

(1) The technical specifications should be created to include submittal requirements defined by the PART 1 Submittals section within the technical specification. Suggested submittals may include pre-functional and functional checklists, commissioning procedures, and startup/operational testing results.

(2) The designer will develop the PART 3 Execution section of the specifications to contain the procedural, data collection, factory/field/endurance/acceptance testing requirements.

e. This commissioning approach involves the contract requirement to have the contractor hire a third-party commissioning firm to oversee and manage all activities associated with project commissioning during construction. The comprehensive commissioning process is not intended to duplicate efforts or to require the subcontractor to perform any check or test twice. Checks and testing by the subcontractor are expected to occur once in the normal sequence of installation and check if appropriate coordination has occurred. This process allows the government and the Lead Commissioning Specialist to witness installations and testing.

(1) For the comprehensive approach, the commissioning firm must be a first-tier subcontractor of the general or prime contractor and must be financially and corporately independent of all other subcontractors. The commissioning firm must employ a lead commissioning specialist that coordinates all aspects of the commissioning process.

(2) The lead commissioning agent must be qualified and certified, and they have the responsibility to coordinate with all technical commissioning specialists who will be conducting commissioning for the equipment or systems. The lead commissioning specialist must submit all plans, schedules, reports, and documentation directly to the Contracting Officer Representative concurrent with submission to the CQC System Manager.

(3) The lead commissioning specialist must have direct communication with the Contracting Officer's Representative regarding all elements of the commissioning process; however, the government has no direct contract authority with the lead commissioning specialist.

(4) The comprehensive commissioning approach is assembled with an overarching General Commissioning specification section that defines how all technical specifications will be collectively managed for commissioning submittals, plans, and reporting. The technical commissioning requirements are still defined within their respective technical specification sections, but they are also referenced to follow the General Commissioning specification section.

f. Active engagement by the engineering support team during construction helps to assure the commissioning process is successful. Engineering involvement allows design intent knowledge to be transferred to all parties during the project completion.

g. Principal tasks at this early stage that contribute to a successful commissioning are review of construction submittals, responding to contractor requests for information (RFI), site visits, witnessing factory testing, and preliminary steps for preparation of the O&M manual. The inspector or inspecting engineer should read and understand the contract plans and specifications (technical and non-technical). Referenced industry standards should be obtained and pertinent sections should be read.

h. It is essential that the design engineer be involved in all phases of construction. The review of equipment shop drawings is the best opportunity for the design engineer to ensure contract requirements will be met. It is also the best and least costly time to implement any changes to the plans or specifications required due to design deficiencies, equipment changes, or to implement design improvements.

i. In addition to reviewing submittals to ensure components satisfy contractual requirements, the design engineers should also be attentive to component compatibility. Components and sub-components should be evaluated to ensure functional and operational design intent is being satisfied. Dimensional information from shop drawings and product cut sheets should be reviewed to ensure the installation will function and provide access as envisioned during design. O&M instructions will provide additional operating requirements for the equipment that must be vetted for consistency and overall project operation.

j. Submittals for factory and field-testing plans and test reports are key to the commissioning process of a CW project. On large projects, stipulating the contractor maintain an updated schedule for anticipated testing dates assists in avoiding conflicts and ensure appropriate government witnesses are available at the time testing is to be performed.

k. As construction progresses and the contractor begins integrating systems, questions about design intent, functionality, possible issues, or optional ways of implementing items will likely result in contractor requests for information. The RFI response process is a beneficial method of resolving issues prior to the formal commissioning process. Maintaining organized records of RFI resolutions is recommended.

28–6. Commissioning agency

The commissioning agency or organization is an unbiased third party that provides professional services to document the approval, receipt, and installation of devices, equipment, installations, and systems. The commissioning organization must be independent of the contractors, manufacturers, suppliers, and installers of the equipment or systems to be installed. It is recommended to always have the contractor provide the commissioning agency for comprehensive commissioning.

a. Government hired. A third-party commissioning agency could be used to augment USACE personnel in oversight of the process, technical support, and quality assurance. In this case, the government may elect to contract and hire their own third-party commissioning firm. It is crucial the designer explicitly define the commissioning relationship and provide well-developed commissioning requirements.

b. Contractor hired. This is the preferred method to acquire the commissioning agency for contractor involvement to avoid complications with coordination and responsibilities. When the project prime contractor hires the commissioning firm, that firm must be a first-tier subcontractor of the general or prime contractor and must be financially and corporately independent of all other subcontractors. The commissioning firm works jointly with the government and the prime contractor to coordinate all aspects of the commissioning process.

28–7. Communication with the government

The lead commissioning specialist must submit all plans, schedules, reports, and documentation directly to the Contracting Officer Representative concurrent with submission to the CQC System Manager. The lead commissioning specialist must have direct communication with the Contracting Officer's Representative regarding all elements of the commissioning process. However, the government has no direct contract authority with the lead commissioning specialist when the prime contractor hires the specialist.

28–8. Sequencing and scheduling

The designer must have a good understanding of the commissioning sequence to ensure specific activities are completed before functional performance testing begins.

a. All equipment and systems must be installed, calibrated, tested, and operated according to the contract documents. Test reports must be submitted and approved.

b. All pre-functional checklists must be completed, submitted, and approved. The designer should have a contract requirement for the contractor to include these types of commissioning activities within their project schedule submissions. These requirements can be applied to both the technical specification approach and the comprehensive commissioning approach. Other commissioning activities for consideration to include in the schedule submission requirements are:

(1) Submission and approval of the technical commissioning specialists for all equipment and control systems.

(2) Installation of any permanent utilities (gas, water, electric).

(3) Installation of machinery.

(4) Installation of control systems.

(5) Factory acceptance testing for each of the systems to be commissioned as required by technical specifications.

(6) Manufacturer's equipment start-up for each of the systems to be commissioned.

(7) Pre-functional checklist submittal for each piece equipment that is part of functional test.

(8) Functional performance testing for each system to be commissioned.

(9) Tests.

(10) Post-test deficiency correction for each system to be commissioned.

(11) Retesting.

(12) Training for each of the systems to be commissioned.

(13) Submission and approval of the commissioning report.

28–9. Submittals

The designer will need to identify and develop the contract submittal list and submittal requirements for the project. There is currently no UFGS to address commissioning of CW projects. As a template for possible submittals, the following headings are offered as a suggested submittal format. The designer will need to designate if the submittals are intended for government approval with a "G" designation or if they are intended for information only. The designer may elect to provide an additional designation following the G to identify a particular office that will review the submittal for the government.

a. Preconstruction submittals will include following:

(1) Commissioning Firm; G.

(2) Lead Commissioning Specialist; G.

(3) Technical Commissioning Specialists; G.

(4) Commissioning Firm’s Contract; G.

b. Test report submittals will include:

(1) Interim Construction Phase Commissioning Plan; G.

(2) Final Construction Phase Commissioning Plan; G.

(3) Pre-Functional Checklists; G.

(4) Issues Log.

(5) Commissioning Report; G.

c. O&M data submittals will include:

(1) Training Plan; G.

(2) Training Attendance Rosters; G.

(3) Systems Operation and Maintenance Manual; G.

d. Closeout submittals will include the final commissioning report.

28–10. Factory and field testing

Factory and field testing both play a complimentary role in the testing and commissioning process for CW projects.

a. Factory testing generally occurs much earlier in the construction process and thereby reduces the impact of any remediation necessary in the event of an unsatisfactory test. Factory testing also may benefit from the ability to isolate systems, closely monitor under controlled conditions, and facilitate thorough inspection by factory staff. Factory tests also benefit from having a clear delineation of the responsible party. Both the prime contractor and the fabricator have a vested interest to ensure the product is functional and without defects prior to factory release and shipment to the project site. See Figure 28–2.

Figure 28–2. Factory testing of pump gearbox

b. Late in a project construction when field testing typically occurs, the contractor's quality control team may apply fewer resources to discovering problems with installed equipment. Disputes may arise between the installer and supplier during this period over who has the responsibility to address any problems discovered. There is a definite value to factory testing, and it should be used where appropriate and as closely matched to field conditions as practical. This includes such factors as environmental conditions and machinery duty cycle.

c. Field testing ensures that equipment has remained defect free during shipment, and that the design and installation are performing as intended. The testing of individual components in the field is generally followed by full system tests of the entire project. This exercise is essential for fine tuning and adjustment as a critical element of the commissioning process. The design engineer is responsible for defining the testing parameters, alarms/monitors, shutdowns, sensor feedback, temperature, speed, time, pressure, vibration, rpm, coating quality, flow rates, levels, loads, megger criteria, etc. that must be evaluated during the factory and field tests.

d. When field-testing mechanical equipment, the designer and commissioning agent must be aware of the limitations of the machinery. For example, depending on the type and size of the motor being tested, there may be limitations on the number of starts per hour. The same issue may apply to gearboxes and gear reducers.

28–11. Commissioning firm

The commissioning firm should be certified, to the extent available from the certifying body, in all systems and equipment intended to be commissioned. Any firm or commissioning specialist that has been the subject to disciplinary action by the certifying body within five years preceding contract award should not be allowed to perform any duties related to commissioning.

a. The commissioning firm must provide the lead commissioning specialist and must show the individual has a minimum of five years of commissioning experience specifically for mechanical and electrical equipment. It is recommended the designer specify as a submittal requirement to have the lead commissioning specialist and all technical commissioning specialists provide certification of qualifications.

b. These should include the name of the specialists and firms, certifications held, years of experience, and a list of representative projects of similar size and complexity. The submittal is recommended to be provided no later than 30 calendar days after notice to proceed.

c. Since there is a general lack of commissioning authorities for CW construction projects, the designer will need to apply engineering judgement in the development of the requirements for the lead commissioning specialist. The following references are generally more specific to vertical building construction, but the designer may find useful information within these references to help define the criteria for the lead commissioning specialist.

(1) National Environmental Balancing Bureau (NEBB)-qualified Systems Commissioning Administrator.

(2) ACG Certified Commissioning Authority (CxA).

(3) Building Commissioning Association (BCA) Certified Commissioning Professional (CCP).

(4) University of Wisconsin-Madison Qualified Commissioning Process Provider (QCxP).

(5) Building Commissioning Professional (BCxP).

d. The technical commissioning specialists are employed by the commissioning firm and perform the technical work associated with each system to be commissioned. They should be specified to meet one or more of the following qualifications based on the type of commissioning to be executed.

(1) A mechanical-HVAC technical commissioning specialist conducts the technical work associated with mechanical systems including heating, ventilating, air conditioning, and refrigeration systems, steam systems, building automation system, service water heating systems, water pumping and mixing systems and compressed air. A specialist

for each system is recommended but an individual may cover more than one system provided the experience in each system is shown.

(2) A mechanical technical commissioning specialist conducts the technical work associated with non-HVAC mechanical systems including hydraulic systems, pumping systems, fire suppression systems, and mechanical drive and gear systems. A specialist for each system is recommended but an individual may cover more than one system provided the experience in each system is shown.

(3) An electrical technical commissioning specialist conducts the technical work associated with electrical systems including lighting systems; low-voltage distribution systems, medium-voltage distribution systems, lightning protection systems, relay-based control systems and PLC systems.

(4) The CTC (certified testing company) performing the electrical work must be qualified to test electrical equipment and is a NETA-certified testing agency. The CTC must not be associated with the manufacturer of equipment or systems under test. The CTC must provide all test equipment necessary to fulfill the checks and testing requirements. All test equipment used during the commissioning must have been calibrated within one year of its use on the project.

(5) All electrical testing must be performed by an engineering technician certified by NETA or the National Institute for Certification in Engineering Technologies (NICET) with five years of experience inspecting, testing, and calibrating electrical distribution and generation equipment, systems, and devices.

28–12. Commissioning standard

The designer should specify the commissioning firm must comply with the requirements of the commissioning standard under which they are approved. When there are electrical commissioning requirements, the designer should specify the commissioning firm comply with applicable NETA testing standards for electrical systems. The commissioning firm should be provided with and required to follow guidelines related to commissioning standards.

a. Implement all recommendations and suggested practices contained in the commissioning standard and electrical test standards.

b. Use the commissioning standard for all aspects of commissioning, including calibration of instruments.

c. Where the instrument manufacturer’s calibration recommendations are more stringent than those listed in the commissioning standard, adhere to the manufacturer calibration recommendations.

d. All quality assurance provisions of the commissioning standard, such as performance guarantees, should be included as part of the contract requirements.

e. The commissioning specialists must develop commissioning procedures for any systems or system components not covered in the commissioning standard.

f. The commissioning firm and specialists must be required to follow any new requirements, recommendations, and procedures published or adopted prior to contract solicitation by the body responsible for the commissioning standard.

28–13. Issue resolution

When a comprehensive project commissioning approach is taken, it is recommended the designer specify a requirement to have the lead commissioning specialist develop and maintain an issues log. the issues log is for tracking and resolution of all deficiencies discovered through submittal reviews, inspection, and testing.

a. The issues log must include the date of final resolution of issues as confirmed by the commissioning specialist. The issues log should be submitted monthly at a minimum. At any point during construction, any commissioning team member finding deficiencies may communicate those deficiencies in writing to the commissioning specialist for inclusion into the issues log.

b. The commissioning submittals and issue log should be tracked using the project QC system software. The Resident Management System (RMS) is an example.

28–14. Construction phase

The designers will need to identify and specify the contract products or deliverables the government desires to have provided during the construction phase of a project. This is true whether a technical specification commissioning approach or a comprehensive project commissioning approach is used.

a. Lead commissioning specialist. The lead commissioning specialist has a higher level of responsibility to create the commissioning plan and deliverables under the comprehensive project commissioning approach. The lead commissioning specialist will use the requirements defined by the applicable commissioning standards to develop the commissioning plan. Commissioning products that are suggested to be incorporated into the contract documents by the designer or developed and provided by the lead commissioning specialist are described below.

(1) A construction commissioning coordination meeting is recommended to be held after approval of the commissioning firm and commissioning specialists, and no more than 30 days following construction notice to proceed. This meeting will be led by the lead commissioning specialist for a comprehensive project commissioning approach or by the prime contractor for technical specification commissioning approach.

(2) The focus of this meeting is to discuss the commissioning process, including contract requirements, lines of communication, roles and responsibilities, schedules, documentation requirements, inspection and test procedures, and logistics as specified in the project plans and specification documents. The contractor's superintendent or

project manager, the contractor's quality control representative, and the government must attend this meeting. It is also recommended the user be invited to attend this meeting.

b. Owner's project requirements meetings. For a comprehensive project commissioning approach, the designer must include specification language to have the lead commissioning specialist conduct the owner's project requirements meeting.

(1) The lead commissioning specialist will be responsible to invite the appropriate technical commissioning specialists, project design team members, Contracting Officer's Representative (COR), and owner representatives to the meeting(s).

(2) The lead commissioning specialist will document the attendee names and responsibilities during the meetings. It is recommended that these meetings be attended in person, but at a minimum, the lead commissioning specialist, COR, owner representative, and lead project engineer must be in person.

(3) Other PDT member participation will be at the discretion of the COR. Other commissioning team members attendance will be at the discretion of the lead commissioning specialist.

c. Progress meetings. Progress meetings can be specified and held for either the technical specification commissioning approach or the comprehensive project commissioning approach. If there is a lead commissioning specialist involved with the project, they must invite the appropriate technical commissioning specialists to the meetings based on the upcoming project schedule activities.

(1) For each weekly progress meeting, the lead commissioning specialist must document the responsible person names and responsibilities required during the look ahead schedule, to be provided to the government for information only.

(2) The contractor's Superintendent or Project Manager, the contractor's quality control representative, and the government must attend the progress meetings. It is also recommended the user be invited to attend the progress meetings.

d. Final construction phase commissioning plan. It must be specified the lead commissioning specialist is responsible to prepare the final construction phase commissioning plan. The final construction phase commissioning plan is recommended to be submitted no later than 30 calendar days prior to the start of pre-functional checks.

(1) The final construction phase commissioning plan should include the information provided in the interim construction phase commissioning Plan and any updates for the final commissioning plan.

(2) Each technical commissioning specialist is responsible for developing the pre-functional checklists, integrated systems test checklists, and functional performance test checklists for each system of components or building. The tests and checklists must be

included in the final construction phase commissioning plan. Examples of checklists that may be useful for commissioning are provided in the paragraphs below.

(3) Pre-functional testing is that testing performed prior to operation. Functional testing is performed during initial startup under controlled testing environment. Integrated system testing is performed with one or more systems operating together.

(4) For some systems, such as lighting, plumbing, HVAC, etc. that involve industry standard systems and equipment, the commissioning specialists will generally have expertise to develop inspection and test procedures. For actual machinery designed by USACE that is somewhat unique and for unique purposes, the designer of record must develop the test procedures. They can be refined by the commissioning specialists for approval by the designer of record.

e. Pre-functional checklists. The pre-functional checklists must include items for physical inspection or testing that demonstrate that installation and startup of equipment and systems is complete. Pre-functional checklists from the approved final construction phase commissioning plan must be completed by the commissioning team.

(1) One pre-functional checklist should be completed for each individual item of equipment or system required to be commissioned, including, but not limited to, HVAC equipment, piping, fixtures (lighting and plumbing), lock machinery, dam machinery, hydraulic equipment, fire protection, lightning protection, and controls. The checklists should document by signature the commissioning team members who participate in the inspection and acceptance of each pre-functional checklist item.

(2) Acceptance of each pre-functional checklist item by each team member indicates the item conforms to the construction contract and accepted design requirements in their area of responsibility. The technical commissioning specialist's acceptance of each pre-functional checklist item indicates that each item has been installed correctly and according to contract documents and the owner's project requirements.

(3) Each checklist is recommended to be submitted complete and initialed no later than seven calendar days after completion of inspection of each component or system. Submission of one hard copy and an electronic copy is suggested. Manufacturer startup checklists associated with equipment should also be included with the submission of the pre-functional checklists.

f. h. *Functional performance test checklists*. The designer should prepare the contract specification language to have the contractor and lead commissioning agent use the functional performance test requirements from the approved final construction phase commissioning plan.

(1) Functional performance test checklists include procedures that explain, step-by-step, the actions and expected results that will demonstrate that the system performs according to the contract.

(2) The functional performance tests must be performed for each equipment item and system to verify all sensor calibrations, control responses, safeties, interlocks, operating modes, sequences of operation, capacities, lighting levels, and all other performance requirements comply with the construction contract and accepted design requirements. Testing must progress from equipment or components to subsystems and systems. Testing progresses in complexity until all interlocks and connections between systems have been tested.

(3) The contractor should be required to correct all deficiencies identified through any prior review, inspection, or test activity before the start of functional performance tests.

(4) Functional performance tests must be performed with the Contracting Officer's quality assurance representative present.

(5) Technical commissioning specialists must lead and document all functional performance tests for the systems to be commissioned with the contractor and appropriate subcontractors performing the functional performance tests. Representatives identified in the commissioning plan must attend the tests. It is recommended that functional performance tests be aborted when any required commissioning team member is not present for the test.

(6) Electrical functional tests must follow NETA procedures and details.

(7) The order of components and systems to be tested must be determined by the technical commissioning specialists.

g. Integrated systems test checklists. Integrated systems tests must be performed to ensure interlocks work correctly between the control systems and mechanical systems. These are typically done for the interactive operation between systems such as hydraulic machinery, PLC systems, interlock controls, fire protection systems, HVAC systems, backup electrical supply, and energy generation systems. The integrated system tests are to verify correct operation, acceptable speed of response, and other contract requirements for both normal and failure modes, including electrical and mechanical equipment during loss of power.

(1) Integrated systems test checklists must include test procedures that explain, step-by-step, the actions and expected results that will demonstrate that the interactive operations between systems performs according to the contract.

(2) Notable features of the interconnected systems organized by discipline including information to facilitate understanding of system operation.

28–15. Operations training

The designer must determine what amount of contractor-led training is necessary to allow the customer to have a full understanding of the new operating equipment and systems. The customer may often be acquiring for use a completely new operating system and may have little to no familiarity with its operation or maintenance requirements. The designer must coordinate with the customer when developing the contract language needed for a comprehensive training plan for the benefit of the end user. The level of complexity also varies depending on whether an electromechanical drive or hydraulic drive (Figure 28–3) is specified. Similarly, a PLC system will require more training than a relay-based system.

a. The training plan requirements should identify all training required by the specification sections associated with commissioned systems. Include a matrix listing each training requirement, content to be included in the training, the trainer's name, trainer contact information, and schedule and location of training.

b. The lead commissioning agent may also take a role in developing the training plan when a comprehensive project commissioning approach is taken.

c. The training plan should be updated and presented along with the construction schedule as progress is made. The training plan must document training attendance using training attendance rosters. Completed attendance rosters should be submitted to the commissioning specialists and the government no later than seven calendar days following the completion of training for each system commissioned.

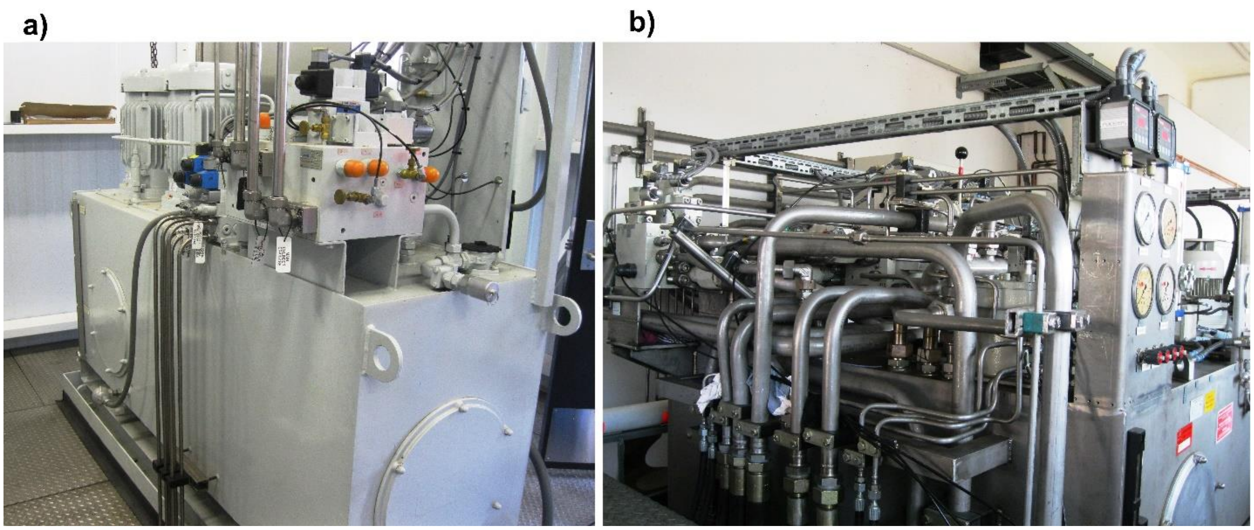


Figure 28–3. Hydraulic drive systems: a) hydraulic power unit, b) hydraulic piping and controls

28–16. Acceptance/certificate of readiness

Prior to the initiation of final acceptance testing, it is recommended a Certificate of Readiness be prepared and submitted to the government. The Certificate of Readiness document should confirm that a piece of equipment or operating system has been proven to be complete and all pre-functional and functional checklists have been completed and signed by the technical commissioning specialists.

a. Acceptance is complete when the functional performance test checklists for each item of equipment or system(s) tested has been signed by the responsible commissioning team members.

b. The contractor's quality control representative and the technical commissioning specialists must indicate acceptance after the equipment and systems are free of deficiencies. A specification requirement to have the contractor and lead commissioning agent submit the final acceptance report is recommended for the complete project commissioning effort.

28–17. Commissioning report

A requirement for the contractor or lead commissioning agent to provide a final commissioning report should be included in the project contract documents specified by the designer(s). The commissioning report should document the completion of functional performance tests and requirements should consider including the following requirements within the report documentation. It is suggested the commissioning report be required to be submitted no later than 14 calendar days following commissioning team acceptance of all functional performance tests.

a. Include an executive summary describing the overall commissioning process, the results of the commissioning process, any outstanding deficiencies and recommended resolutions, and any seasonal testing that must be scheduled for a later date. Indicate in the executive summary whether the systems meet the requirements of the construction contract and accepted design and the owner's project requirements.

b. Detail any deficiencies discovered during the commissioning process and the corrective actions taken in the report. Include the pre-functional checklists, functional performance test checklists, the commissioning plans, the issues log and training attendance rosters.

28–18. Documentation and training

The designer should also reference Chapter 27. To ensure effective knowledge transfer to the owner/operator, the relevant owner/operator personnel should be exposed as much as possible to the commissioning process. This exposure should preferably start during the factory acceptance testing and personnel should also be included in the installation process. Ideally, the personnel should be trained on the operation of the equipment prior to the testing phase to enable them to be actively involved with the fault finding and testing phases.

a. It is recommended that personnel are trained based on the contents of the O&M manuals. The O&M manuals should contain, at a minimum, the following aspects:

(1) Overview of equipment.

(2) Safety and environmental aspects of the gates and valves operations and maintenance.

(3) Operation procedures during normal conditions.

(4) Operation procedures during abnormal/emergency conditions.

(5) Routine inspections.

(6) Routine maintenance.

(7) Major overhaul and refurbishment of equipment.

(8) Fault-finding guide.

(9) As-built drawings.

(10) Spare parts lists.

(11) Equipment datasheets.

b. At the completion of the client/operator personnel training, the trainees should be evaluated to conclude that sufficient knowledge transfer has occurred and that the personnel has sufficient knowledge and experience to operate and maintain the plant. Personnel that pass the evaluation should be presented with a certificate. Note that if a crane/hoist is part of the mechanical equipment, there are normally regulatory requirements to which the crane operators and maintenance crew should adhere.

c. Apart from the O&M manual, it is also recommended that the contractor/installer provide a complete data book at the completion of the commissioning phase that includes the following:

(1) Material certificates.

(2) Quality assurance documents of manufacturing.

(3) Quality assurance documents of installation.

(4) Methods statements for the installation process.

(5) Testing procedures.

(6) Testing results.

Appendix A
References

Section I

Required Publications

Unless otherwise indicated, Department of Defense Instruction (DoDI) publications are available at https://dodcio.defense.gov/library/. Army publications are available on the Army Publishing Directorate website at https://armypubs.army.mil. All U.S. Army Corps of Engineers publications are available on the USACE website at https://publications.usace.army.mil. Engineering and Construction Bulletin (ECB) publications are available at https://www.wbdg.org/dod/ecb. Unified Facilities Criteria (UFC) publications are available at https://www.wbdg.org/dod/ufc. Unified Facilities Guide Specifications (UFGS) publications are available at https://www.wbdg.org/dod/ufgs.

In addition, author-driven publications for USACE, ERDC, CERL, and CRREL are included in this appendix. Unless otherwise noted, those reports are available at https://www.erdc.usace.army.mil/Library.aspx.

Additional home-site URLs for non-Army and non-USACE references are provided alphabetically within the below list of required publications. Many are included as supplemental references for this EM content. No URLs are available unless indicated.

American Association of State Highway and Transportation Officials (AASHTO)
(Available at https://www.transportation.org/ and https://store.transportation.org/)

AASHTO Load and Resistance Factor Design (LRFD)
Movable Highway Bridge Design Specifications, 3rd edition (Available at https://store.transportation.org/item/collectiondetail/249)

American Chain Association (ACA) 1982
Chains for power transmission and material handling: Design and applications handbook, 2nd edition. New York: Marcel Dekker.

American Gear Manufacturers Association (AGMA) publications
(Available at https://www.agma.org/ and https://members.agma.org/)

AGMA 2001-C95
Fundamental Rating Procedures for Involute Spur and Helical Gear Teeth

AGMA 2003-B97
Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zero Bevel and Spiral Bevel Gear Teeth

AGMA 2015-1-A01
Accuracy Classification System –Tangential Measurements for Cylindrical Gears

AGMA 6013-A06
Standard for Industrial Enclosed Gear Drives

AGMA 6113-A06
Standard for Industrial Enclosed Gear Drives (Metric Edition)

AGMA 9005-E02
Industrial Gear Lubrication

American Institute of Steel Construction (AISC)
Steel Construction Manual (Available at https://www.aisc.org/publications/steel-construction-manual-resources/)

American National Standards Institute/Institute of Electrical and Electronics Engineering, Inc. (ANSI/IEEE) publications
(Available at https://standards.ieee.org/standard/index.html and https://www.ansi.org/ and https://webstore.ansi.org/industry/selected-standards)

ANSI B11.0
Safety of Machinery https://webstore.ansi.org/search/find?in=1&st=ansi+b11.0

ANSI B11.26
Functional Safety for Equipment: General Principles for the Design of Safety Control Systems Using ISO 13849-1
https://webstore.ansi.org/search/find?in=1&st=ANSI+B11.26-2024

ANSI B29.10M
Heavy Duty Offset Sidebar Power Transmission Roller Chains and Sprocket Teeth
https://webstore.ansi.org/standards/asme/ansiasmeb2910m1997r2002?srsltid=AfmBOoqMn5-f7X-GKfbp8pnhBH-zGKrb1xShlgadlflocLTNQOqZt_z0

ANSI/IEEE 141, 1999
Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book) https://standards.ieee.org/ieee/141/312/

ANSI/IEEE 142, 2007
Recommended Practices for Grounding of Industrial and Commercial Power Systems (IEEE Green Book) https://standards.ieee.org/ieee/142/315/

ANSI/IEEE 493, 2007
Recommended Practices for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book) https://standards.ieee.org/ieee/493/726/

ANSI/IEEE 3006.8, 2018
Recommended Practice for Analyzing Reliability Data for Equipment Used in Industrial and Commercial Power Systems
https://standards.ieee.org/ieee/3006.8/4447/

ANSI/IEEE C2, 2017
National Electrical Safety Code https://standards.ieee.org/ieee/VuSpec/10332/

ANSI/NETA ATS
InterNational Electrical Testing Association (NETA) Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems, NETA Electrical Commissioning Specifications (Available at https://www.netaworld.org/standards and https://www.netaworld.org/artr/standards/ansi-neta-ats)

ANSI/NETA MTS-2023
Maintenance Testing Specifications For Electrical Power Equipment and Systems
https://www.netaworld.org/standards/ansi-neta-mts

ANSI/Telecommunications Industry Association (TIA)-568.2-D
Copper Cabling Standards Basis https://tiaonline.org/what-we-do/standards/

American Petroleum Institute (API) 2C
Specification for Offshore Pedestal Mounted Cranes. (Available at https://www.api.org/ and https://www.api.org/products-and-services/standards/important-standards-announcements/spec2c)

American Society for Metals (ASM)
Properties and selection of metals. In *Metals handbook, Volume 1*, 2nd edition. (Available at https://www.asminternational.org/ and https://www.asminternational.org/results/-/journal_content/56/05313G/PUBLICATION/)

American Society for Testing and Materials (ASTM) publications
(Available at https://www.astm.org/Standard/standards-and-publications.html)

ASTM A108
Standard Specification for Steel Bars, Carbon, Cold-Finished, Standard-Quality

ASTM A148
Standard Specification for Steel Castings, High Strength, for Structural Purposes

ASTM A27
Standard Specification for Steel Castings, Carbon, for General Application

ASTM A290
Standard Specification for Carbon and Alloy Steel Forgings for Rings for Reduction Gears

ASTM A291
Standard Specification for Steel Forgings, Carbon and Alloy, for Pinions, Gears and Shafts for Reduction Gears

ASTM A36
Standard Specification for Carbon Structural Steel

ASTM A519
Standard Specification for Seamless Carbon and Alloy Steel Mechanical Tubing

ASTM A564
Standard Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes

ASTM A668
Standard Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use

ASTM A705
Standard Specification for Age-Hardening Stainless Steel Forging

ASTM B148
Standard Specification for Aluminum Bronze Sand Castings

ASTM B271
Standard Specification for Copper-Base Alloy Centrifugal Castings

ASTM B505
Standard Specification for Copper-Base Alloy Continuous Castings

ASTM B584
Standard Specification for Copper Alloy Sand Castings for General Applications

American Society of Civil Engineers (ASCE)
Water Control Gates, Guidelines for Inspection and Evaluation. 2012. (Available at https://www.asce.org/publications/)

American Society of Heating and Air Conditioning Engineers (ASHRAE) Standard 202
Commissioning Process for Buildings and Systems. (Available at https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/202_2013_b_20180308.pdf)

American Society of Mechanical Engineers (ASME) publications
(Available at https://www.asme.org/codes-standards/publications-information)

ASME A13.1
Scheme for the Identification of Piping Systems

ASME A17.1
Safety Code for Elevators and Escalators

ASME B106.1
Design of Transmission Shafting

ASME B17.1
Keys and Keyseats

ASME B29.10M
Heavy Duty Offset Sidebar Precision Power Transmission Roller Chains

ASME B29.15M
Steel Roller Type Conveyor Chains, Attachments, And Sprocket Teeth

ASME B29.1 and B29.1M
Precision Power Transmission Roller Chains, Attachments, and Sprockets

ASME B30.2
Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist)

ASME B30.22
Articulating Boom Cranes

ASME B30.4
Portal and Pedestal Cranes

ASME B30.5
Mobile and Locomotive Cranes

ASME B30.6
Derricks

ASME B30.8
Floating Cranes and Floating Derricks

ASME B31.1
Power Piping

ASME B46.1
Surface Texture (Surface Roughness, Waviness and Lay)

American Water Works Association (AWWA) publications
(Available at https://www.awwa.org/)

AWWA C542
Electric Motor Actuators for Valves and Slide Gates

AWWA C560
Cast-Iron Slide Gates

AWWA C561
Fabricated Stainless Steel Slide Gates

American Welding Society (AWS) publications
(Available at https://www.aws.org/)

AWS D1.1
Structural Welding Code Steel

AWS D1.5
Bridge Welding Code

AWS D14.1
Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment

AR 25-2
Army Cybersecurity https://armypubs.army.mil/ProductMaps/PubForm/AR.aspx

AR 190-51
Security of Unclassified Army Resources (Sensitive and Nonsensitive)
https://armypubs.army.mil/ProductMaps/PubForm/AR.aspx

Ashton 1979
Ashton, G.D. 1979. *Point source bubbler systems to suppress ice*. Engineer Research and Development Center (ERDC)/Cold Regions Research and Engineering Laboratory (CRREL). Report 79-12. Available from USACE HQ.
https://www.usace.army.mil/Contact/

Associated Air Balance Council (AABC), AABC Commissioning Group (ACG) Commissioning Guideline
For Building Owners, Design Professionals, and Commissioning Service Providers. (Available at https://www.commissioning.org/wp-content/uploads/2019/07/ACGCommissioningGuideline.pdf)

Avallone and Baumeister 1996
Avallone, E.A., and Baumeister III, T. 1996. *Marks' Standard Handbook for Mechanical Engineers*, 10th edition. McGraw Hill, New York, NY.

Beeman 1955
Beeman, D., ed. 1955. *Industrial Power System Handbook*. General Electric Company. McGraw-Hill, New York NY.

Black and Adams 1968
Black, P.H., and Adams Jr., E. 1968. *Machine design*, 3rd edition. New York: McGraw Hill.

Carey 1983
Carey, K.L. 1983. *Melting ice with air bubblers*. ERDC/CRREL Technical Digest Report 83-1. Available from USACE HQ. https://www.usace.army.mil/Contact/

Carmichael 1950
Carmichael, C. 1950. *Kent's Mechanical Engineers Handbook*, 12th edition. Design and Protection Volume. New York, NY, John Wiley & Sons.

Chowdhury and Hall 1998
Chowdhury, M., and Hall, R. 1998. *Performance Evaluation of Full-Scale Composite and Steel Wickets for Use at Olmsted Locks and Dam*. University of Arizona, Tucson Department of Civil Engineering and Engineering Mechanics. (Available at https://trid.trb.org/view/501136)

Clark 1993
Clark, C.H. 1993. *Monitoring Electrical Dam Gate Heaters*. USACE/CRREL. (Available from USACE HQ at https://www.usace.army.mil/Contact/)

Coastal and Hydraulics Laboratory (CHL) TR-03-3
Filling and Emptying System for Inner Harbor Navigation Canal Lock Replacement, Louisiana.
https://erdclibrary.on.worldcat.org/search?queryString=Filling%20and%20Emptying%20System%20for%20Inner%20Harbor%20Navigation%20Canal%20Lock%20Replacement%2C%20Louisiana.&databaseList=2375%2C2264%2C2363%2C2272%2C2062%2C283%2C3504%2C1875%2C3404%2C3437%2C2237%2C1697%2C2059%2C2310%2C10265%2C638%2C1847%2C10896&clusterResults=false&groupVariantRecords=false

Compressed Air and Gas Institute (CAGI)
Compressed Air and Gas Handbook. (Available at https://www.cagi.org/resource-library)

Crane Manufactures Association of America (CMAA) publications
(Available at http://www.mhia.org/industrygroups/cmaa)

CMAA 70
Multiple Girder Cranes

CMAA 78
Single Girder Cranes

DA Pamphlet 25-403
Guide to Recordkeeping in the Army

Daniel 2011
Daniel, R.A. 2011. *Contact behavior of lock gates and other hydraulic closures: Research results, investigations, and field experiences*. Saarbruecken: Lambert Academic Publishing.

de Béjar 1997
de Béjar, L.A. 1997. Hydraulic Forces on a Wicket Gate Under Upstream Quasi-Laminar Flow – An Experimental Analysis Technique. TR SL-97-12. USACE WES. (Available at https://apps.dtic.mil/sti/tr/pdf/ADA331424.pdf)

Deutsches (German) Institut Fur Normung (DIN) publications
(Available at https://www.din.de/en/about-standards/din-standards)

DIN 5684=1
Round Link Steel Chain

DIN 22252
Steel Chains (Round Link) for Use with Conveyors and Coal-Getting Equipment in Mining: Calibrated, Tested (Part 1)

Dilaura et al. 2011
Dilaura, D.L. et al. 2011. *Lighting Handbook Reference and Application*. 10th edition. Illuminating Engineering Society of North America. (Available at https://www.ies.org/ and https://store.ies.org/?v=0b3b97fa6688)

DoDI 8500.01
Cybersecurity https://dodcio.defense.gov/library/

DoDI 8510.01
Risk Management Framework (RMF) for DoD Information Technology https://dodcio.defense.gov/library/

EC 11-2-218
Policy for Operational Condition Assessments of USACE Assets (Available from USACE HQ at https://www.usace.army.mil/Contact/ and also available with Google Search)

EC 1110-2-6062
Risk and Reliability Engineering for Major Rehabilitation Studies (Available from USACE HQ at https://www.usace.army.mil/Contact/)

EC 1130-2-551
Civil Works Maintenance Portfolio Management

ECB 2006-11
Tainter Gate Trunnion Lubrication (Available from USACE HQ at https://www.usace.army.mil/Contact/)

ECB 2009-3
Ceramic Coated Piston Rods (Available from USACE HQ at https://www.usace.army.mil/Contact/)

ECB 2018-16
Standardization and Sustainability Technical Reports for Locks And Dams

ECB 2019-15
Interim Approach for Risk-Informed Designs for Dam and Levee Projects

ECB 2019-3
Risk Informed Decision Making for Engineering Work During Planning Studies

ECB 2020-10
Facility-Related Control System Cybersecurity Coordination Requirement

ECB 2021-4
Cybersecurity Design Requirements for Non-Permanent Facilities

ECB 2021-5
Interpretation of UFC 1-200-01, Delegation of Building Official/Authority Having Jurisdiction Responsibilities and Waiver/Exemption/Equivalency Approvals

ECB 2022-1
Prohibitions In The Use Of Brand Name (Or Equal) References In Solicitations

ECB 2022-2
Cybersecurity Requirements for Design and Construction Of Control Systems and Integrated Low Voltage Systems For Permanent And Non-Permanent Construction – Category: Directive And Guidance

ECB 2022-7
Interim Approach for Risk-Informed Designs for Dam and Levee Projects

ECB 2024-6
Required use of United Facilities Criteria (UFC) on USACE Civil Works Projects for Electrical Criteria

ECB 2024-7
Engineering, Construction and Maintenance for Fire Protection and Life Safety of Civil Works Buildings, Structures, and Systems

Electrical Apparatus Service Association (EASA) Standard AR100-2015
Recommended Practice for the Repair of Rotating Electrical Apparatus. (Available at https://www.apprep.com/Site/articles/EASA_AR100-2015_0815_0.pdf)

EM 385-1-1
Safety and Health Requirements Manual

EM 1110-2-1424
Lubricants and Hydraulic Fluids

EM 1110-2-1604
Hydraulic Design of Navigation Locks

EM 1110-2-1610
Hydraulic Design of Lock Culvert Valves

EM 1110-2-1612
Ice Engineering

EM 1110-2-1619
Risk Based Analysis for Flood Damage Reduction Studies

EM 1110-2-1908
Instrumentation of Embankment Dams and Levees

EM 1110-2-2107
Design of Hydraulic Steel Structures

EM 1110-2-2602
Planning and Design of Navigation Locks

EM 1110-2-2607
Planning and Design of Navigation Dams

EM 1110-2-2704
Cathodic Protection Systems for Civil Works Structures

EM 1110-2-3006
Mechanical and Electrical Design of Hydroelectric Power Plants

EM 1110-2-3105
Mechanical and Electrical Design of Pumping Stations

EM 1110-2-3200
Wire Rope for Civil Works Structures

EM 1110-2-3400
Painting: New Construction and Maintenance

EP 385-1-100
Implementation of Arc Flash Hazard Program

ER 25-1-113
Critical Infrastructure Cybersecurity Mandatory Center of Expertise

ER 385-1-100
Arc Flash Hazard Program

ER 415-1-11
Biddability, Constructability, Operability, Environmental, and Sustainability Review (BCOES)

ER 1105-2-101
Risk Analysis for Flood Damage Reduction Studies

ER 1110-1-8168
Roles and Responsibilities of the Inland Navigation Design Mandatory Center of Expertise

ER 1110-2-112
Required Visits to the Construction Sites by Design Personnel

ER 1110-2-1150
Engineering and Design for Civil Works Projects

ER 1110-2-1156
Engineering and Design Safety of Dams: Policies and Procedures

ER 1110-2-8157
Responsibility for Hydraulic Steel Structures

ER 1110-2-8159
Life Cycle Design and Performance

ER 1110-2-8173
Energy and Water Optimization

ER 1165-2-217
Civil Works Review Policy

Faires 1965
Faires, V.M. 1965. *Design of machine elements*, 4th edition. New York: MacMillan Publishing.

Fink and Beaty 1987
Fink, D.B., and Beaty, H.W., eds. 1987. *Standard Handbook for Electrical Engineers,* 12th edition. McGraw-Hill, New York, NY.

Gibbs 1971
Gibbs, C.W. 1971. *Compressed Air and Gas Data.* Ingersoll Rand Corporation.

Harman and Allen 1987
Harman, T.L., and Allen, C.E. 1987. *Guide to the National Electric Code*. Prentiss-Hall, Englewood Cliffs, NJ.

Hayes et al. 1995
Hayes, F.D., Haehnel, R., Clark, C.H., and Zabliansky, L. 1995. "Use of radiant heaters to prevent icing." REMR Bulletin Vol. 12, No. 2. USACE WES. (Available from USACE HQ at https://www.usace.army.mil/Contact/)

Hite 2003
Hite, J. 2003. *In-Chamber Longitudinal Culvert Design for Lock Filling and Emptying System.* ERDC/CHL TR-03-8. (Available at https://erdclibrary.on.worldcat.org/search?queryString=ERDC%20CHL%20TR-03-8&clusterResults=true&stickyFacetsChecked=true&baseScope=wz%3A63341&groupVariantRecords=false&scope=wz%3A63341)

Homeland Security Presidential Directive 12
Policy for a Common Identification Standard for Federal Employees and Contractors (Available at https://www.dhs.gov/homeland-security-presidential-directive-12)

House Report 5515
John S. McCain National Defense Authorization Act (NDAA) for Fiscal Year 2019 https://www.congress.gov/bill/115th-congress/house-bill/5515/text

Hydraulic Institute (HI) 9.8
Rotodynamic Pumps for Pump Intake Design (Available at https://www.pumps.org/what-we-do/standards/)

IEEE 802.11ax
Information Technology – Telecommunications and Information Exchange between Systems Local and Metropolitan Area Networks – Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 1: Enhancements for High-Efficiency WLAN. Institute of Electrical and Electronics Engineering, Inc. (IEEE). (Available at https://standards.ieee.org)

International ElectroTechnical Commission (IEC) publications
(Available at https://www.iec.ch)

IEC 60034-1
Duty Cycles of Operating Electrical Motors

IEC 60034-5
Rotating Electrical Machines – Part 5: Degrees of Protection Provided by the Integral Design of Rotating Electrical Machines (Ingress Protection Code) – Edition 4.1 Consolidated Report

IEC 60034-6
Rotating Electrical Machines – Part 6: Methods of Cooling

Illumination Engineering Society (IES) RP-8
Recommended Practice for Lighting Roadway and Parking Facilities (2018). Illuminating Engineering Society of North America. (Available at https://www.ies.org/)

International Fire Code Section 510 (a) 510.4.1.1
Minimum Signal Strength Into the Building. (Available at https://up.codes/s/emergency-responder-communication-enhancement-system-signal-strength)

International Organization for Standardization (ISO) publications
(Available at https://www.iso.org/home.html)

ISO 281
Rolling Bearings – Dynamic Load Ratings and Rating Life

ISO 4413
Hydraulic fluid power – General rules and safety requirements for systems and their components

ISO/IEC TR 24750
Information Technology–Assessment and Mitigation of Installed Balanced Cabling Channels to Support 10GBASE-T

ISO/Technical Specification (TS) 13725
Hydraulic Fluid Power - Method for evaluating the buckling load of a hydraulic cylinder

Japanese Standards Association (JIS) B1519
Dynamic Load Ratings for Rolling Bearings (Available through Accuris at https://store.accuristech.com/standards/jis-b-1519-2023?product_id=2566211&srsltid=AfmBOorTyEOM4Efyat5HjWrb-rxyF4K_HgEWYUV-10AubiBlOpKA0vVj)

Jones et al. 1999
Jones, J.A., Palytyk, R.A, Willis, P., and Weber, R.A. 1999. *Greaseless bushings for hydropower applications: Program, testing, and results*. USACE ERDC/CERL TR-99-104.
(https://safe.menlosecurity.com/doc/docview/viewer/docNDBE3D99A1D52d4ef0f4470732e904c5c495592831664dc5451a3a6323626126dfd7611d4b98f)

Karassik et al. 1986
Karassik, I.J., Krutzsch, W.C., Fraser, W.H., and Messina, J.P. 1986. *Pump Handbook,* 2nd edition. McGraw-Hill, New York, NY.

Kingsbury, Inc. 2010
A general guide to the principles, operations, and troubleshooting of hydrodynamic bearings. (Available at https://www.kingsbury.com/Products/hydrodynamic_bearings)

Knovel
Online engineering database and search engine: http://why.knovel.com/

Kumar et al 1989
Kumar, A., Odeh, A.A., and Myers, J.R. 1989. *Mechanical properties and corrosion behavior of stainless steel for locks, dams, and hydroelectric plant applications*. REMR-EM-6. USACERL. (Available at https://safe.menlosecurity.com/doc/docview/viewer/docNFD62D051589D1725c45793ae107f8404d4dd533b7ed48bc70ea90235fc8acc139f16db372ad8)

Kumar et al 2002
Kumar, A., Stephenson, L.D., and Willis, P. 2002. *Advanced materials selection guide for lock, dam, and hydroelectric plant components*. ERDC/CERL TR-02-7. https://erdc-library.erdc.dren.mil/items/81b728f7-9cbe-4ef8-e053-411ac80adeb3

Lewis and Telford 2001
Lewis, J., and Telford, T. 2001. *Hydraulic gates and valves in free surface flow and submerged Outlets*. 2nd edition. London: Thomas Telford Publishing.

Mancuso and South 1994
Mancuso, J.R., and South, D.W. 1994. *Mechanical Power Transmission Components*. 1st edition. Marcel Dekker, Inc., New York, NY.

Murray and Simmons 1966
Murray, R.I., and Simmons, W.P. 1966. *Hydraulic Downpull Forces on Large Gates*. Technical Report No RR-4, Bureau of Reclamation. (Available at https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB95102109.xhtml)

National Association of Corrosion Engineers (NACE) SP0169
Control of External Corrosion on Underground or Submerged Metallic Piping Systems. (Available at https://store.nace.org/sp0169-2013-formerly-rp0169-2)

National Electrical Manufacturers Association (NEMA) publications
(Available at https://www.nema.org/Standards/Pages/default.aspx)

NEMA 250 2018
Enclosures for Electrical Equipment (1000 Volts Maximum)

NEMA ICS 2
Standards for Industrial Control Devices, Controller, and Assemblies, New Name ICS 2-200 (R2005) Industrial Control and Systems Controllers, Contactors, and Overload Relays Rated 600 Volts

NEMA ICS 2.3
Instructions for the Handling, Installation, Operation, and Maintenance of Motor Control Centers

NEMA ICS 3
Industrial Control and Systems. Medium Voltage Controllers Rated 2,001 to 7,200 Volts AC.

NEMA ICS 3.1
Guide for the Application, Handling, Storage, Installation, and Maintenance of Medium-Voltage AC Contractors, Controllers, and Control Centers

NEMA ICS 6
Enclosures for Industrial Controls and Systems

NEMA ICS 7.2
Application Guide for AC Adjustable Speed Drive Systems

NEMA Industrial Control and Systems (ICS) 1
Industrial Control and Systems: General Requirements

NEMA MG 1
Motors and Generators

NEMA Wire and Cable 70
Power Cables Rated 2000 Volts or Less for the Distribution of Electrical Energy

National Fire Protection Association (NFPA) publications
(Available at https://www.nfpa.org/codes-and-standards)

NFPA 101
Life Safety Code

NFPA 110
Emergency and Standby Power Systems

NFPA 20
Installation of Stationary Pumps for Fire Protection

NFPA 70
National Electrical Code

NFPA 70E
Standard for Electrical Safety in the Workplace

NFPA 780
Installation of Lightning Protection Systems (Current Edition)

NFPA 79
Electrical Standard for Industrial Machinery

NFPA 820
Fire Protection in Wastewater Treatment and Collection Facilities

National Institute of Standards and Technology (NIST) Special Publication (SP) publications
(Available at https://csrc.nist.gov/publications)

NIST SP 800-37 Revision 1
Guide for Applying the Risk Management Framework to Federal Information Systems: A Security Life Cycle Approach (2014)

NIST SP 800-37 Revision 2
Risk Management Framework for Information Systems and Organizations: A System Life Cycle Approach for Security and Privacy (2018)

NIST SP 800-53 Revision 5
Security and Privacy Controls for Information Systems and Organizations (2020)

NIST SP 800-60 Volume II Revision 1
Appendices to Guide for Mapping Types of Information and Information Systems to Security Categories (2008)

Naval Facilities Engineering Command (NAVFAC) P-307
Weight Handling Equipment, Navy Crane Center. (Available at https://ncc.navfac.navy.mil/Popular-Links/P307/)

Noria Corporation 2011
The Practical Handbook of Machinery Lubrication, 4th edition. https://store.noria.com/products/the-practical-handbook-of-machinery-lubrication-4th-edition

Oberg et al. 2012
Oberg, E., Jones, F.D., Horton, H.L., and Ryffel, H.H. 2024. *Machinery's handbook*, 32nd edition. New York, NY, Industrial Press. https://books.industrialpress.com/machinery-handbook/

Occupational Safety and Health Administration (OSHA) publications
(Available at https://www.osha.gov/)

OSHA 29 CFR 1910.179
Overhead and Gantry Cranes

OSHA 29 CFR 1910.95
Occupational Noise Exposure

Paulus and Daniel 2018
Paulus, T., and Daniel, R.A. 2018. *Lock Gates and Other Closures in Hydraulic Projects.* Elsevier. https://www.sciencedirect.com/book/9780128092644/lock-gates-and-other-closures-in-hydraulic-projects

PIANC publications
(Available at https://www.pianc.org/)

PIANC Working Group 106 Report
Innovations in Navigation Lock Design (2009)

PIANC Working Group 138 Report
Navigation Locks and Dams, Mechanical and Electrical Lessons Learned (2012)

PIANC Working Group 166 Report
Inflatable Structures in Hydraulic Engineering. PIANC Inland Navigation Commission (InCom). Brussels 2017.

PIANC Working Group 173 Report
Movable Bridges and Rolling Gates

PIANC Working Group 191 Report
Composites for Hydraulic Structures (2020)

PIANC Working Group 192 Report
Developments in the Automation and Remote Operation of Locks and Bridges (2019)

PIANC Working Group 206 Report
Design of Locks

Planning Bulletin 2019-04
Incorporating Life Safety into Flood and Coastal Storm Risk Management Studies. (Available at https://planning.erdc.dren.mil/toolbox/library/PB/PB2019-04.pdf)

Race et al. 2004
Race, T.D., Kumar, A., and Stephenson, L.D. 2004. *Field evaluation of self-lubricated mechanical components for civil works navigation structures*. ERDC/CERL SR-04-8. https://erdc-library.erdc.dren.mil/items/81b728f7-a685-4ef8-e053-411ac80adeb3

Rijkswaterstaat – Ministry of Infrastructure and Water Management
(Available at https://www.rijkswaterstaat.nl/en)

Roark 2020
Updated by Budynas, Sadejh. *Roarke's Formulas for stress and strain,* 9th edition. New York: McGraw Hill. (Amazon at https://www.amazon.com/Roarks-Formulas-Stress-Strain-8th/dp/0071742476)

SAE International (SAE) J1273
Recommended Practices for Hydraulic Hose Assemblies
https://www.sae.org/standards/content/j1273_200902/

SAE J517
Hydraulic Hose https://www.sae.org/standards/content/j517_202007/

Saint Lawrence Seaway Management Corporation (SLSMC) 2012.
Ship Arrestor Study, Niagara and Maisonneuve Regions. St. Lawrence Seaway Management Corporation Final Report. (Available from USACE HQ at https://www.usace.army.mil/Contact/)

Schmid et al. 2013
Schmid, S.R., Hamrock, B.J., and Jacobson, B.O. 2013. *Fundamentals of Machine Elements*, 3rd edition. CRC Press (Amazon at https://www.amazon.com/Fundamentals-Machine-Elements-Steven-Schmid/dp/143989132X)

Schultz 1998
Schultz, R.W. 1998. "Results of the Olmstead hydraulic operated wicket dam." *In Proceedings, Heartland Technology Transfer Conference, 1998, Kansas City*. (Available from USACE HQ at https://www.usace.army.mil/Contact/)

Seely and Smith 1952
Seely, F.B., and Smith, J.O. 1952. *Advanced mechanics of materials,* 2nd edition. New York: John Wiley & Sons. (Amazon at https://www.amazon.com/Advanced-mechanics-Materials-Second-Seely/dp/B009NO0KSG)

Shigley and Mischke 2024
Updated by Budynas, Nisbett. 2024. *Mechanical engineering design,* 10th edition. New York, NY, McGraw Hill. (Amazon at https://www.amazon.com/Shigleys-Mechanical-Engineering-Design-McGraw-Hill/dp/0073398209)

Shipp et al. 2010
Shipp, D.D, Dionise, T.J., Lorch, V., and MacFarlane, B.G. 2010. "Transformer Failure Due to Circuit-Breaker-Induced Switching Transients." *IEEE Transactions on Industry Applications.* 47(2): 707–178. (Research Gate at https://www.researchgate.net/publication/224207533_Transformer_Failure_Due_to_Circuit-Breaker-Induced_Switching_Transients)

Smeaton 1977
Smeaton, R.W., ed. 1977. *Switchgear and Control Systems Handbook,* 2nd edition. McGraw-Hill, New York, NY. (Amazon at https://www.amazon.com/Switchgear-Control-Handbook-Robert-Smeaton/dp/0070584494)

Smeaton 1987
Smeaton, R.W., ed. 1987. *Motor Application and Maintenance Handbook*, 2nd edition. McGraw-Hill, New York, NY. (Amazon at https://www.amazon.com/Application-Maintenance-Handbook-Robert-Smeaton/dp/0070584486)

Spotts 1962
Spotts, M.F. 1962. *Design of machine elements,* 3rd edition. Englewood Cliffs, NJ: Prentice Hall. (Amazon at https://www.amazon.com/Design-Machine-Elements-Third-Spotts/dp/B000FS6FME)

Stockstill et al. 2011
Stockstill, R.L., Hammack, E.A., and Hite, J.E. 2011. *Lock culvert valves: Hydraulic design considerations*. ERDC/CHL TR-11-4. Vicksburg, MS: U.S. Army Engineer Research and Development Center. (Available at https://safe.menlosecurity.com/doc/docview/viewer/docN13839713549A9a35065210e38126baf78262f3c8f131f4212a9a70a22d91f2abb5f4db5050de)

TIA Telecommunication Standardization Bureau (TSB)-162
Telecommunications Cabling Guidelines for Wireless Access Points. (Available at https://store.accuristech.com/tia/searches/40011127)

TR 2018-01
Mechanical Equipment Lubrication. (Available at https://stg.wbdg.org/dod/ecb/usace-ecb-2018-16

TR 2018-02
Exterior Lighting for Navigation Locks and Dams. (Available at https://usace.dps.mil/sites/KMP-IND/Shared%20Documents/Forms/AllItems.aspx?as=json&FolderCTID=0x012000CC1BA63FBE94FE4A9AE8E22C2890FEBB&id=%2Fsites%2FKMP%2DIND%2FShared%20Documents%2FINDC%20Technical%20Reports)

Tribology-abc
Online machinery and lubrication and bearing database and unit conversion calculator: http://www.tribology-abc.com/.

Tuthill 1995
Tuthill, A. 1995. *Structural Ice Control Review of Existing Methods.* CRREL Report 95-18. U.S. Army Engineer Research and Development Center. (Available at https://erdclibrary.on.worldcat.org/search/detail/33062703?queryString=CRREL%20Report%2095-18&clusterResults=true&stickyFacetsChecked=true&baseScope=wz%3A63341&groupVariantRecords=false&scope=wz%3A63341)

Tuthill 2000
Tuthill, A. 2000. “A physical model study of ice passage at the Soo Locks.” *Canadian Journal of Civil Engineering*. (Available at https://doi.org/10.1139/l00-070)

UFC 1-200-01
DoD Building Code

UFC 1-200-02
High Performance And Sustainable Building Requirements

UFC 3-190-06
Protective Coatings and Paints

UFC 3-401-01
Mechanical Engineering

UFC 3-410-01
Heating, Ventilating, and Air Conditioning Systems

UFC 3-410-04
Industrial Ventilation

UFC 3-420-01
Plumbing Systems

UFC 3-420-02
Compressed Air

UFC 3-490-06
Elevators

UFC 3-501-01
Electrical Engineering

UFC 3-520-01
Interior Electrical Systems

UFC 3-530-01
Interior and Exterior Lighting Systems and Controls

UFC 3-540-01
Engine-Driven Generator Systems for Prime and Standby Power Applications

UFC 3-550-01
Exterior Electrical Power Distribution

UFC 3-560-01
Operation and Maintenance: Electrical Safety

UFC 3-570-01
Cathodic Protection

UFC 3-570-06
O&M: Cathodic Protection Systems

UFC 3-575-01
Lightning and Static Electricity Protection Systems

UFC 3-580-01
Information and Communications Technology Infrastructure Planning and Design

UFC 3-600-01
Fire Protection Engineering for Facilities

UFC 3-601-02
Fire Protection Systems Operations, Testing, and Maintenance

UFC 4-010-01
DoD Minimum Antiterrorism Standards For Buildings

UFC 4-010-06
Cybersecurity of Facility-Related Control Systems

UFC 4-021-02
Electronic Security Systems

UFGS 01 91 00.15
Building Commissioning

UFGS 09 90 00
Painting and Coating

UFGS 22 15 26.00 20
High and Medium Pressure Compressed Air Piping

UFGS 25 05 11
Cybersecurity for Facility-Related Control Systems

UFGS 26 05 19.00 10
Insulated Wire and Cable

UFGS 26 29 01.00 10
Electric Motors 3-Phase Vertical Induction Type

UFGS 26 29 02.00 10
Electric Motors 3-Phase Vertical Synchronous Type

UFGS 26 56 00
Exterior Lighting

UFGS 27 10 00
Building Telecommunications Cabling System

UFGS 28 10 05
Electronic Security Systems

UFGS 35 01 41.00 10
Electromechanical Operating Machinery for Locks and Dams

UFGS 35 01 70.13
Wire Rope for Gate Operating Devices

UFGS 35 05 40.14 10
Hydraulic Power Systems For Civil Works Structures

UFGS 35 05 40.17
Self-Lubricated Materials, Fabrication, Handling, and Assembly

UFGS 35 20 16.54
Slide Gates and Actuators

UFGS 35 20 20
Electrical Equipment for Gate Hoist

UFGS 41 22 13.14
Bridge Cranes, Overhead Electric, Top Running

UFGS 41 22 13.15
Bridge Cranes, Overhead Electric, Under Running

UFGS 41 22 13.16
Gantry Cranes

UFGS 41 22 13.33
Portal Crane Track Installation

UFGS 41 22 23.19
Monorail Hoists

UL 96A 2018
Underwriters Laboratories (UL) Standard for Safety Installation Requirements for Lightning Protection Systems – 13th edition. (Available at https://ulstandards.ul.com/)

USACE 33 CFR Part 207
Navigation and Navigable Waters, Navigation Regulations. (Available at https://www.ecfr.gov/current/title-33/chapter-II/part-207?toc=1)

USACE 1951
Filling characteristics Algiers Lock Intracoastal Waterway, Gulf Section, Louisiana. Waterways Experiment Station (WES) Technical Memorandum 2-309. USACE (WES). (Available from USACE HQ and ERDC at https://www.usace.army.mil/Contact/)

USACE 1954
Greenup navigation dam: Analysis of hydrodynamic forces acting on emergency gate. USACE WES. (Available from USACE HQ and ERDC at https://www.usace.army.mil/Contact/)

USACE 1959
Emergency gate, Greenup Locks, Ohio River, Kentucky. WES TR 2-527. USACE WES. (Available from USACE HQ and ERDC at https://www.usace.army.mil/Contact/)

USACE 1961
Culvert valves, new Lock No. 19, Mississippi River, hydraulic model investigation. WES TR 2-537. USACE WES. (Available from USACE HQ and ERDC https://www.usace.army.mil/Contact/)

USACE 1964
Operating forces on miter-type lock gates. WES TR 2-651. USACE WES. (Available from USACE HQ and INDC) Also available at: https://erdc-library.erdc.dren.mil/jspui/handle/11681/4728

USACE 1970
Operating forces on sector gates under reverse heads. WES TR H-70-2. USACE WES. https://usace.contentdm.oclc.org/digital/collection/p266001coll1/id/4971

USACE 1971a
Operating forces on sector gates under reverse heads, Appendix A: Results of supplemental tests. WES TR H-70-2. USACE WES. https://erdc-library.erdc.dren.mil/jspui/handle/11681/13498

USACE 1971b
Calcasieu Saltwater Barrier Prototype Sector Gate Tests. WES Miscellaneous Paper H-71-4. USACE WES. https://erdc-library.erdc.dren.mil/jspui/handle/11681/10745

USACE 1974
Study of the forces occurring during the movement of miter gate of locks. Translation No. 74-11. USACE WES. (Available from USACE HQ https://www.usace.army.mil/Contact/)

USACE 1987
Lock and Dam 2 Tainter Gates, De-Icing Report, Mississippi River, Hastings, Minnesota. RCM 861608-7. (Available from USACE HQ https://www.usace.army.mil/Contact/)

USACE IMTS 2014
Interlock Standard (Available from USACE HQ and INDC at https://www.usace.army.mil/Contact/)

USACE Remote Lock Operations
National Assessment and Framework, August 2022 (Available from USACE HQ and INDC at https://www.usace.army.mil/Contact/) Also at: https://usace.dps.mil/sites/KMP-CW/SitePages/Remote-Lock-and-Dam-Operations.aspx

USACE Remote Lock Operations
National Implementation Plan, January 2023 (Available from USACE HQ and INDC) Also at: https://usace.dps.mil/sites/KMP-CW/SitePages/Remote-Lock-and-Dam-Operations.aspx

USACE REMR Bulletin Volume 12, No 2
Use of Radiant Heaters to Prevent Icing and Air Bubbler Systems. 1995. (Available at https://usace.contentdm.oclc.org/digital/collection/p266001coll1/id/7391/)

USACE REMR: HY-N-1.4
Interim Guidance on Lock Gate Barrier Systems, Repair, Evaluation, Maintenance, and Rehabilitation Research. Technical Note, August 1988. (Available from USACE HQ https://www.usace.army.mil/Contact/)

USACE, Portland District 2008
John Day Navigation Lock Upstream Lift Gate Repairs, Letter Report for the John Day Navigational Lock, April 2008 (Available from USACE HQ https://www.usace.army.mil/Contact/)

USACE, Technical Evaluation Report (TER) CS-3108
Folsom Dam Auxiliary Spillway, Hydraulic Cylinder Rod Coating Selection, October 2020. Available from USACE HQ. https://www.usace.army.mil/Contact/

USACE, The Engineer School
Fort Belvoir Engineer School Design Manual, Canalization of the Upper Mississippi River and Ohio River (USACE, The Engineer School 1939). Design of locks: Engineering construction, canalization, Vol. II. Available from USACE HQ. https://www.usace.army.mil/Contact/

Westinghouse Electric Corporation 1982
Applied Protective Relaying, Relay Instrument Division. (available from Google Books https://www.scribd.com/document/384867457/Applied-Protective-Relaying-Westinghouse-pdf)

Westinghouse Electric Corporation 1988
Westinghouse Synchronous Motors. Westinghouse Publication No. B-9388-R. (available from Google Books)

Whole Building Design Guide
Online data base for industry specifications, guide specifications, and building materials: http://www.wbdg.org/

Wilson et al. 2001
Wilson, P., Stephenson, L.D., and Kumar, A. 2001. *Critical evaluation of lock automation and control equipment at Corps operated navigation locks*. ERDC/CERL TR-00-29. U.S. Army Engineer Research and Development Center. https://safe.menlosecurity.com/doc/docview/viewer/docN1ABC3B9EBE0958f5b2bf6b7f2586a793bebb3c60bc07f761c9fe3cd1f6454f5d638a5c6dfd7e

Wire Rope Technical Board 2005
Wire Rope User's Manual. 4th edition. (Available at https://www.wireropetechnicalboard.org/ and https://www.wireropetechnicalboard.org/products/wire-rope-users-manual-5th-edition-printed)

10 United States Code (USC) Section 2304
Contracts: Competition Requirements (Available at https://uscode.house.gov/view.xhtml?req=Title+18&f=treesort&num=885)

44 USC Section 3542
Public Printing and Documents – Definitions (Available at https://www.govinfo.gov/app/details/USCODE-2011-title44/USCODE-2011-title44-chap35-subchapIII-sec3542)

Section II

Prescribed Forms

This section contains no entries.

Appendix B
Computer-Aided Design Drawings (Illustrative Plates)

B–1. Overview

The drawings and plates in this appendix provide typical designs for both mechanical and electrical features of locks and dams. The designer should use these drawings and plates in conjunction with the main text of EM 1110-2-2610, as they are intended to illustrate specific design details. Machinery details are provided for miter gates, sector gates, vertical lift gates, and hinged crest gates as described in the main text. Typical electrical one-line diagrams and electrical design details are provided.

a. The full-size PDF drawings and the MicroStation files can be requested from USACE HQ. The designer should reach out to the USACE Mechanical Engineering Community of Practice Lead (Civil Works) at HQ in Washington DC at the following link: https://www.usace.army.mil/Contact/.

b. Full size PDF files are also posted on the INDC Sharepoint site at: https://usace.dps.mil/sites/KMP-IND/SitePages/Engineering-%26-Design-Guidance-Documents.aspx

B–2. Illustrative plates

Illustrative plates are provided for the following categories:

a. B–3: Mechanical components (plates 1–6)

b. B–4: Hydraulic drives (plates 7–10)

c. B–5: Miter gates (plates 11–27)

d. B–6: Sector gates (plates 28–36)

e. B–7: Tainter valves (plates 37–43)

f. B–8: Vertical lift gates (plates 44–56)

g. B–9: Tainter gates (plates 57–69)

h. B–10: Wicket gates (plates 70–71)

i. B–11: Hinged crest gates (plates 72–73)

j. B–12: Other systems – cathodic protection (plates 74–77)

k. B–13: Electrical (plates 78–95)

l. B–14: Reference drawings to support Appendix C tainter gate calculations

B–3. Mechanical components

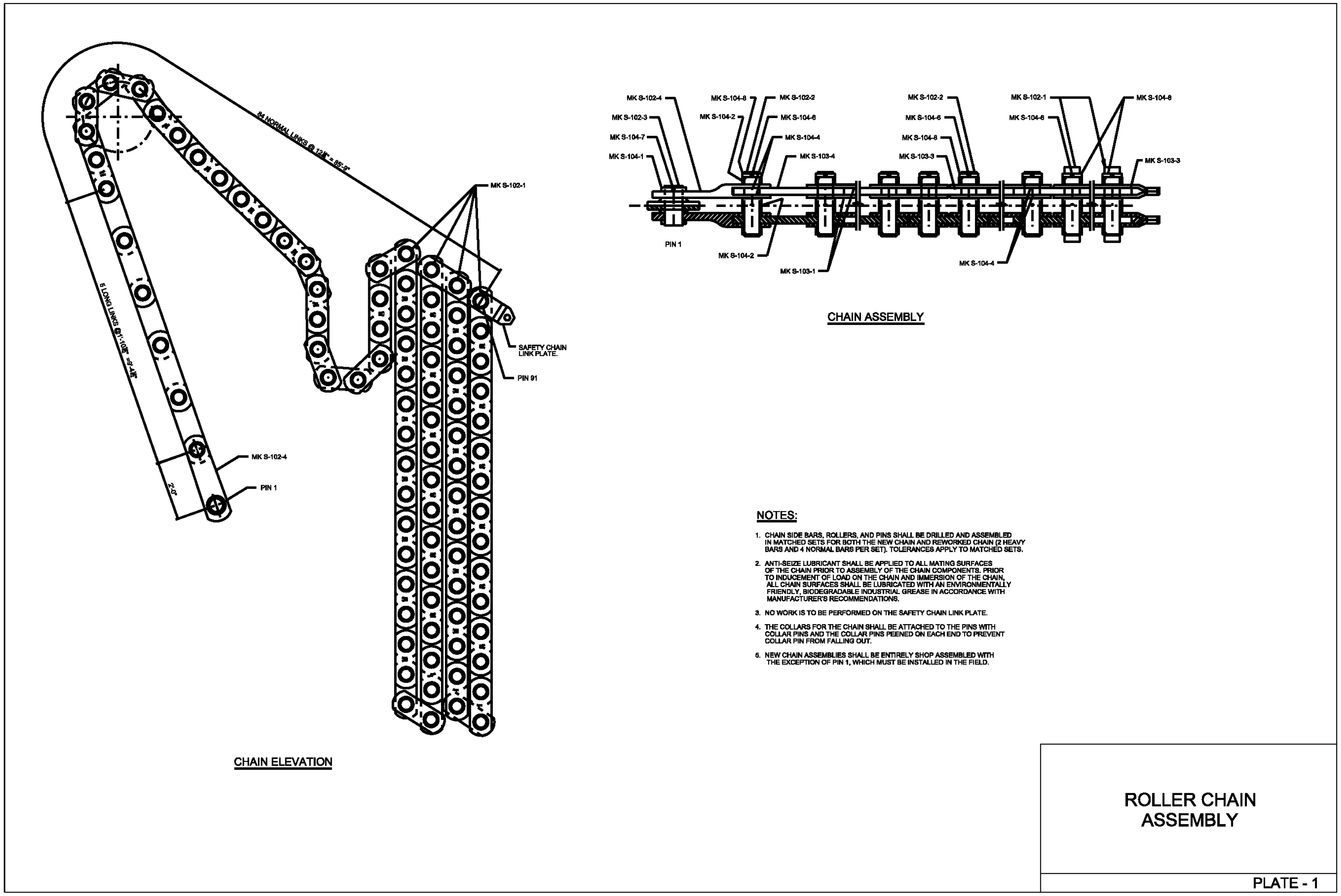


Figure B–1. Plate 1: Roller chain assembly

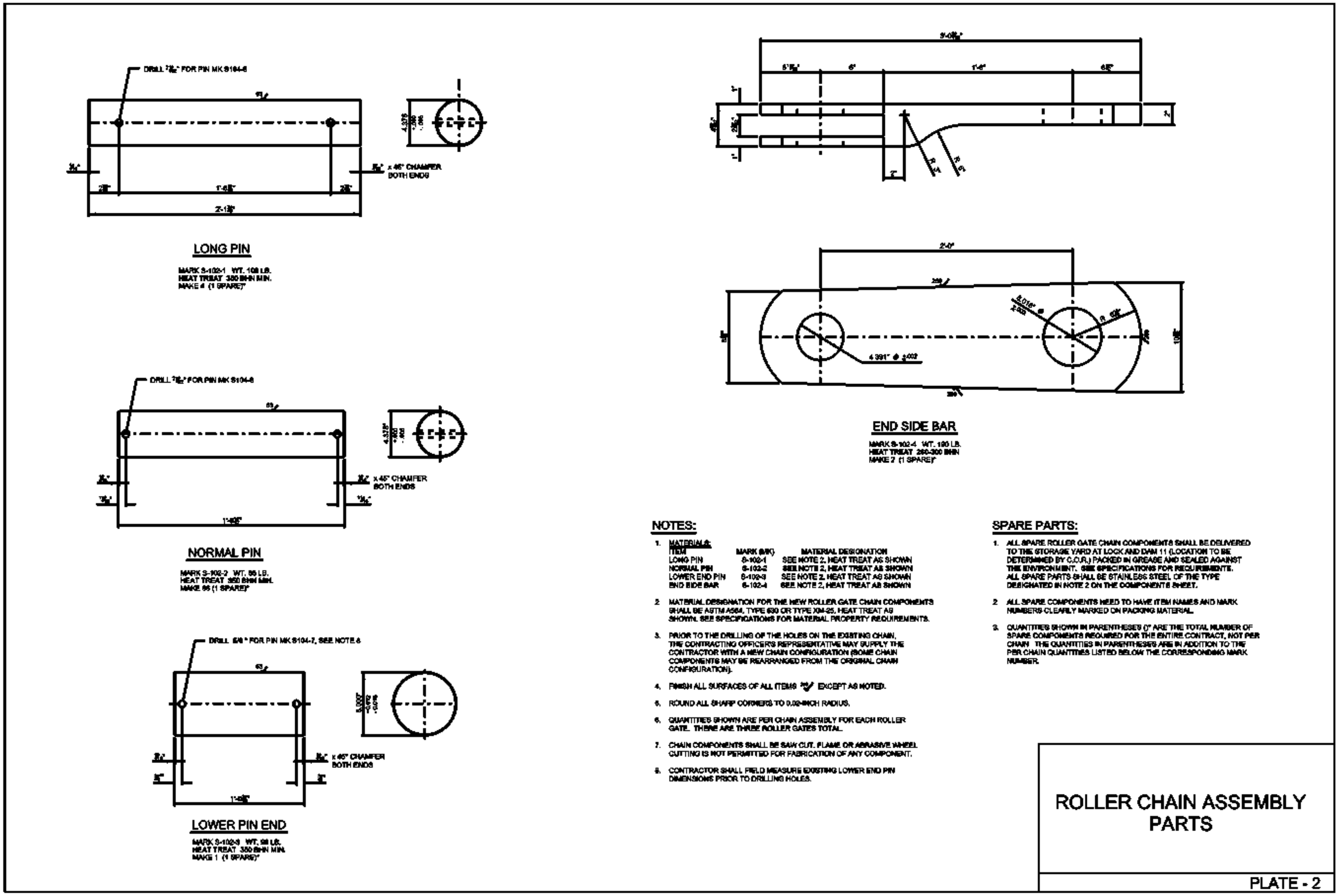


Figure B–2. Plate 2: Roller chain assembly parts

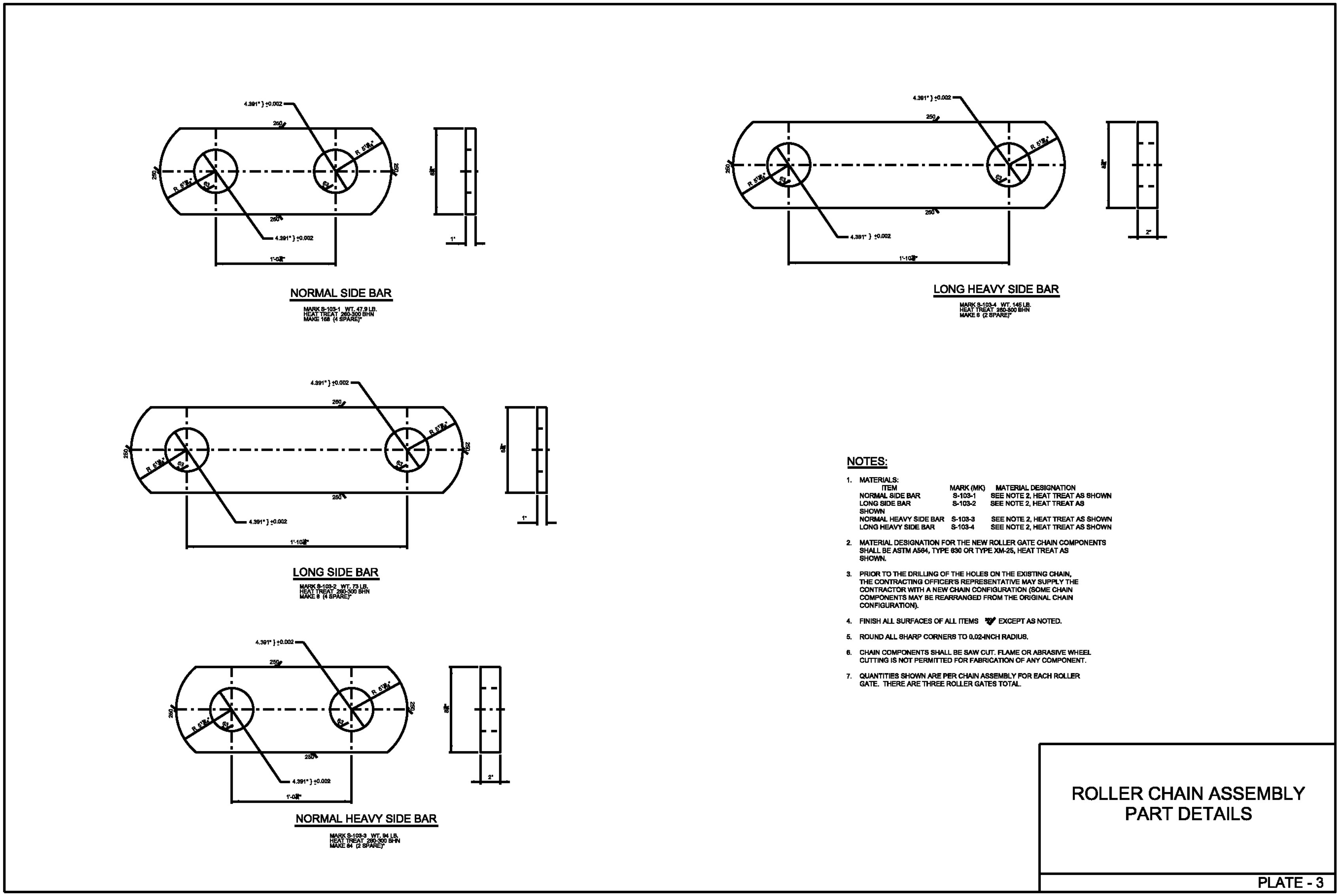
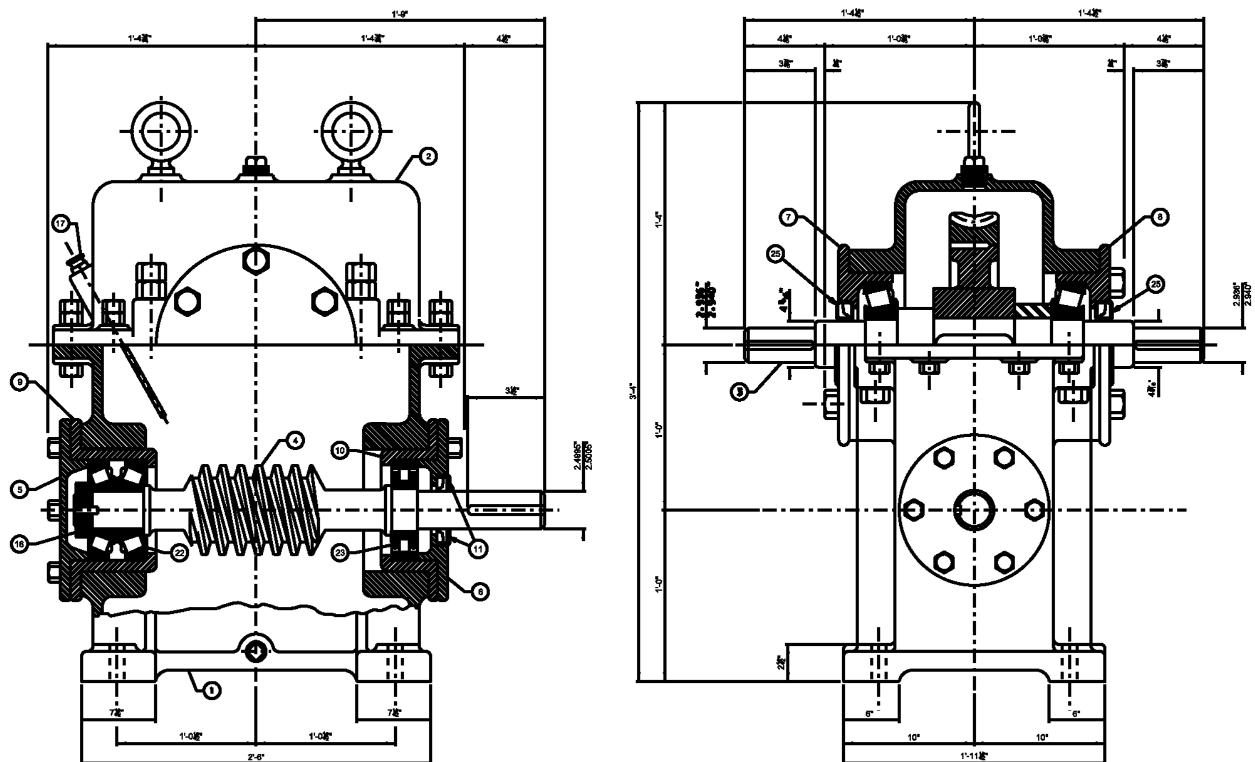


Figure B–3. Plate 3: Roller chain assembly part details



PART NO.	NAME	PART NO.	NAME
1	WORM AND GEAR HOUSING	15	
2	WORM AND GEAR COVER	16	SKF LOCKNUT & LOCK WASHER
3	SLOW SPEED GEAR SHAFT	17	BAYONNET OIL GAUGE
4	WORM SOLID ON SHAFT	18	
5	HIGH SPEED CLOSED END PIECE	19	
6	HIGH SPEED OPEN END PIECE	20	
7	SLOW SPEED OPEN END PIECE	21	
8	SLOW SPEED OPEN END PIECE	22	H.S. TIMKEN BEARING
9	TIMKEN BEARING CASE	23	NORMA HOFFMAN BEARING
10	HOFFMAN BEARING CASE	24	
11	OIL SEAL (HIGH SPEED)	25	OIL SEAL (SLOW SPEED)
12			
13			
14			

NOTE: REPLACE ITEMS SHOWN IN BOLD

SIZE 1200 WORM GEAR SPEED REDUCER

TAINTER GATE
SPEED REDUCER
DETAILS

PLATE - 4

Figure B–4. Plate 4: Tainter gate speed reducer details

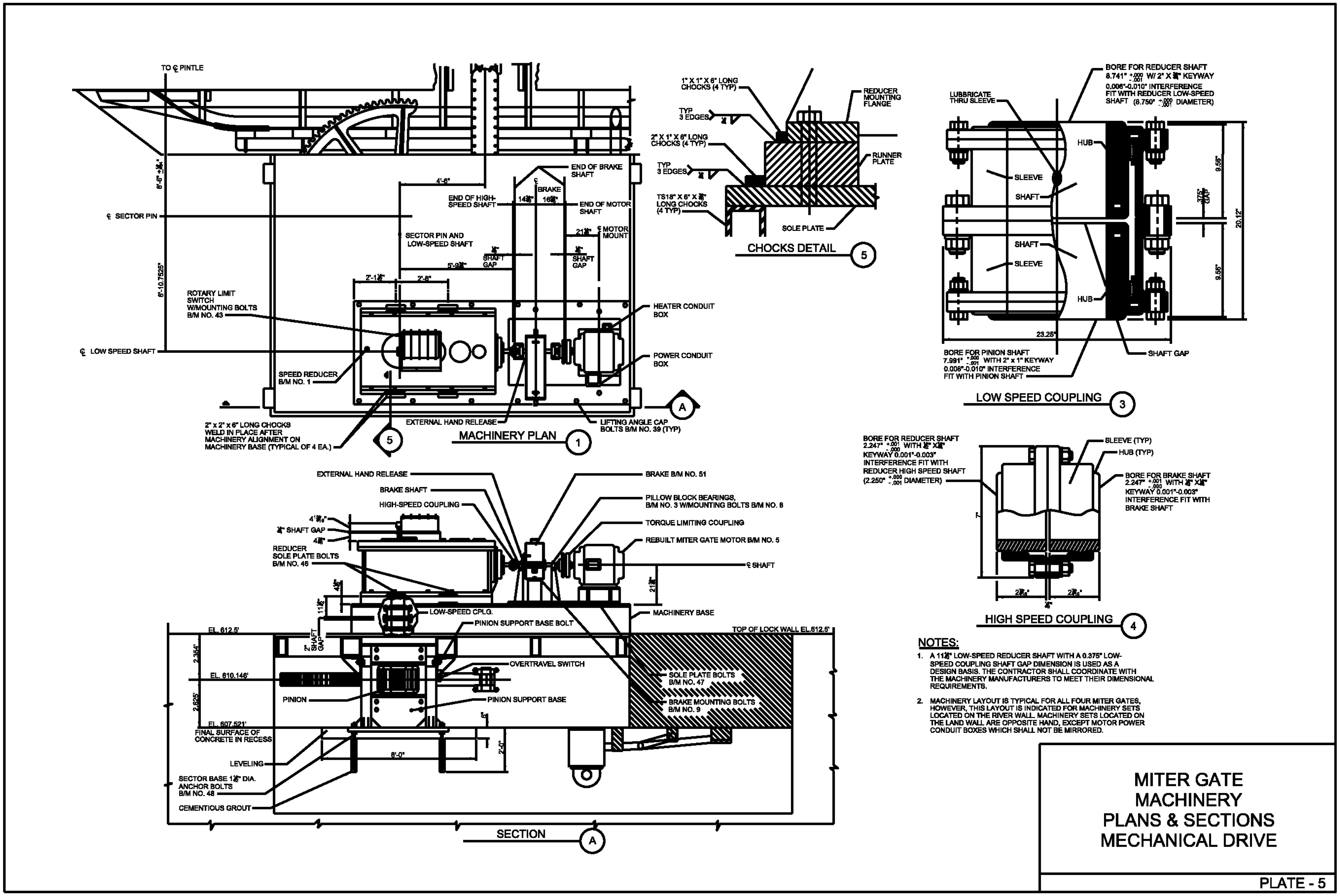


Figure B–5. Plate 5: Miter gate machinery plans and sections – mechanical drive

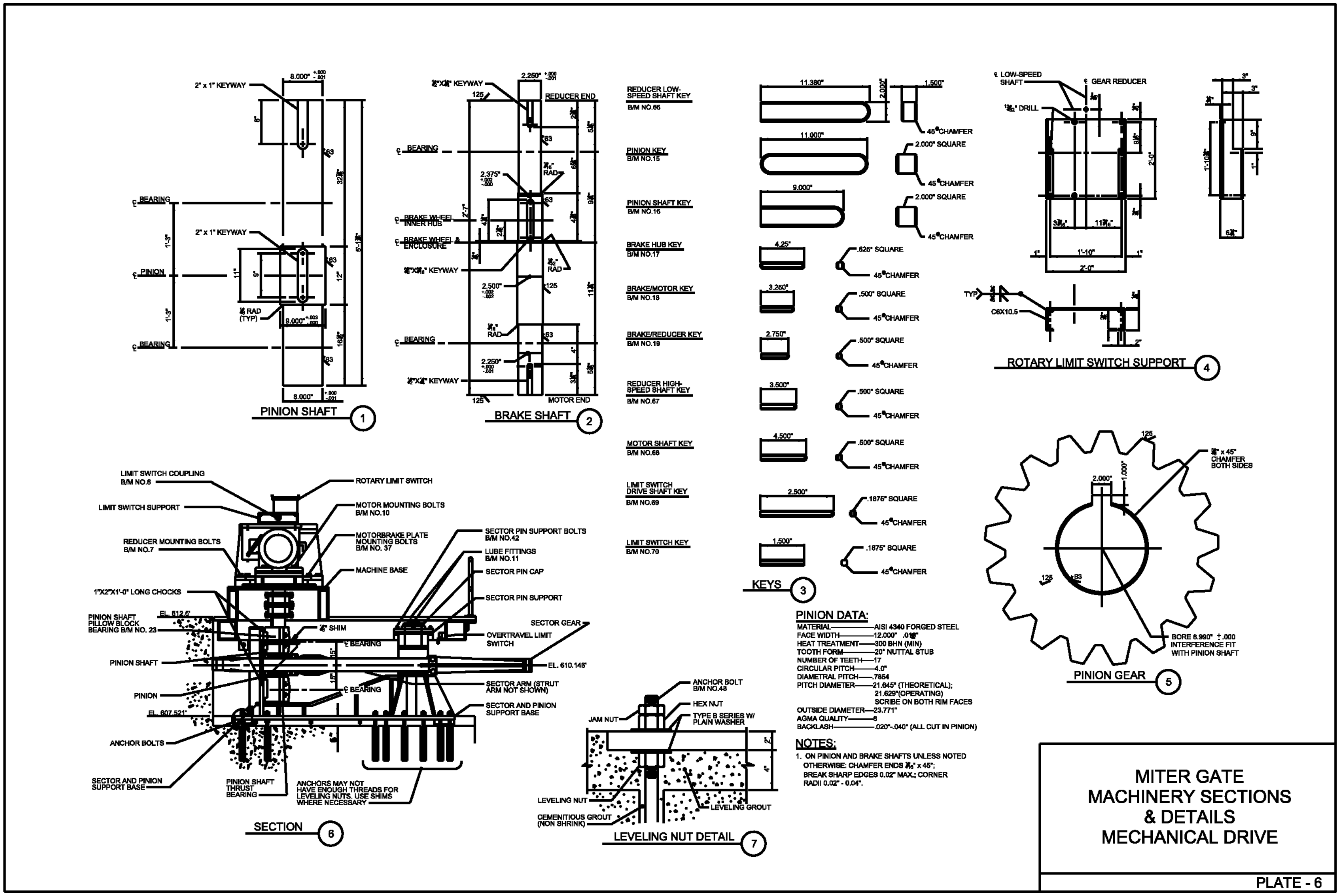


Figure B–6. Plate 6: Miter gate machinery sections and details – mechanical drive

B–4. Hydraulic drives

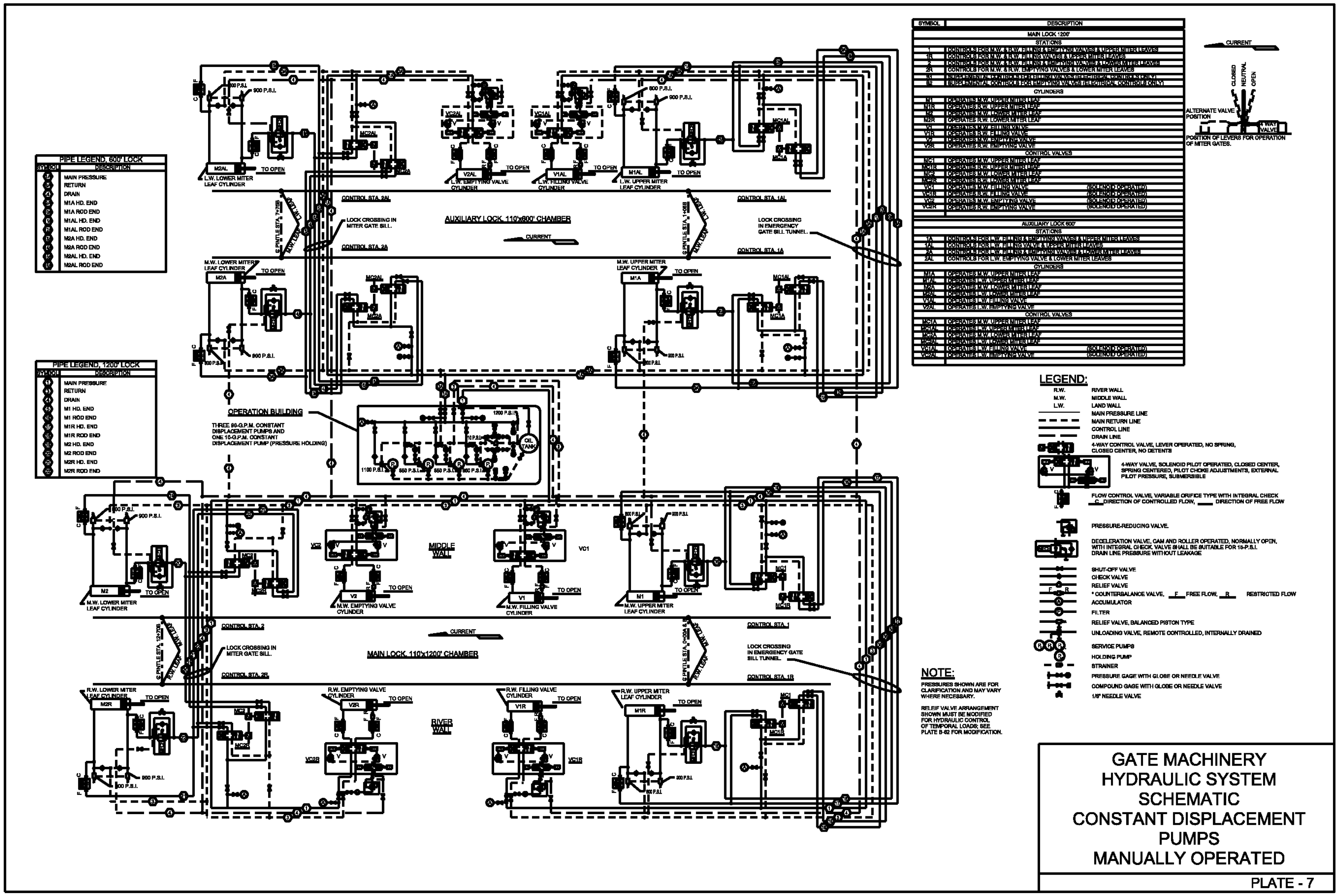


Figure B–7. Plate 7: Gate machinery hydraulic system schematic, constant displacement pumps, manually operated

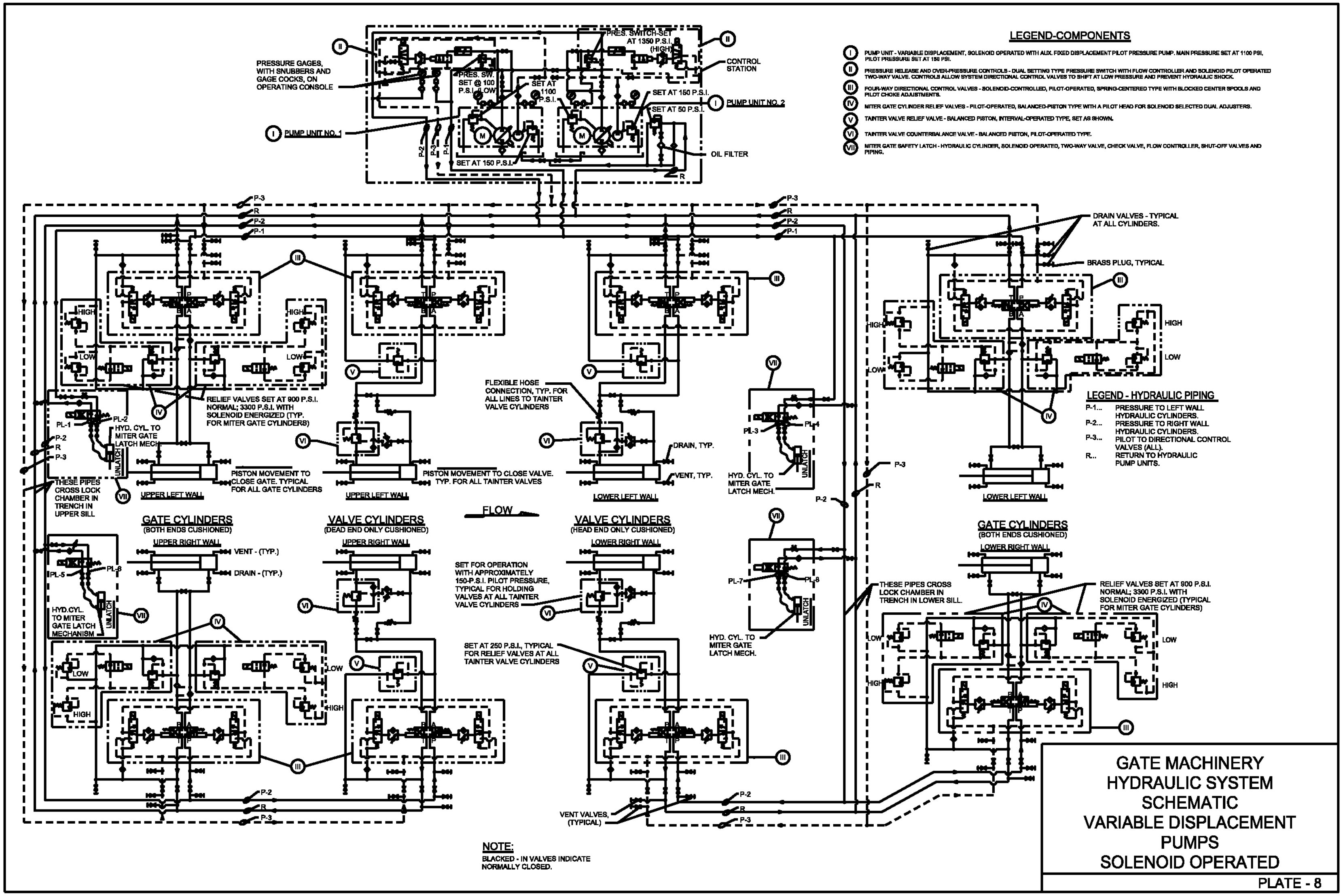


Figure B–8. Plate 8: Gate machinery hydraulic system schematic, variable displacement pumps, solenoid operated

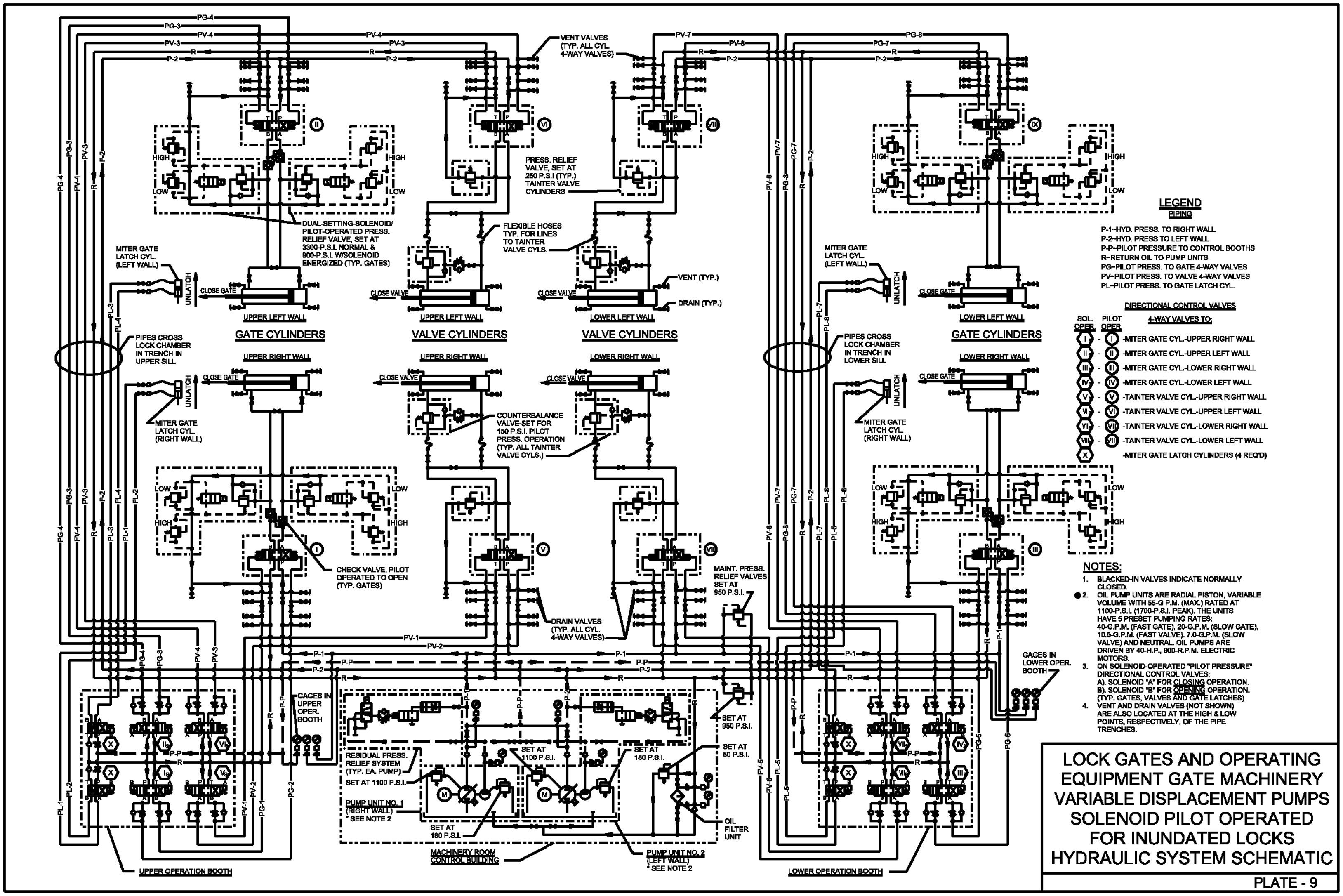


Figure B–9. Plate 9: Lock Gates and operating equipment gate machinery, variable displacement pumps, solenoid pilot operated for inundated locks, hydraulic system schematic

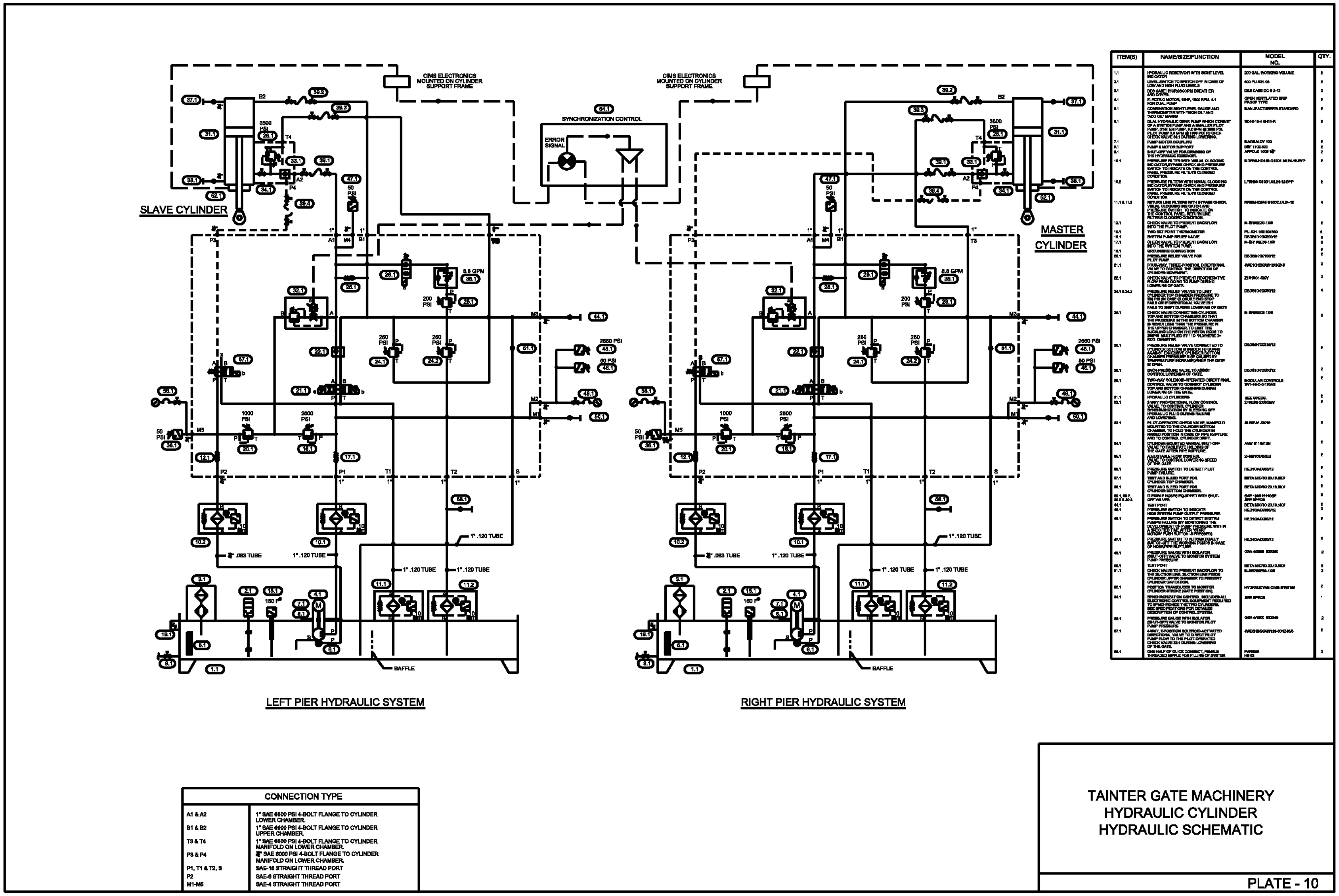


Figure B–10. Plate 10: Tainter gate machinery, hydraulic cylinder, hydraulic schematic miter gates

B–5. Miter gates

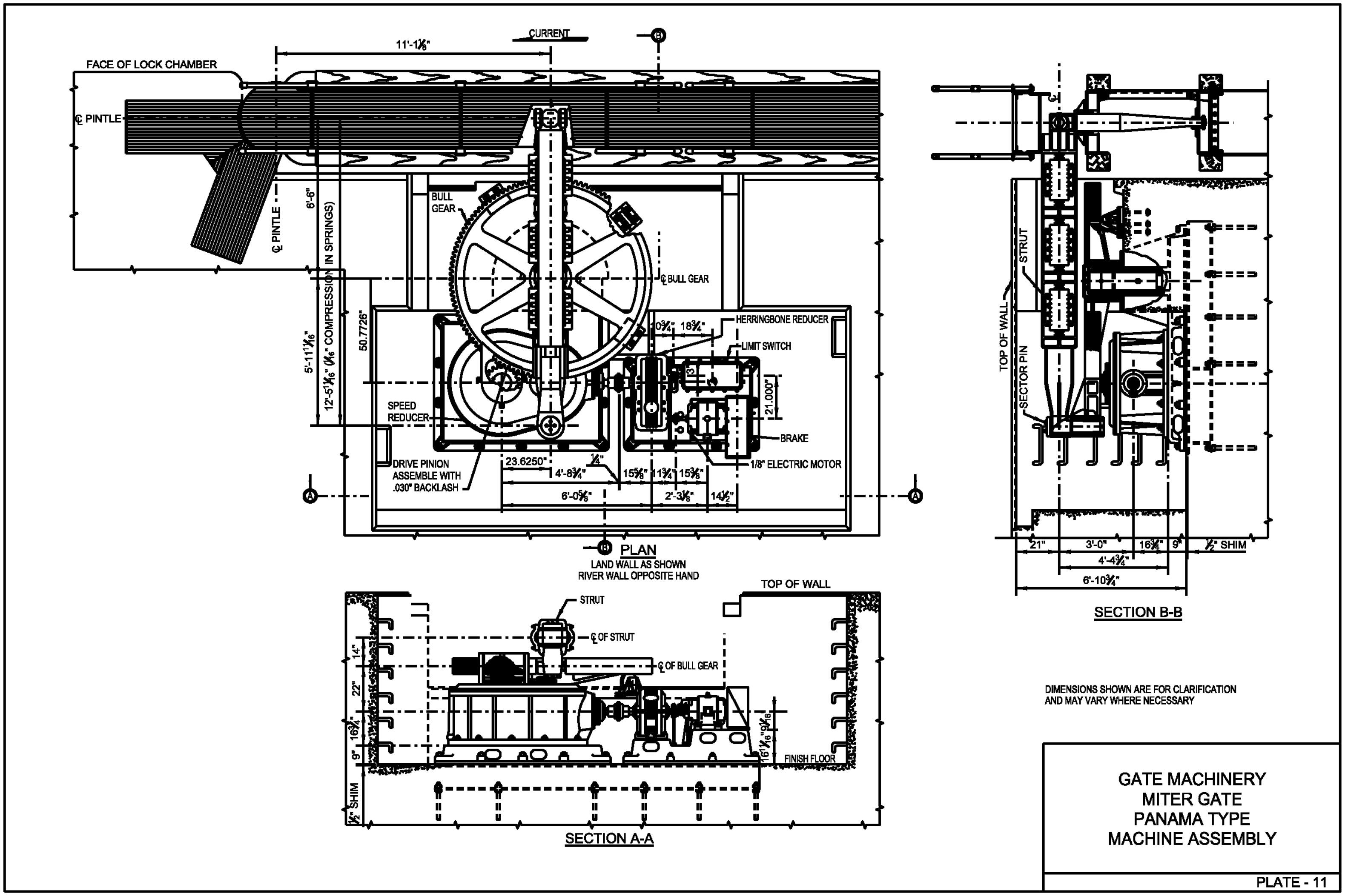


Figure B–11. Plate 11: Gate machinery miter gate, Panama type machine assembly

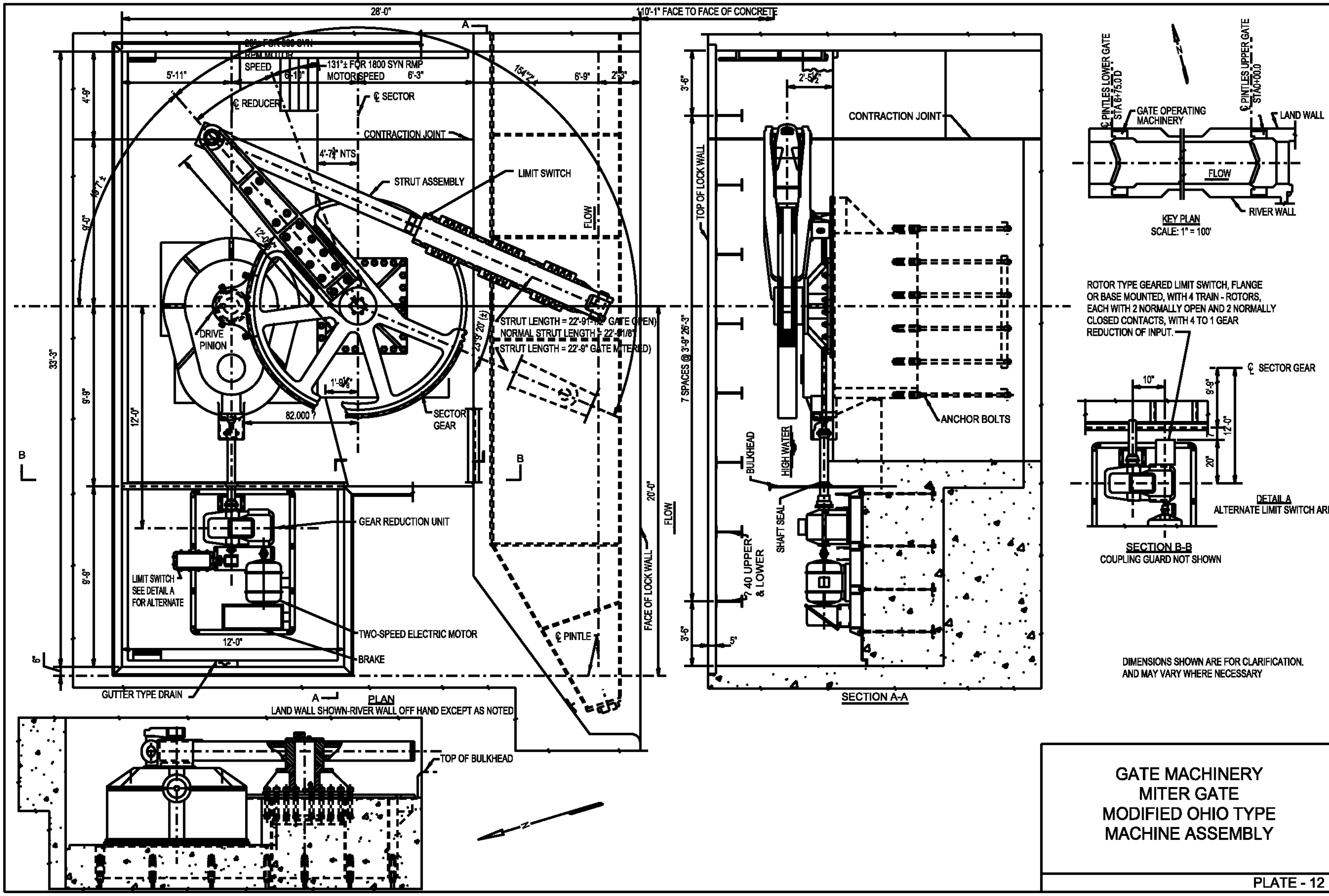


Figure B–12. Plate 12: Gate machinery miter gate, modified Ohio type machine assembly

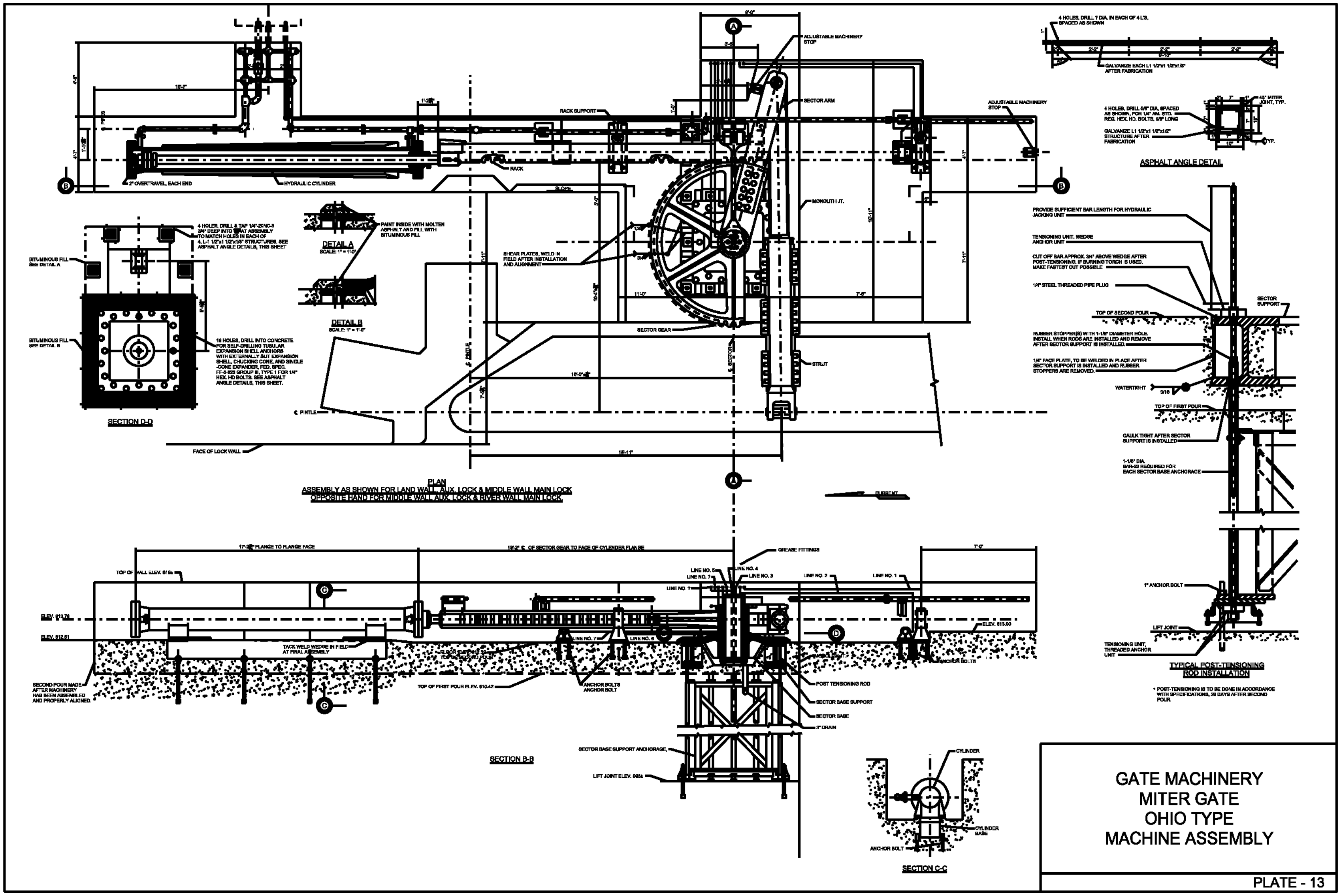


Figure B–13. Plate 13: Gate machinery miter gate, Ohio type machine assembly

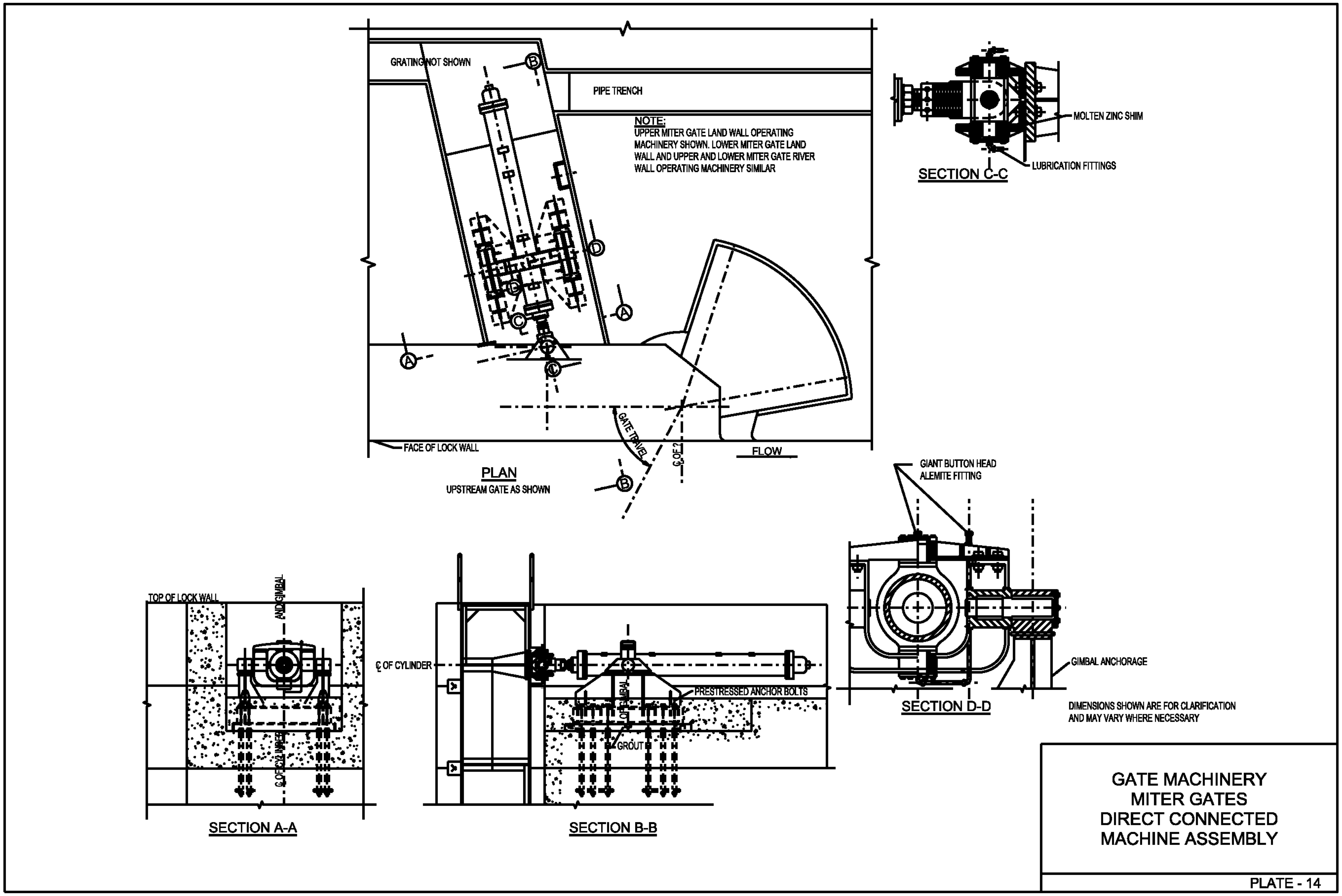


Figure B–14. Plate 14: Gate machinery miter gates, direct connected machine assembly

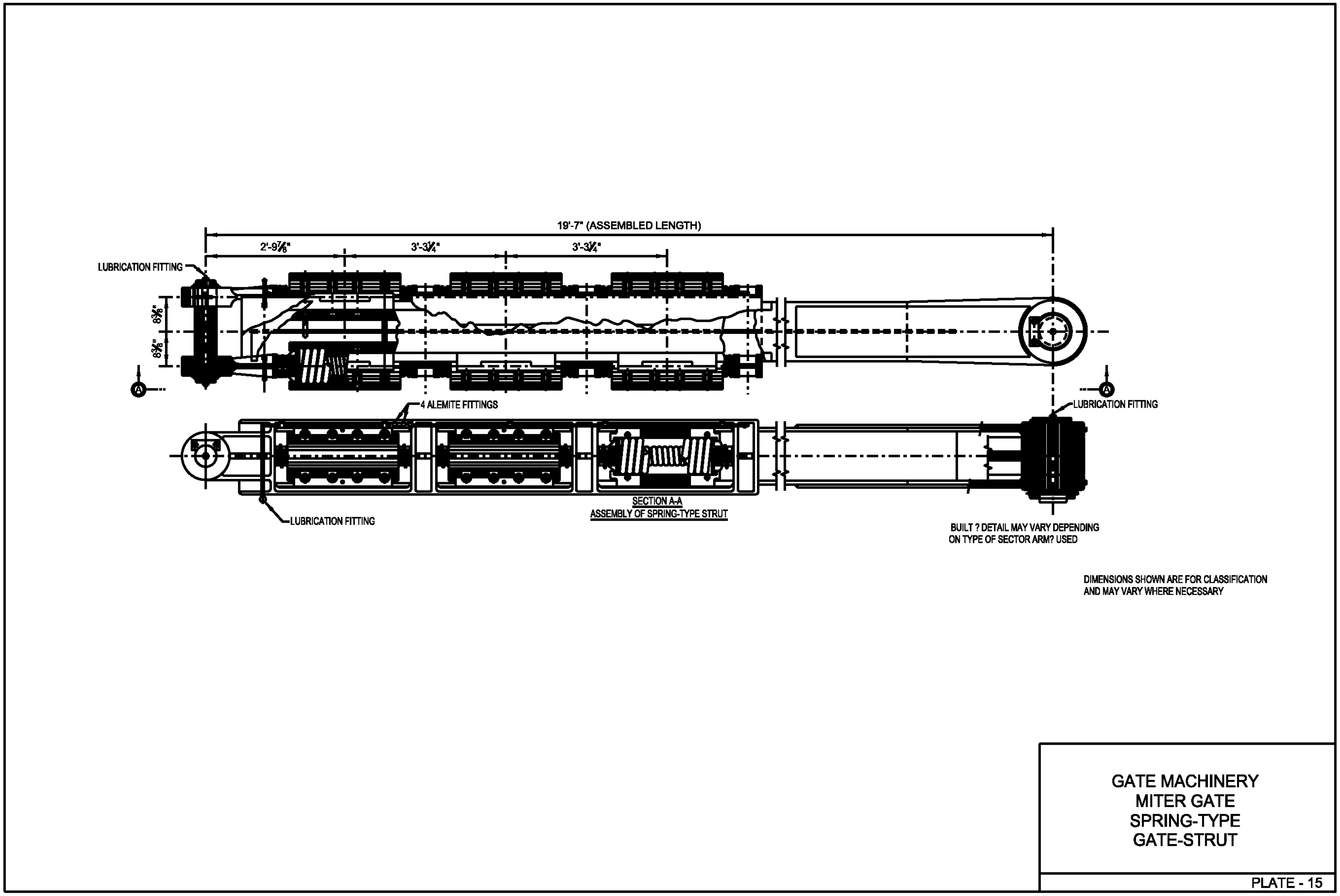


Figure B–15. Plate 15: Gate machinery miter gate, spring-type gate strut

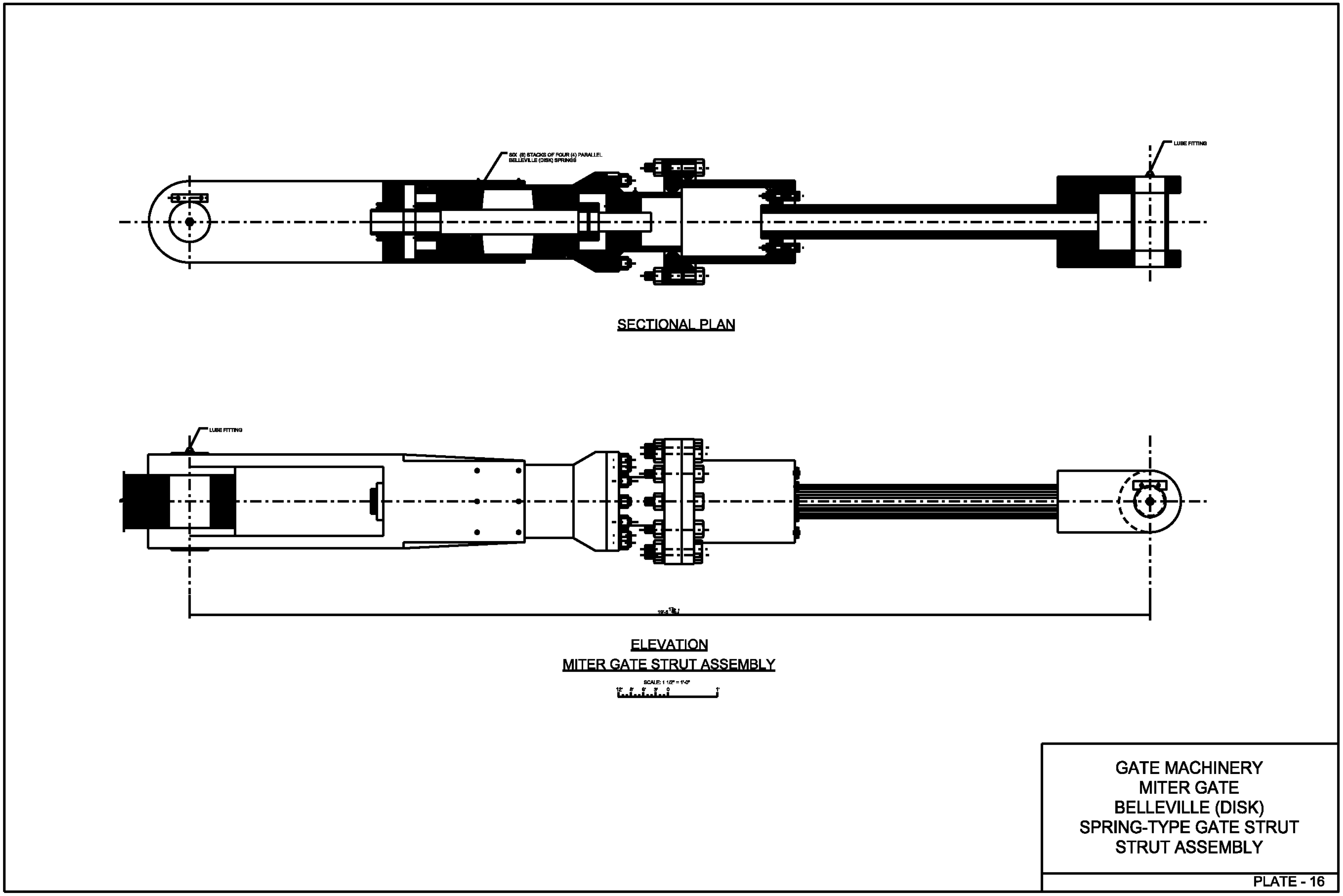


Figure B–16. Plate 16: Gate machinery, miter gate, Belleville (disk) spring-type gate strut, strut assembly

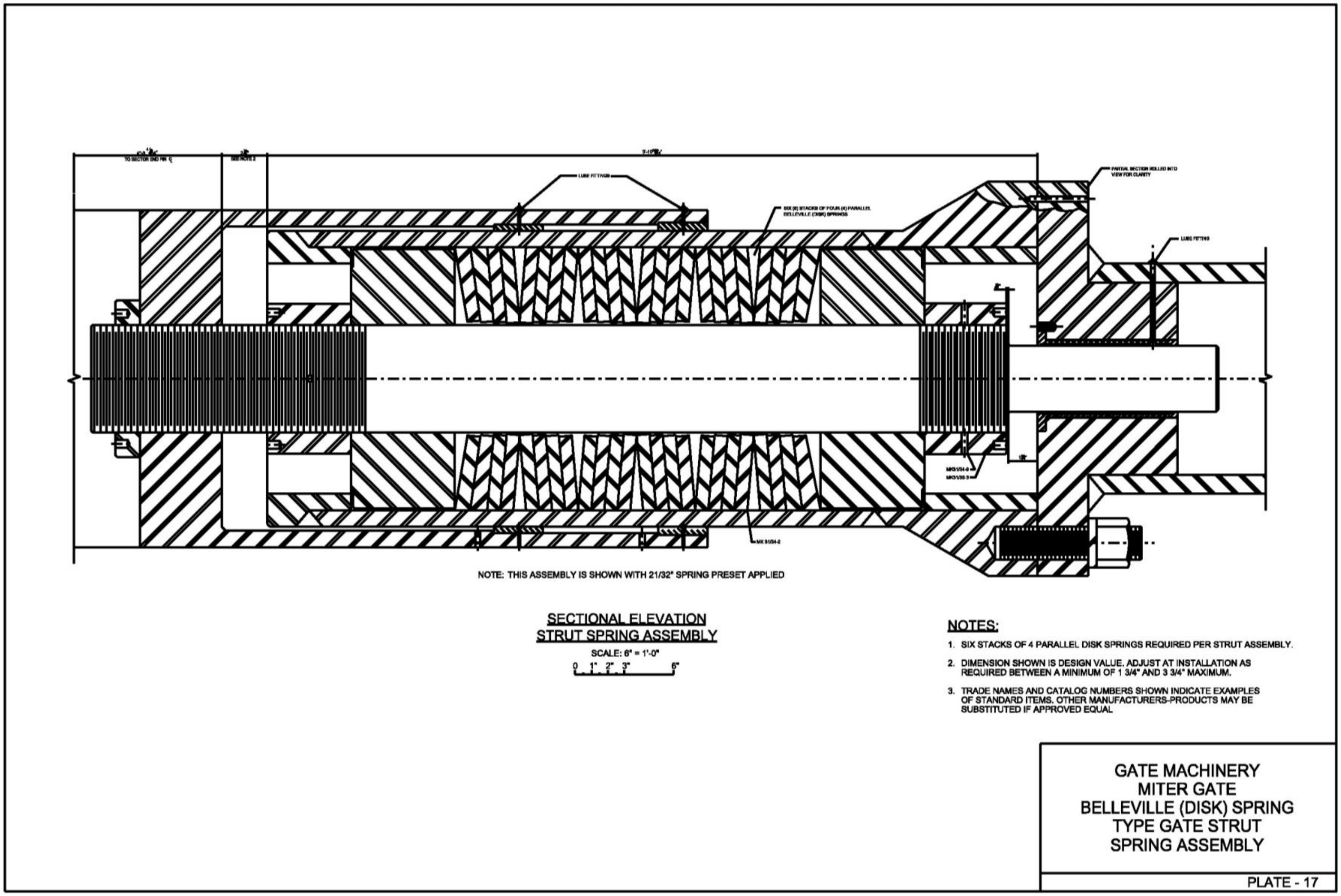


Figure B–17. Plate 17: Gate machinery, miter gate, Belleville (disk) spring type gate strut spring assembly

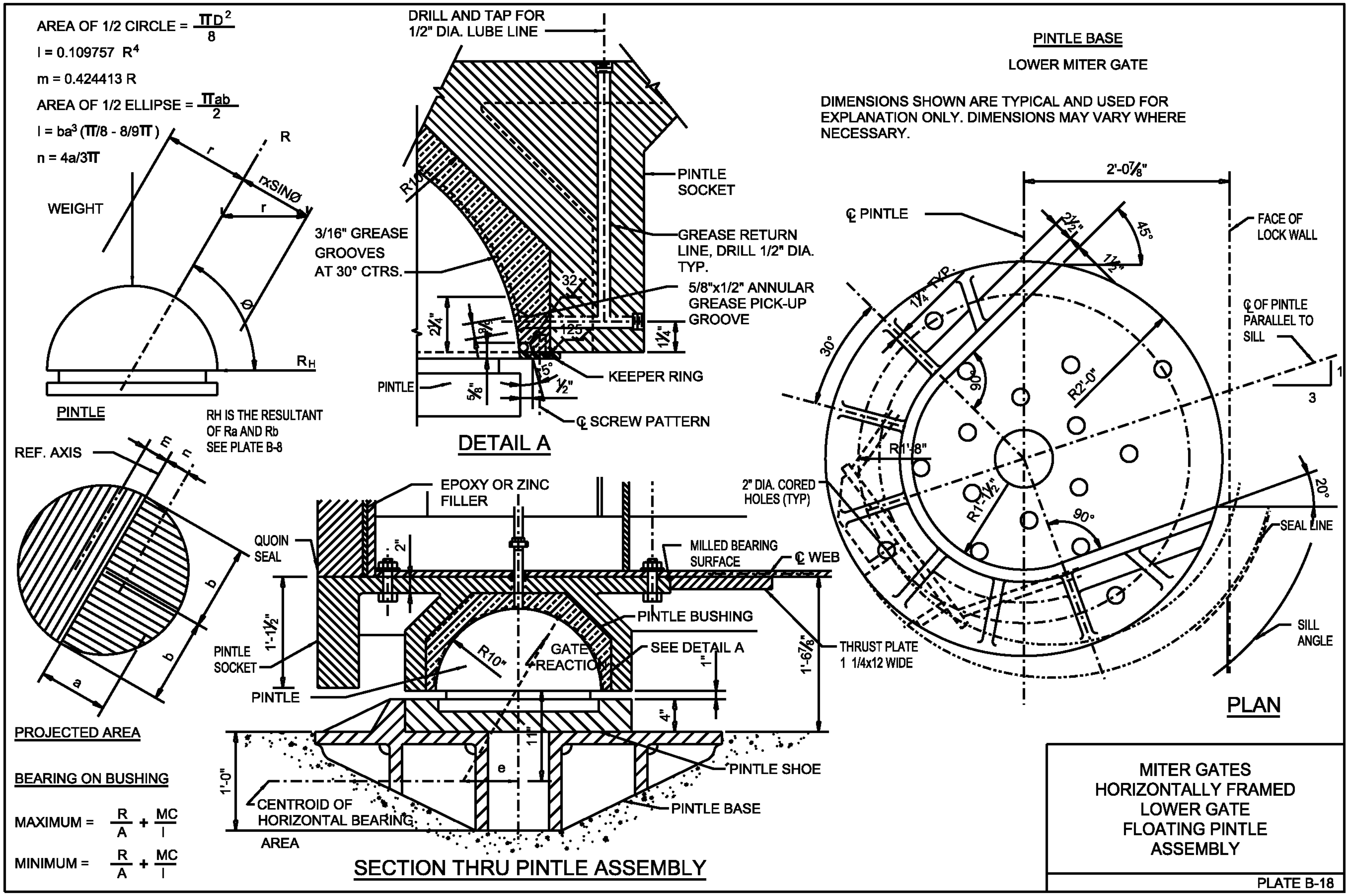


Figure B–18. Plate 18: Miter gates, horizontally framed lower gate, floating pintle assembly

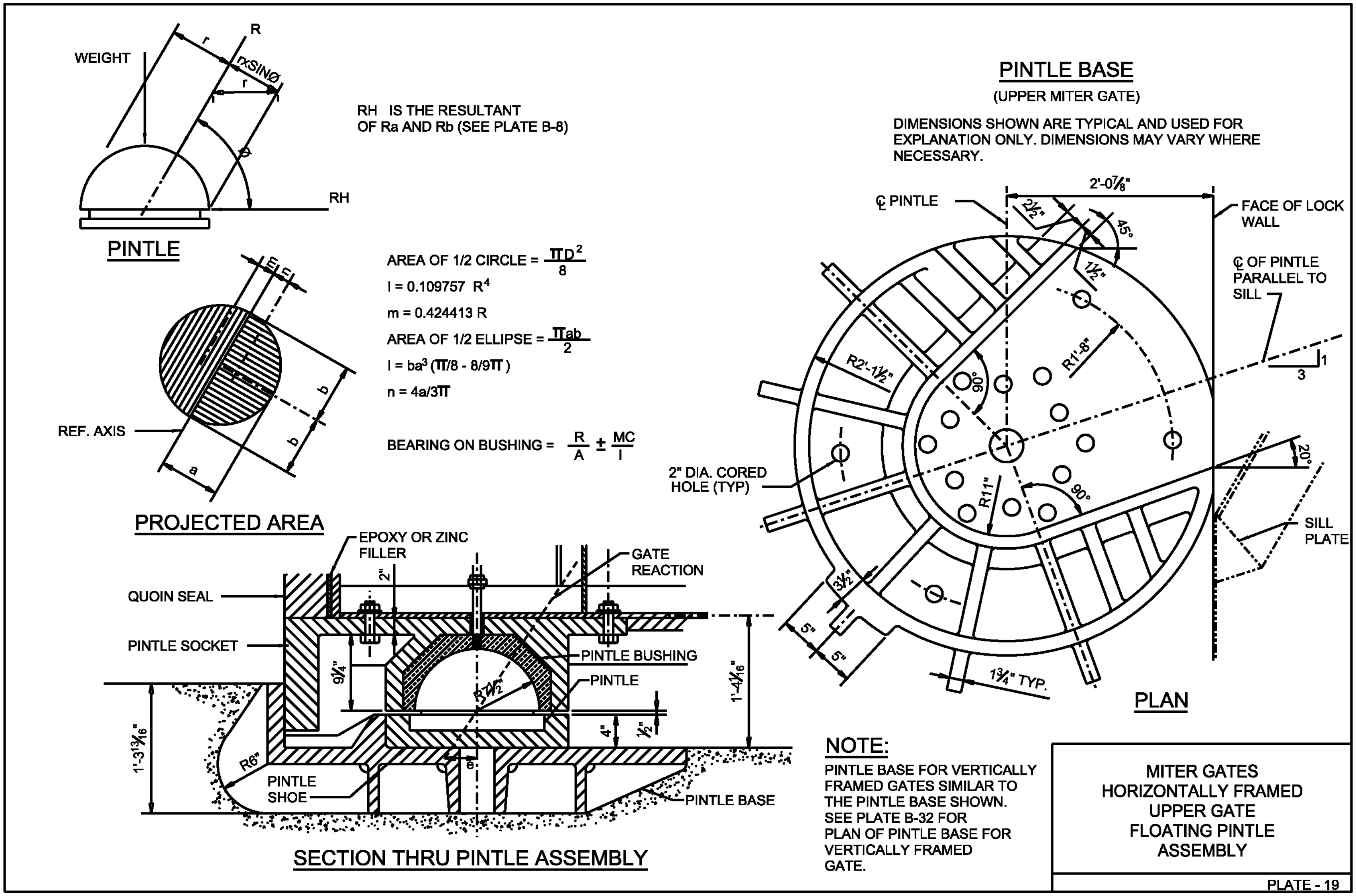


Figure B–19. Plate 19: Miter gates, horizontally framed upper gate, floating pintle assembly

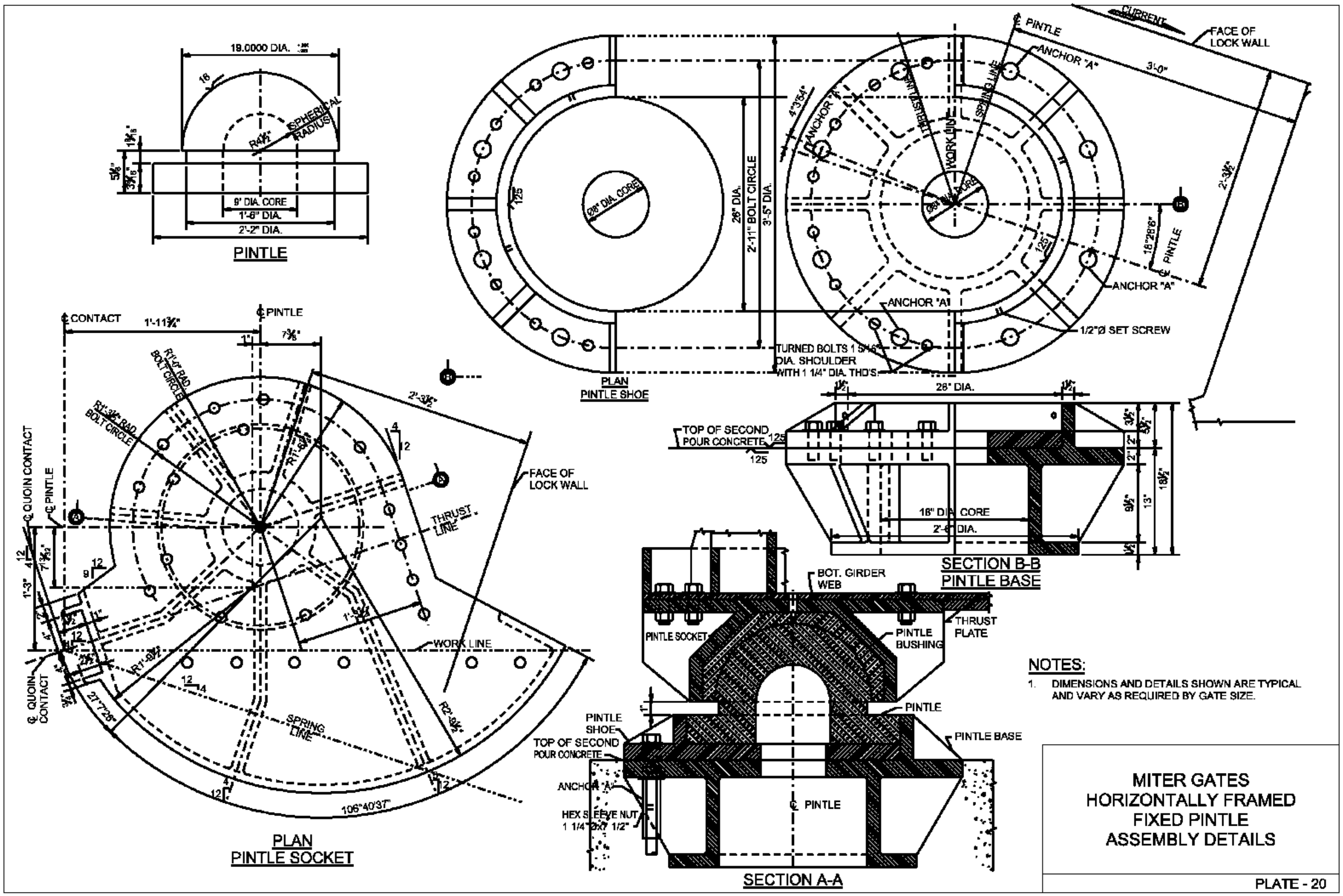


Figure B–20. Plate 20: Miter gates, horizontally framed, fixed pintle assembly details

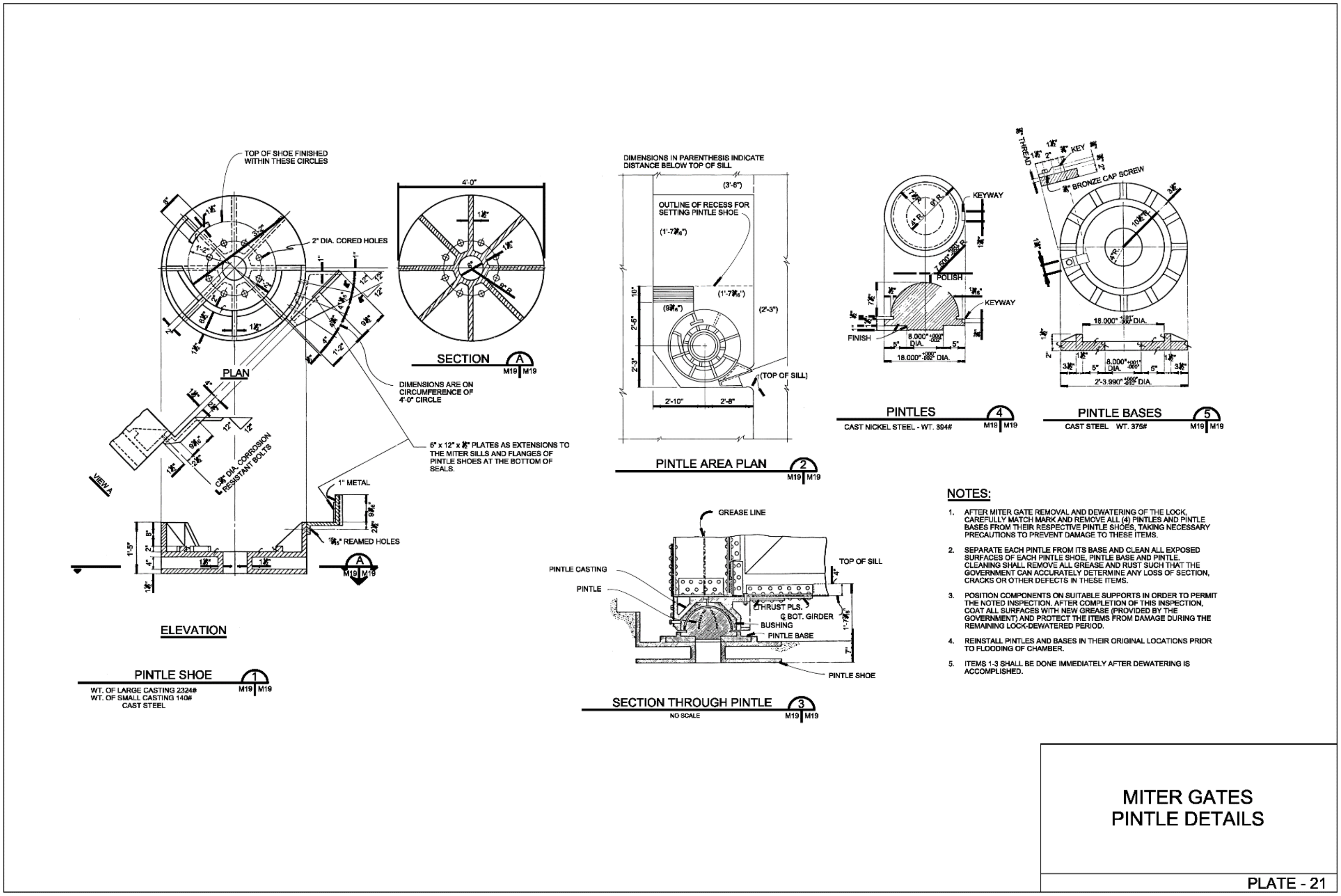


Figure B–21. Plate 21: Miter gates, pintle details

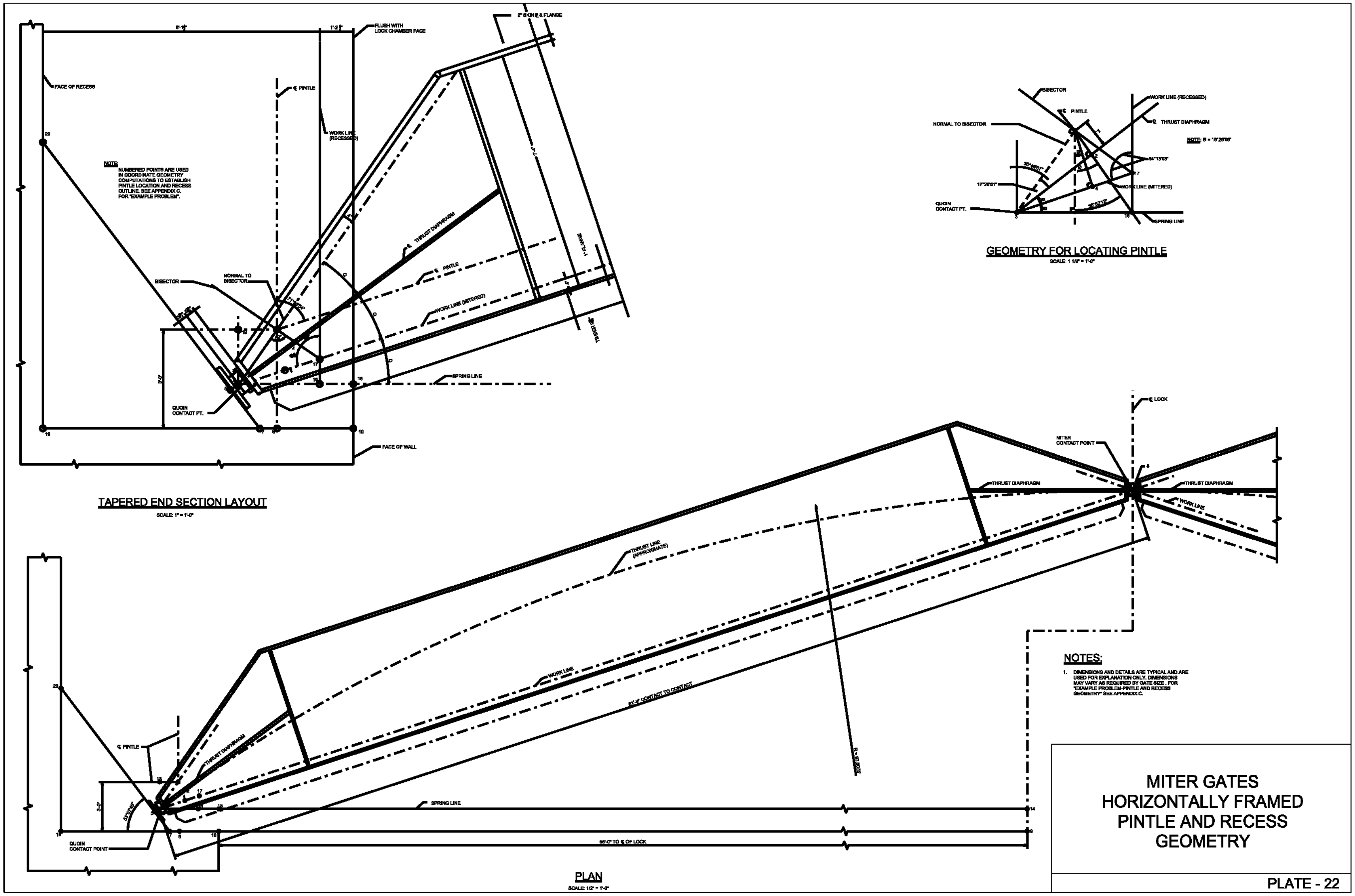


Figure B–22. Plate 22: Miter gates, horizontally framed, pintle and recess geometry

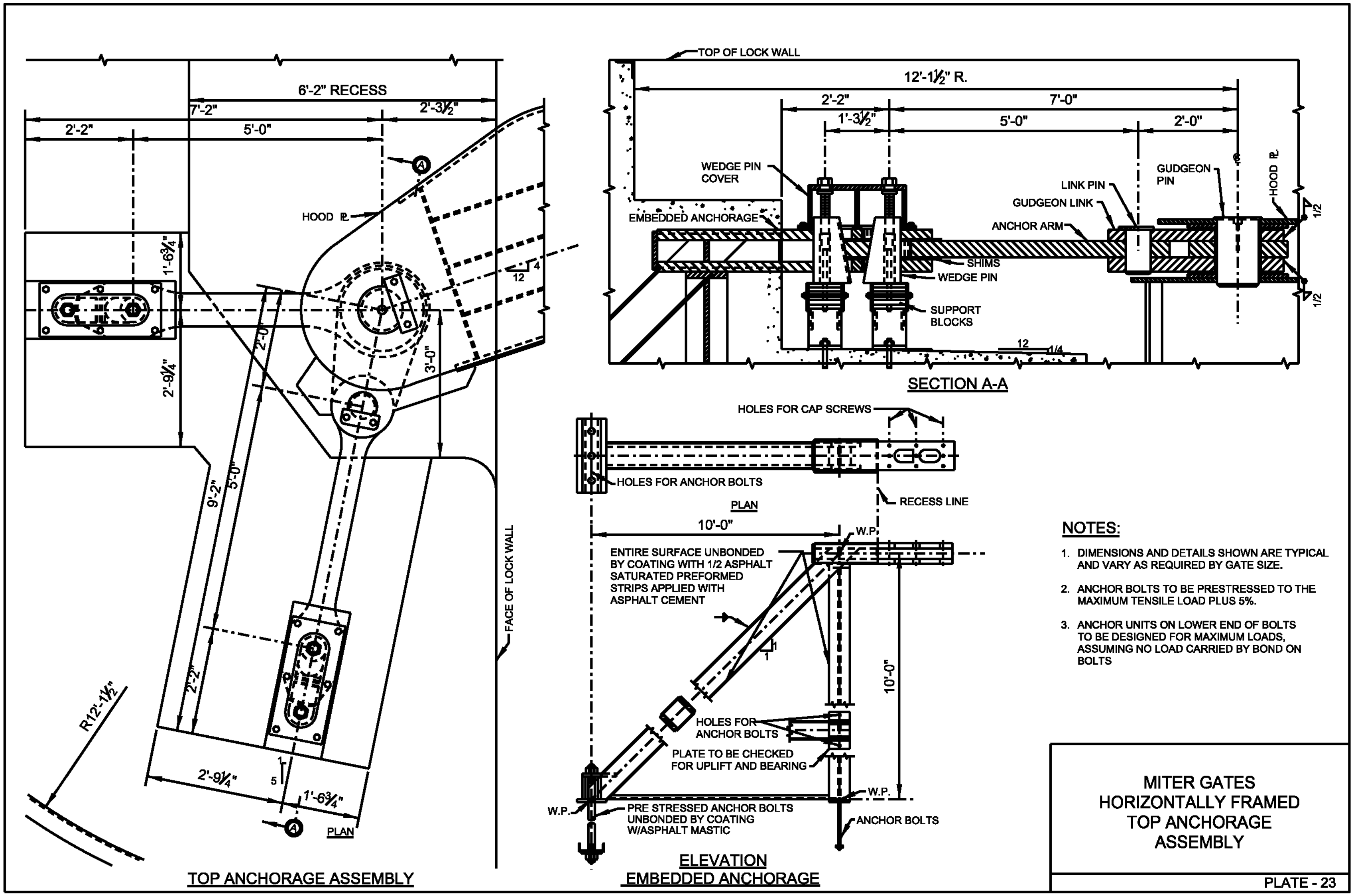


Figure B–23. Plate 23: Miter gates, horizontally framed, top anchorage assembly

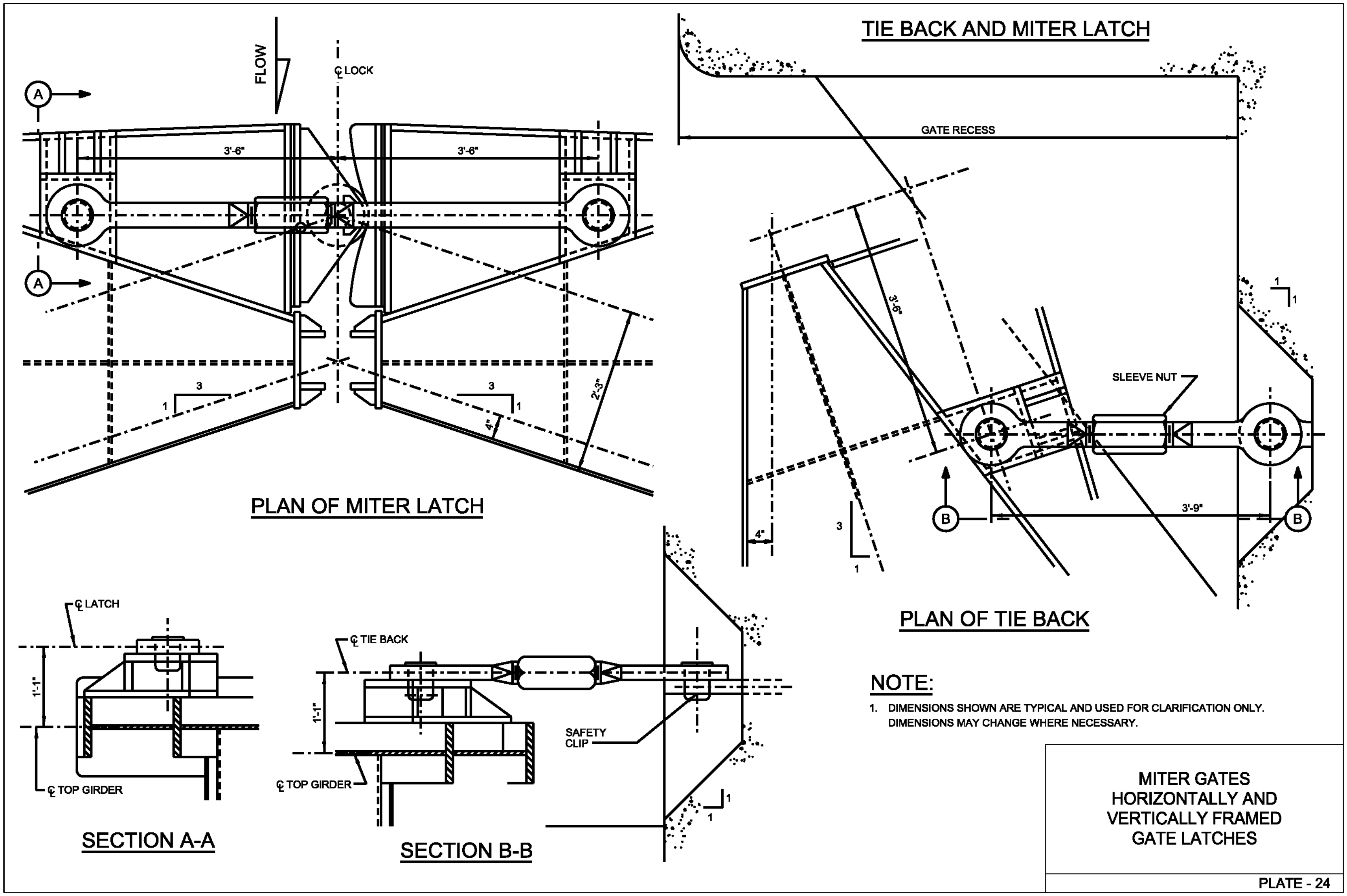


Figure B–24. Plate 24: Miter gates, horizontally and vertically framed gate latches

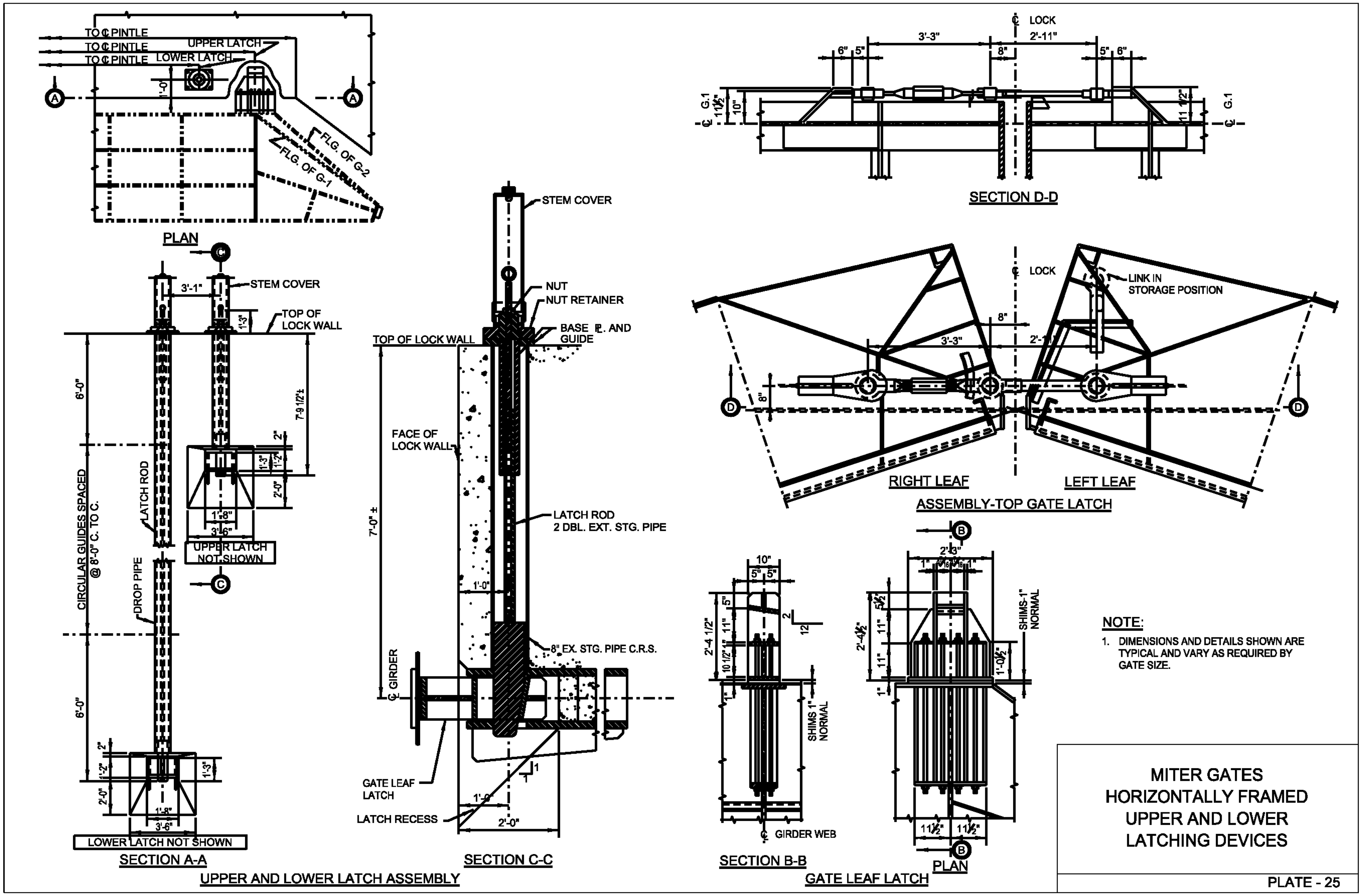


Figure B–25. Plate 25: Miter gates, horizontally framed, upper and lower latching devices

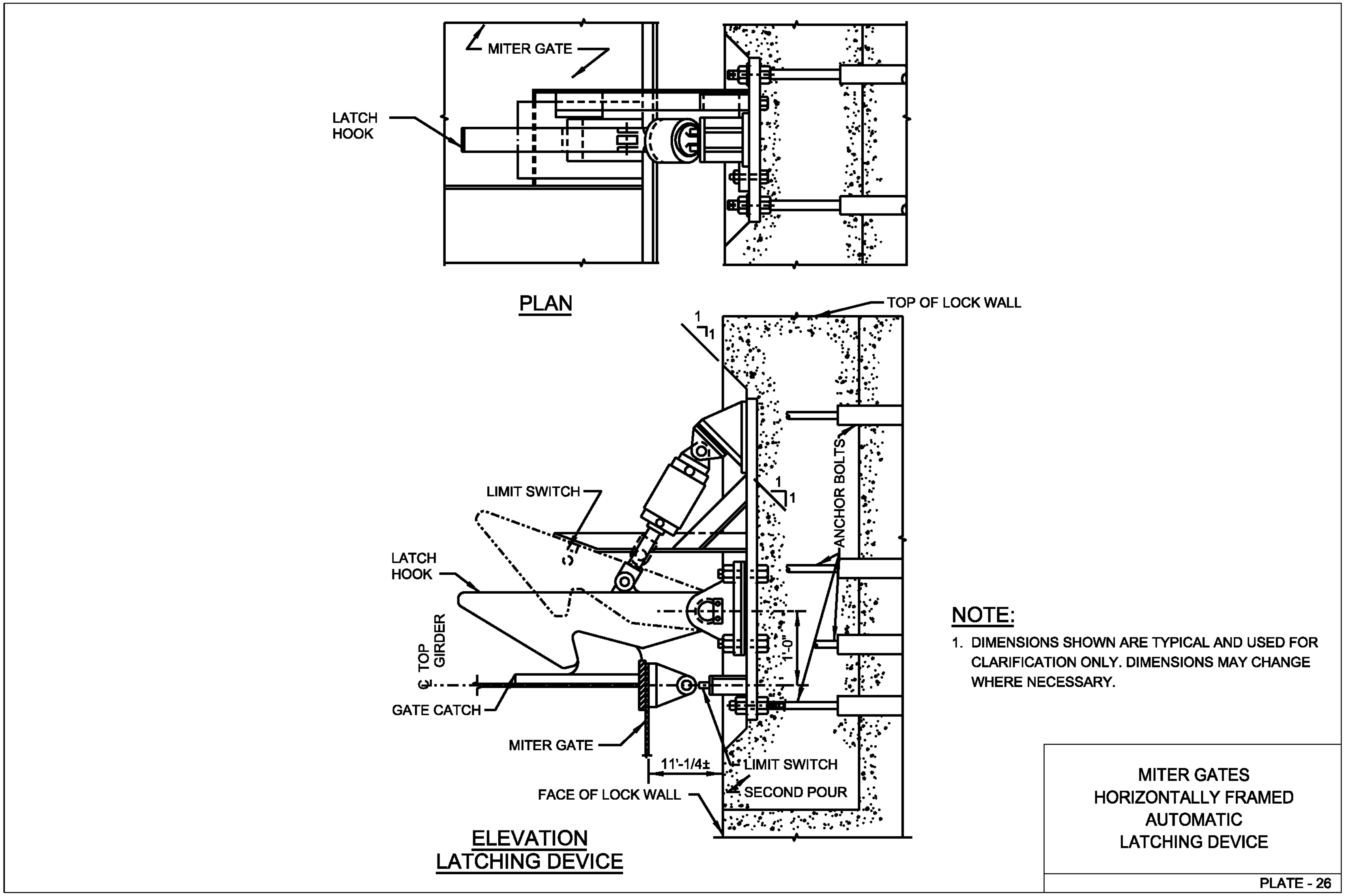


Figure B–26. Plate 26: Miter gates, horizontally framed, automatic latching device

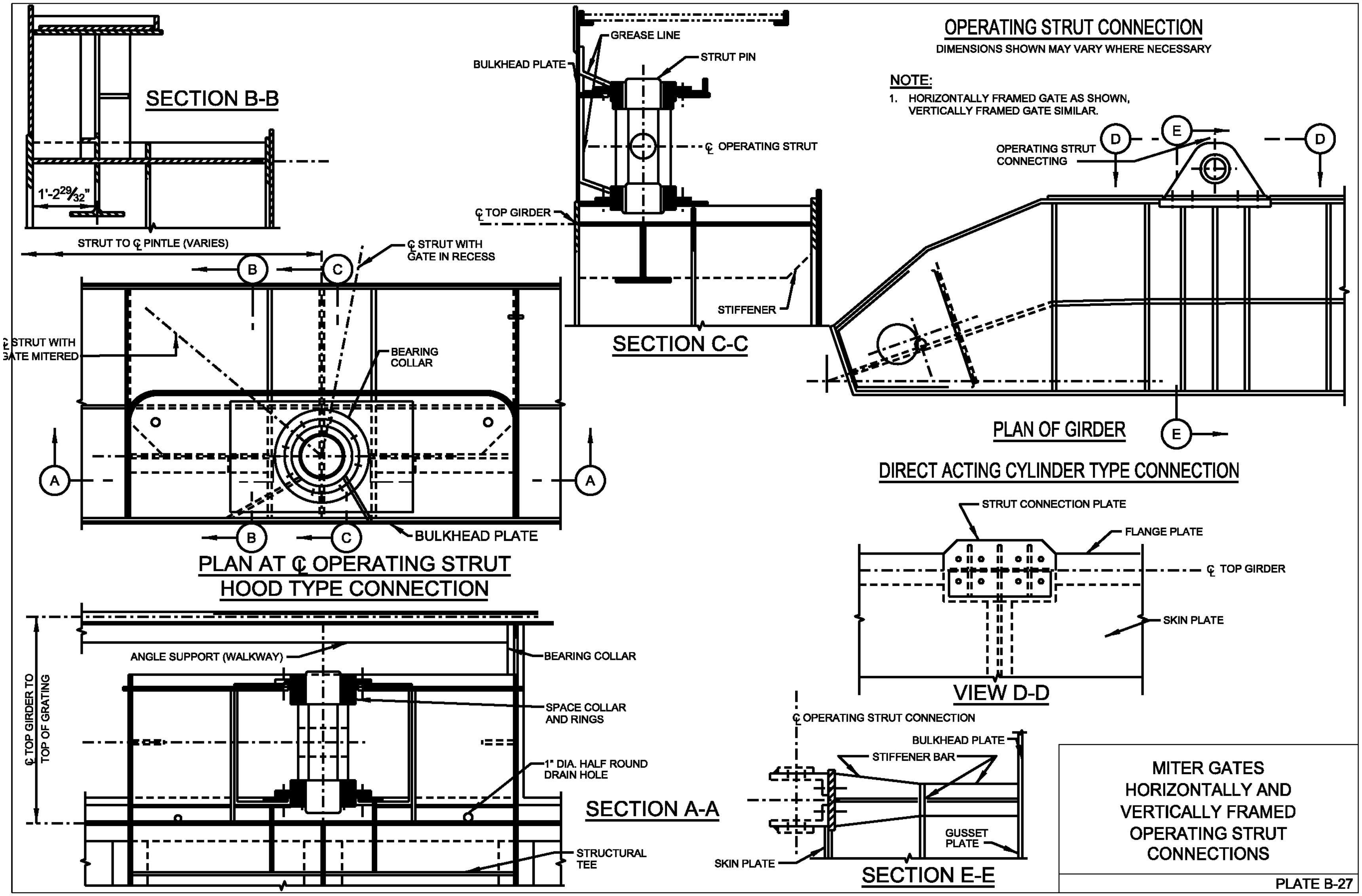


Figure B–27. Plate 27: Miter gates, horizontally and vertically framed, operating strut connections

B–6. Sector gates

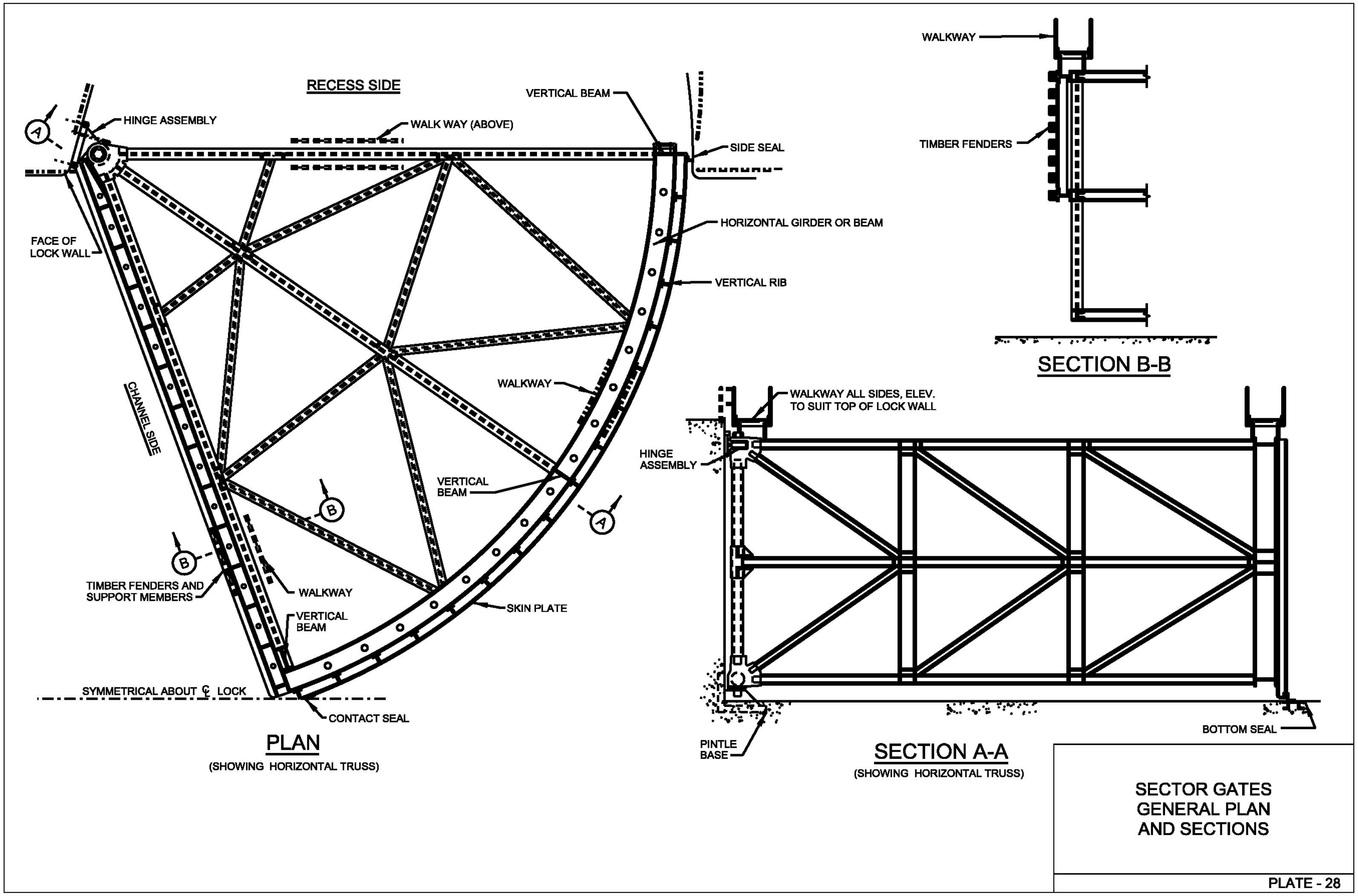


Figure B–28. Plate 28: Sector gates, general plan, and sections

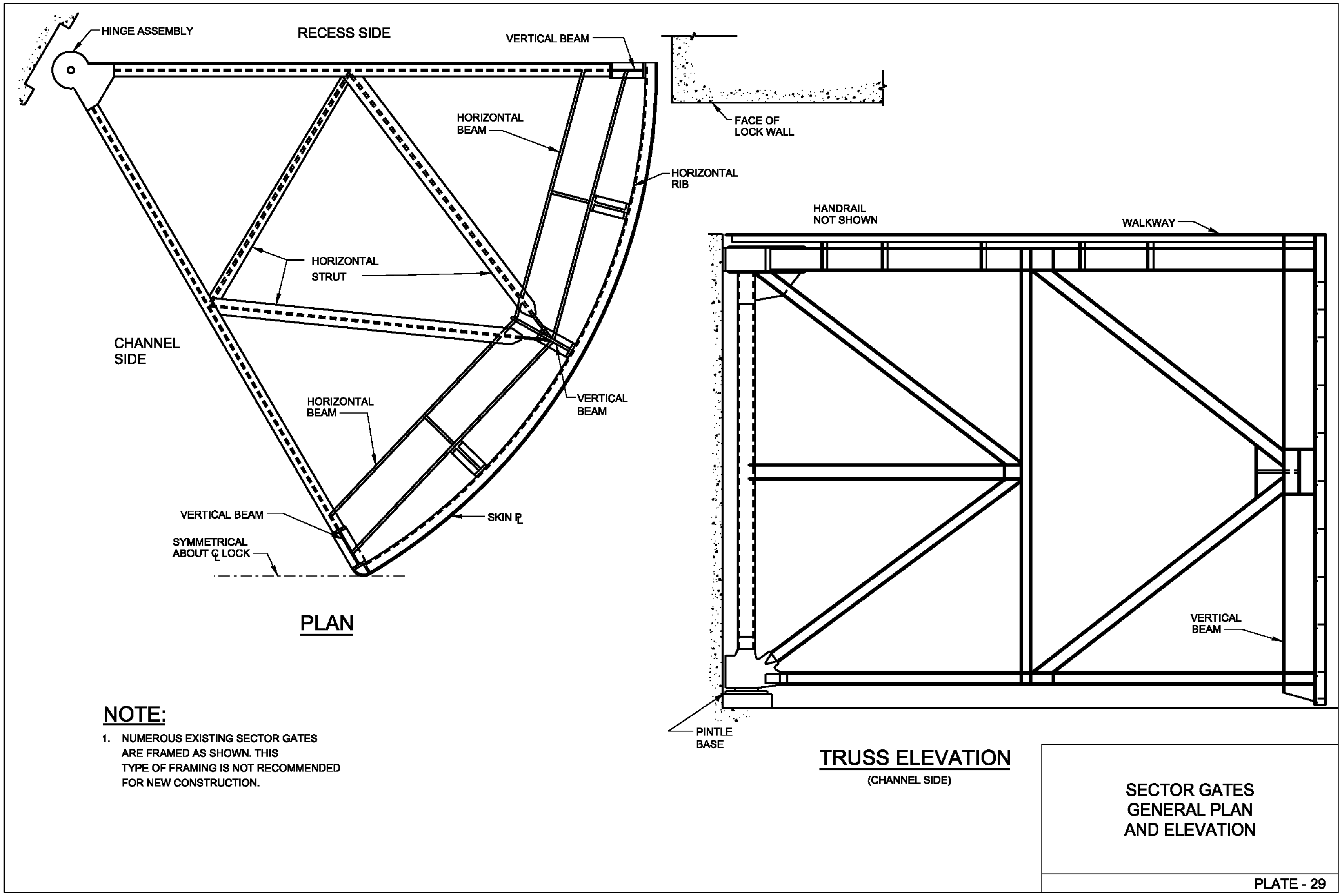


Figure B–29. Plate 29: Sector gates, general plan, and elevation

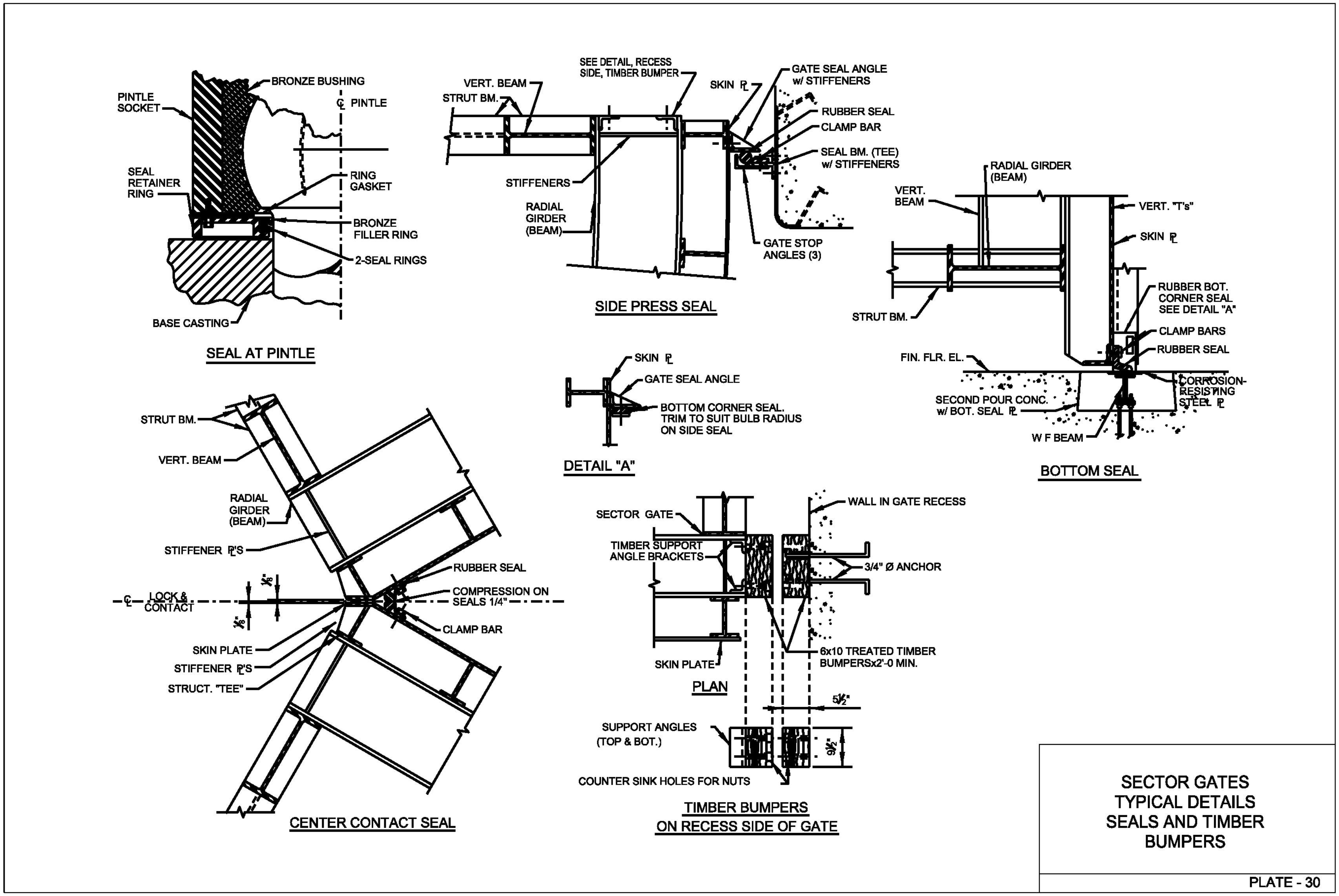


Figure B–30. Plate 30: Sector gates, typical details, seals, and timber bumpers

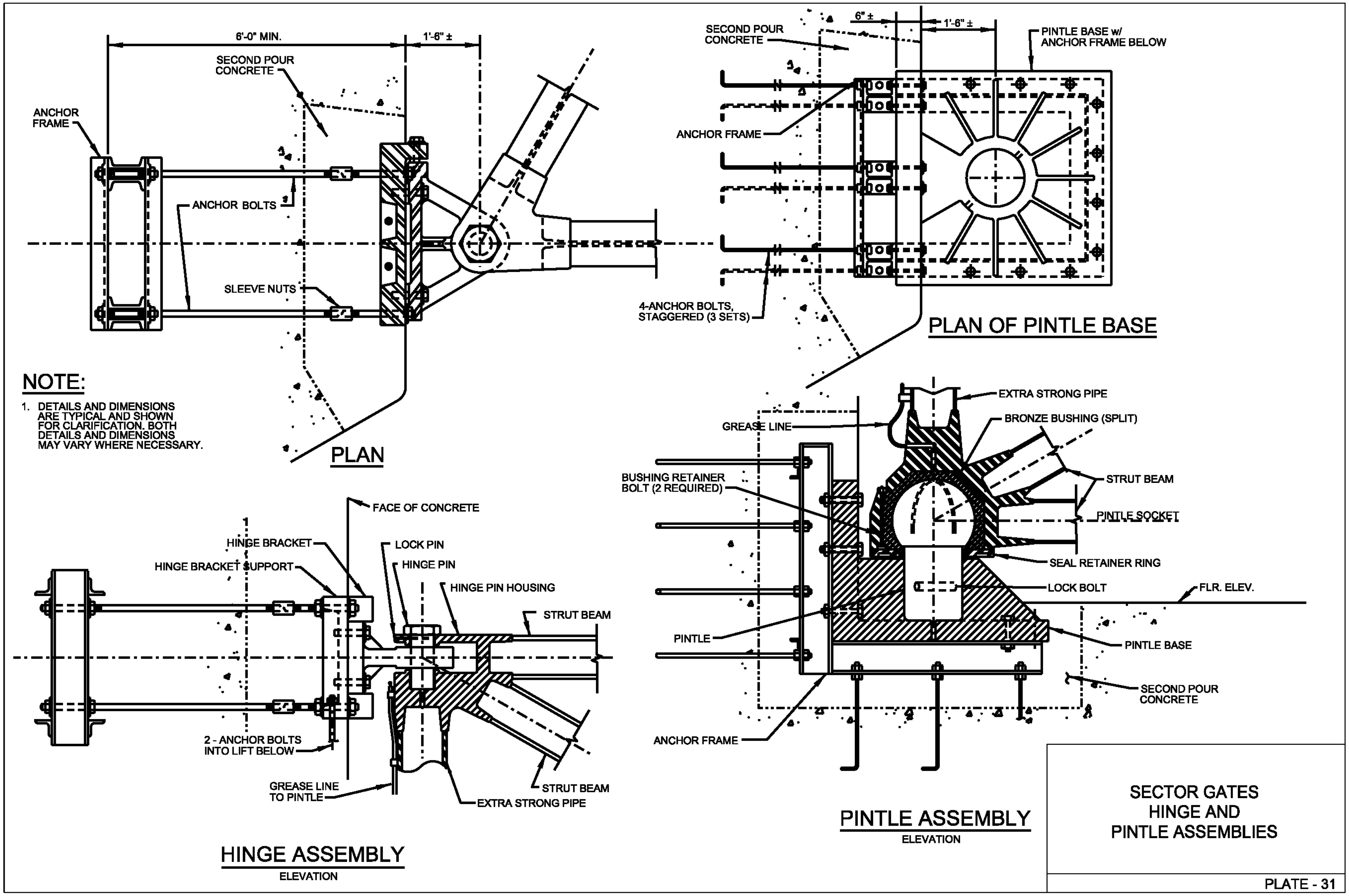


Figure B–31. Plate 31: Sector gates, hinge and pintle assemblies

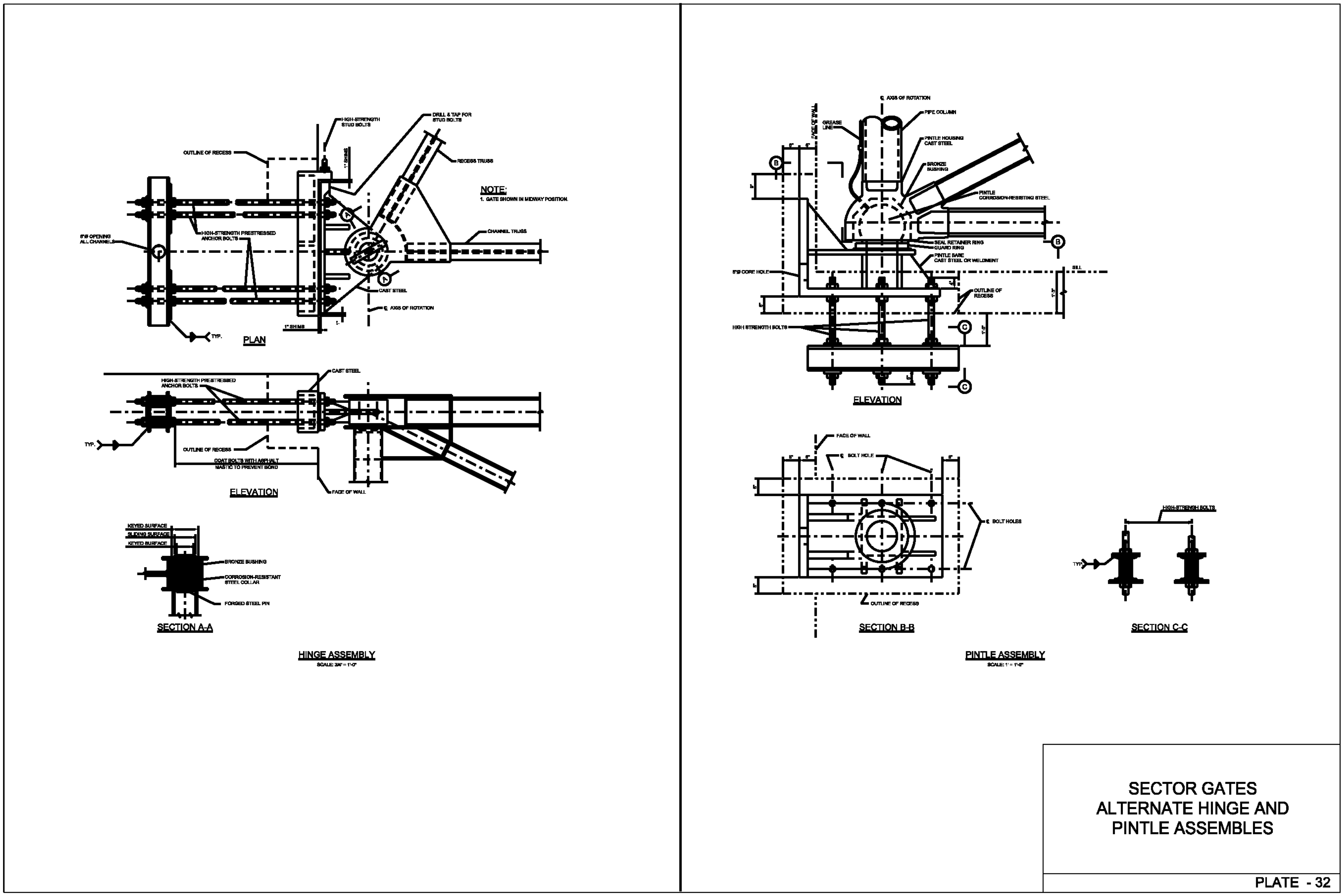


Figure B–32. Plate 32: Sector gates, alternate hinge and pintle assemblies

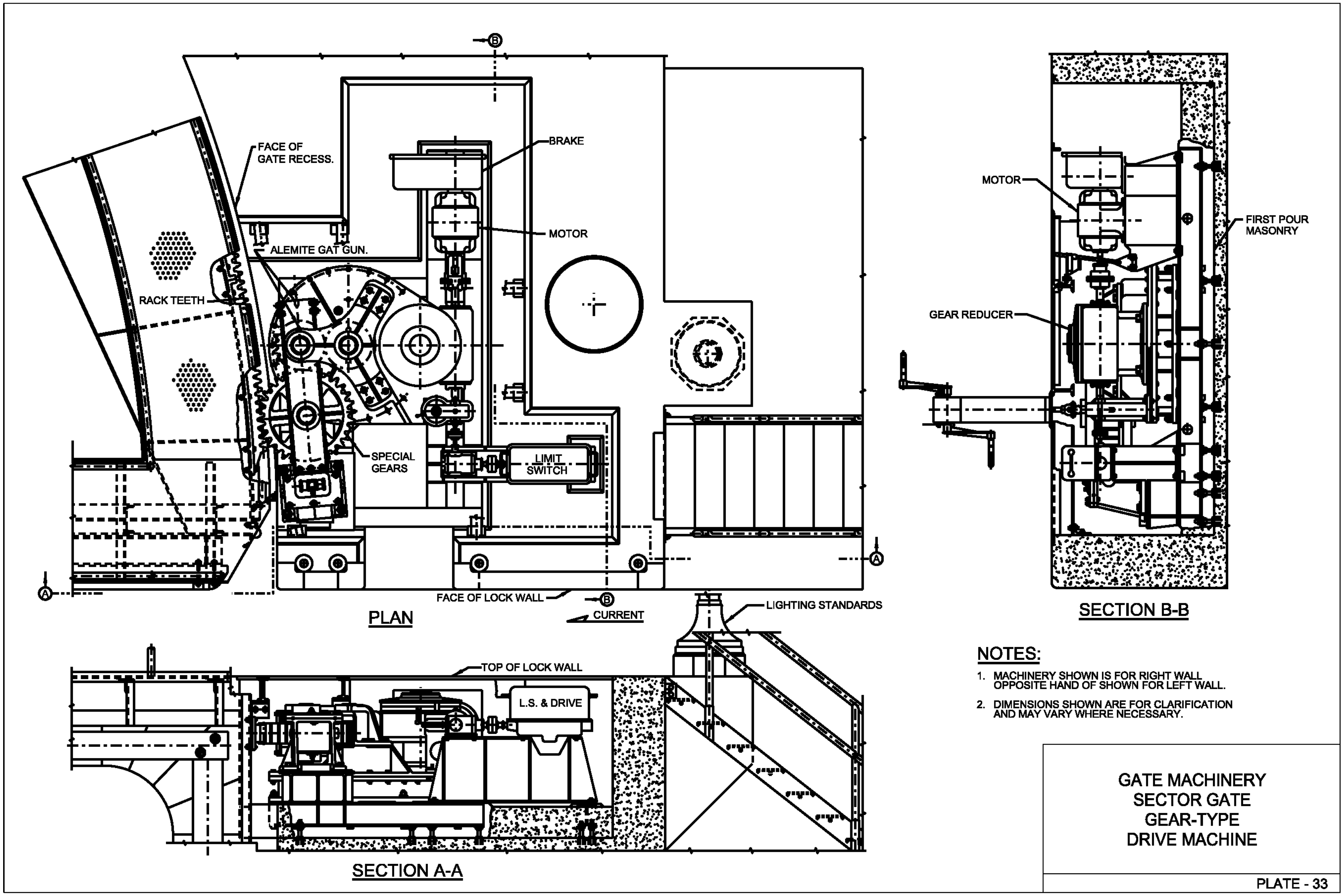


Figure B–33. Plate 33: Gate machinery, sector gate, gear-type drive machine

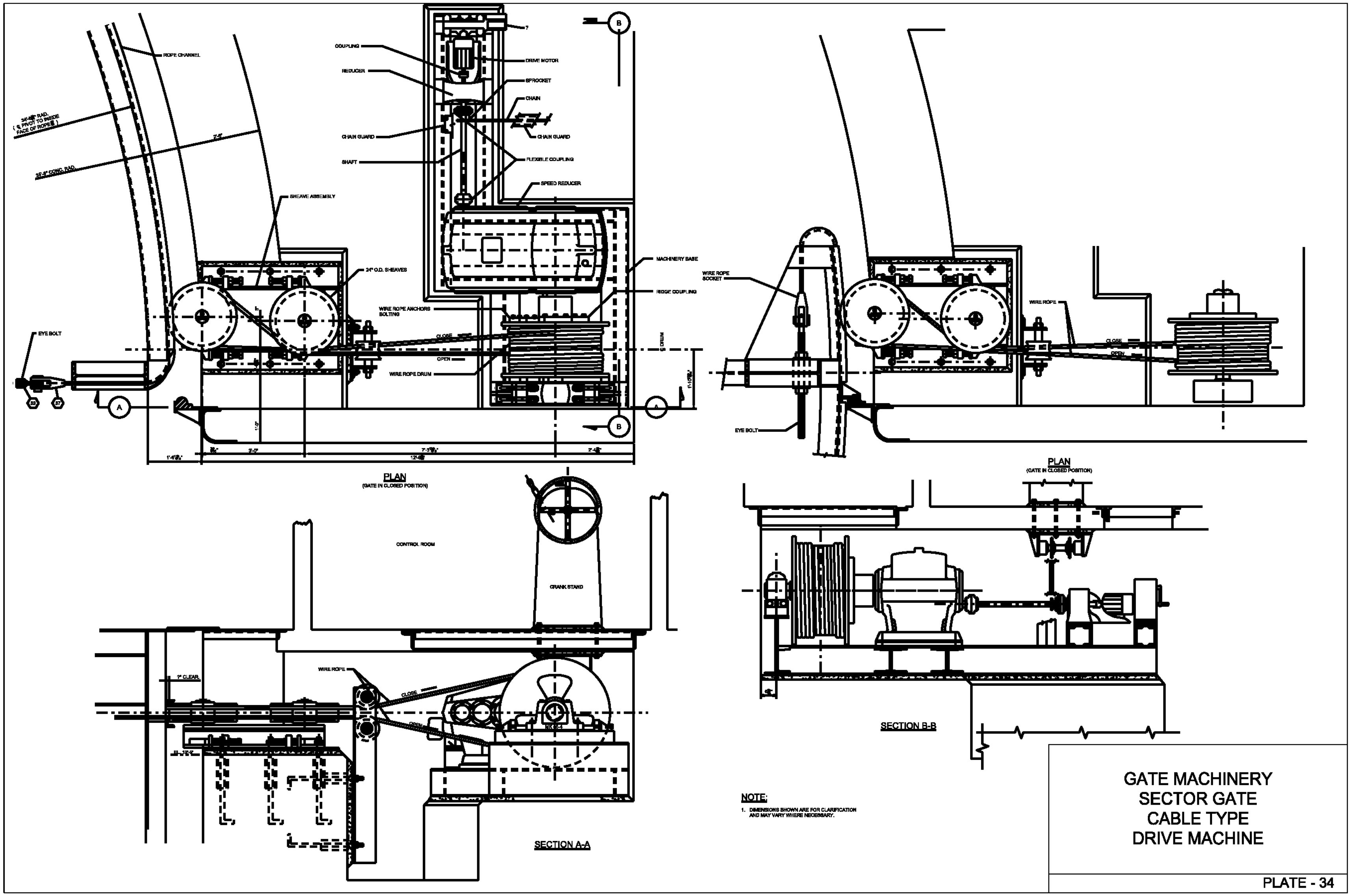


Figure B–34. Plate 34: Gate machinery, sector gate, cable type drive machine

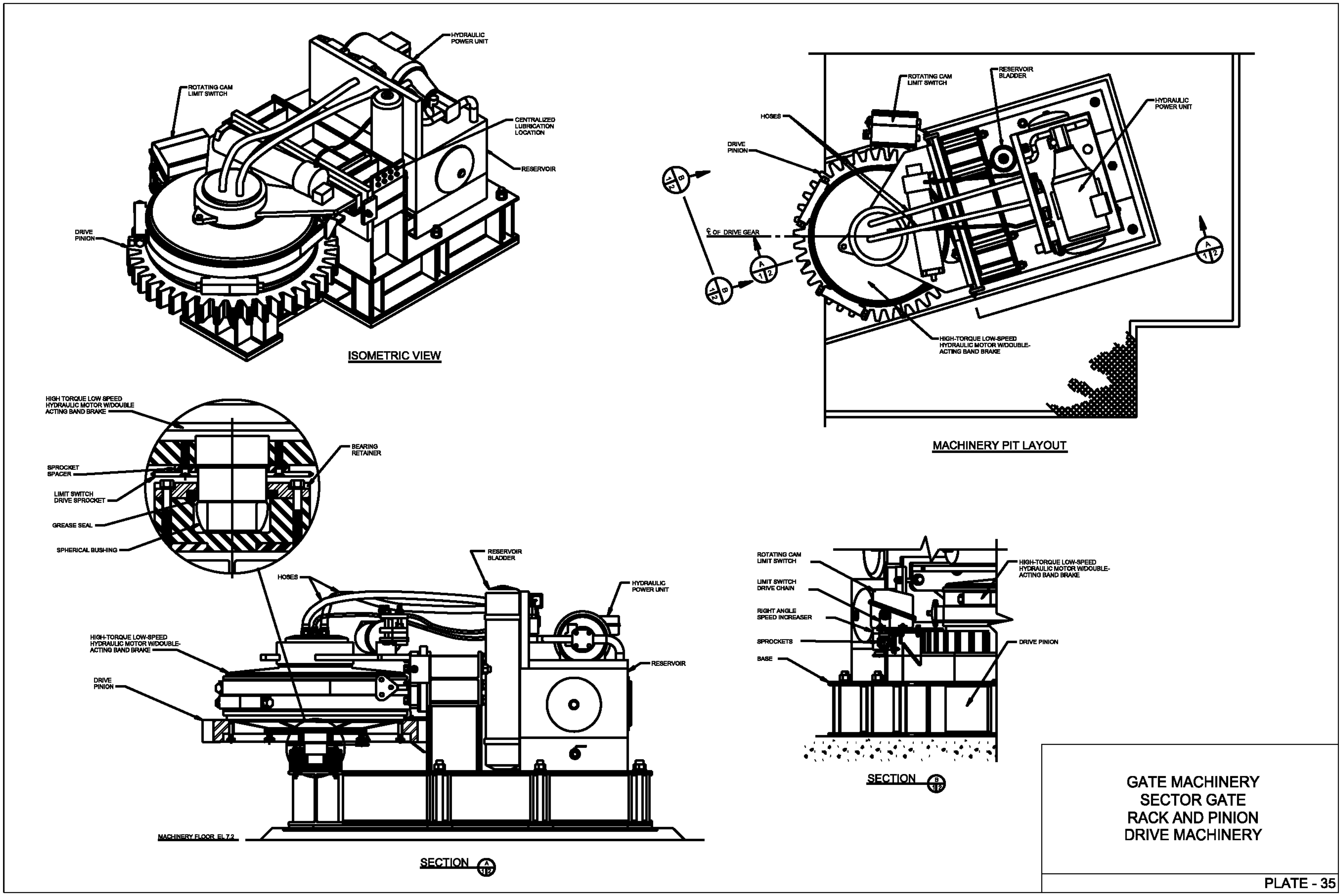


Figure B–35. Plate 35: Gate machinery, sector gate, rack, and pinion drive machinery

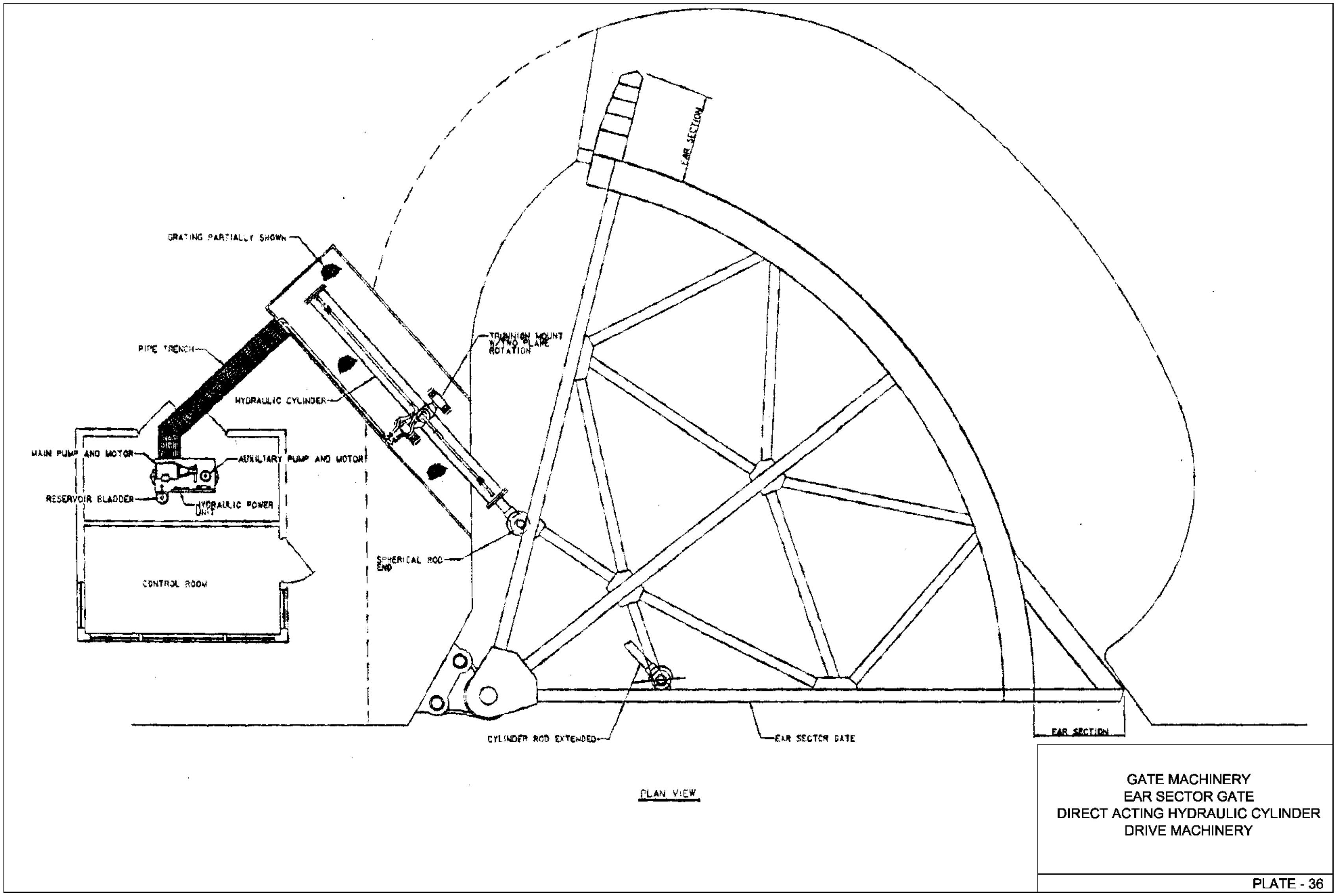


Figure B–36. Plate 36: Gate machinery, ear sector gate, direct acting hydraulic cylinder drive machinery

B–7. Tainter valves

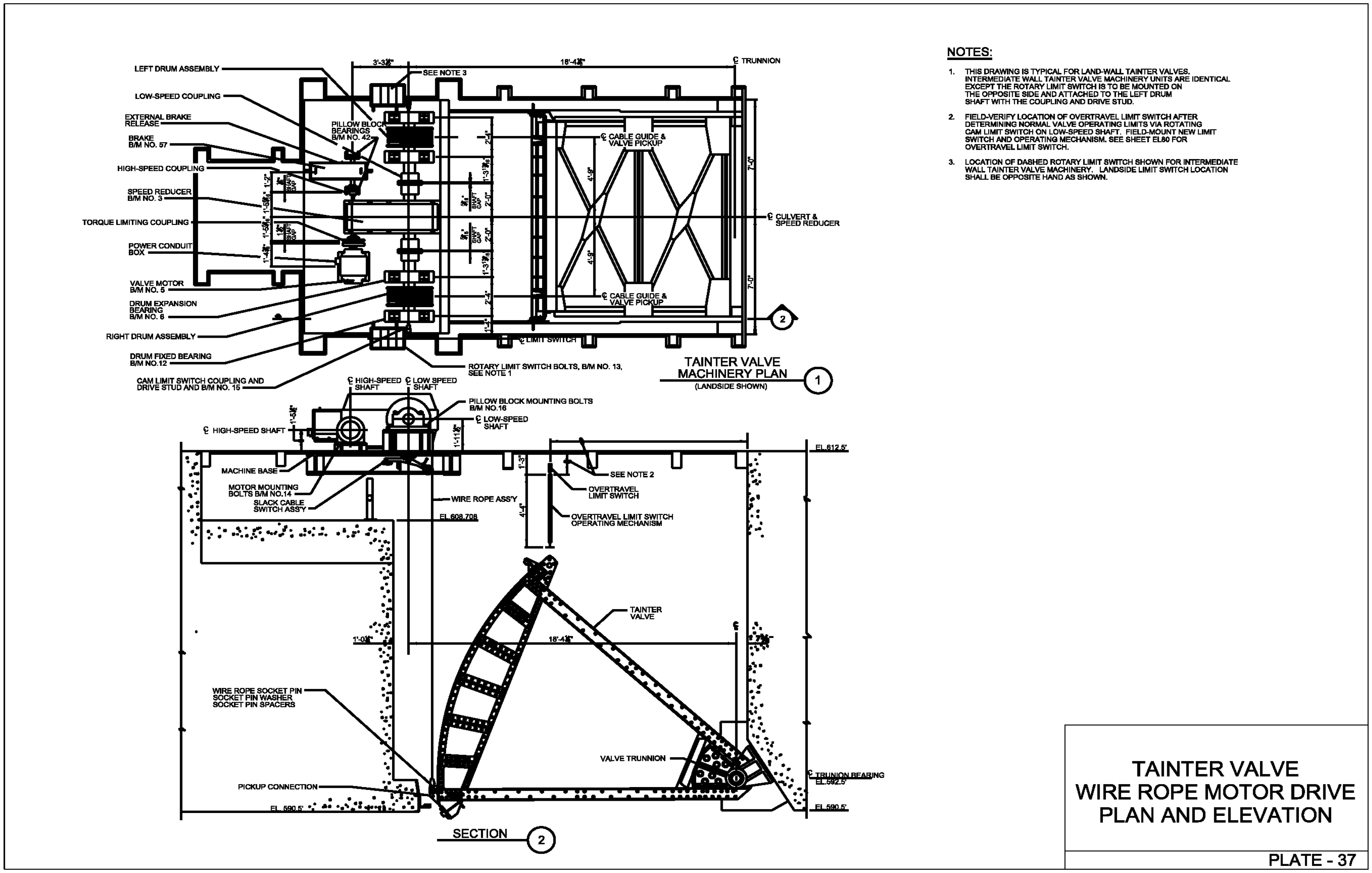


Figure B–37. Plate 37: Tainter valve wire rope motor drive plan and elevation

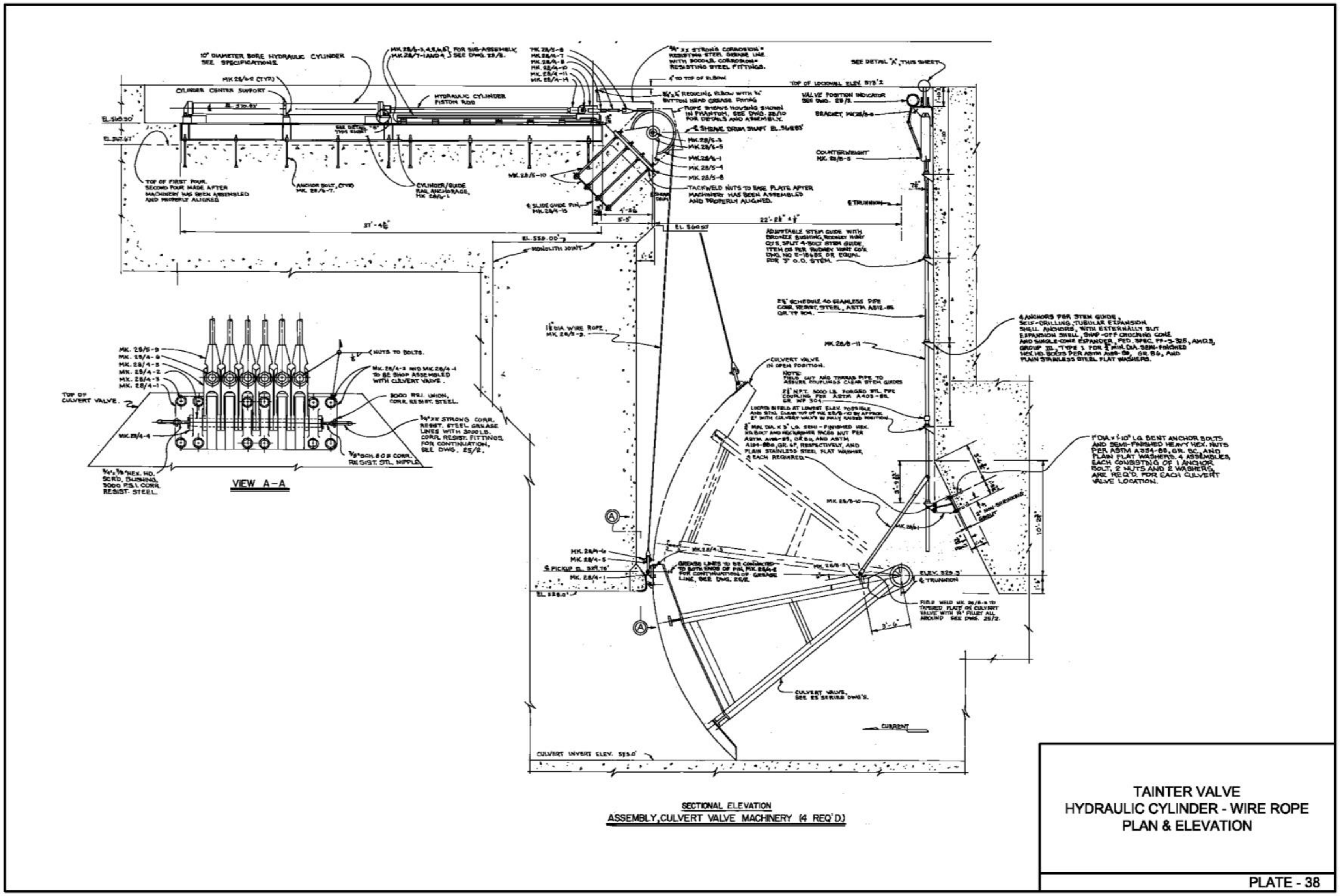


Figure B–38. Plate 38: Tainter valve hydraulic cylinder-wire rope plan & elevation

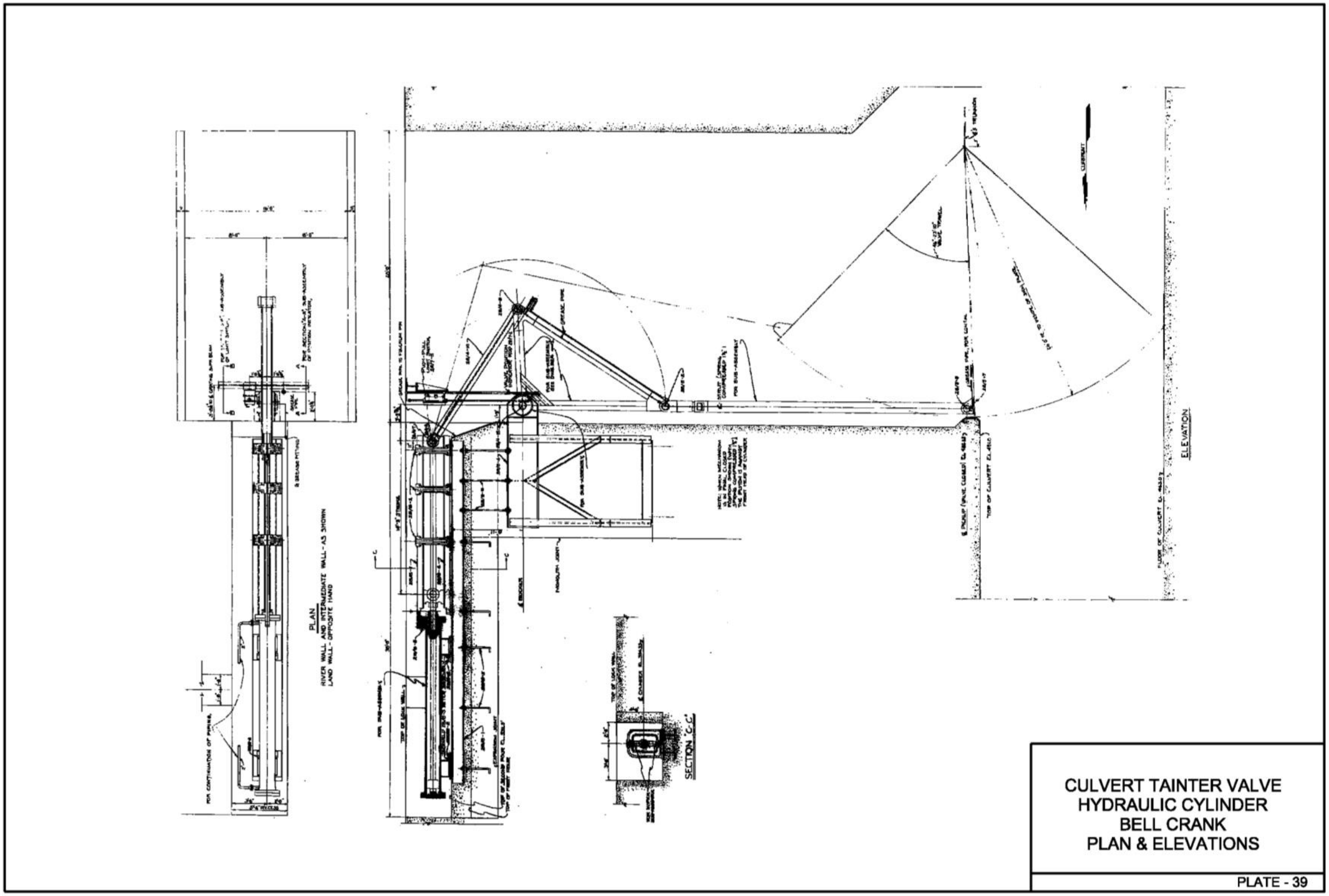
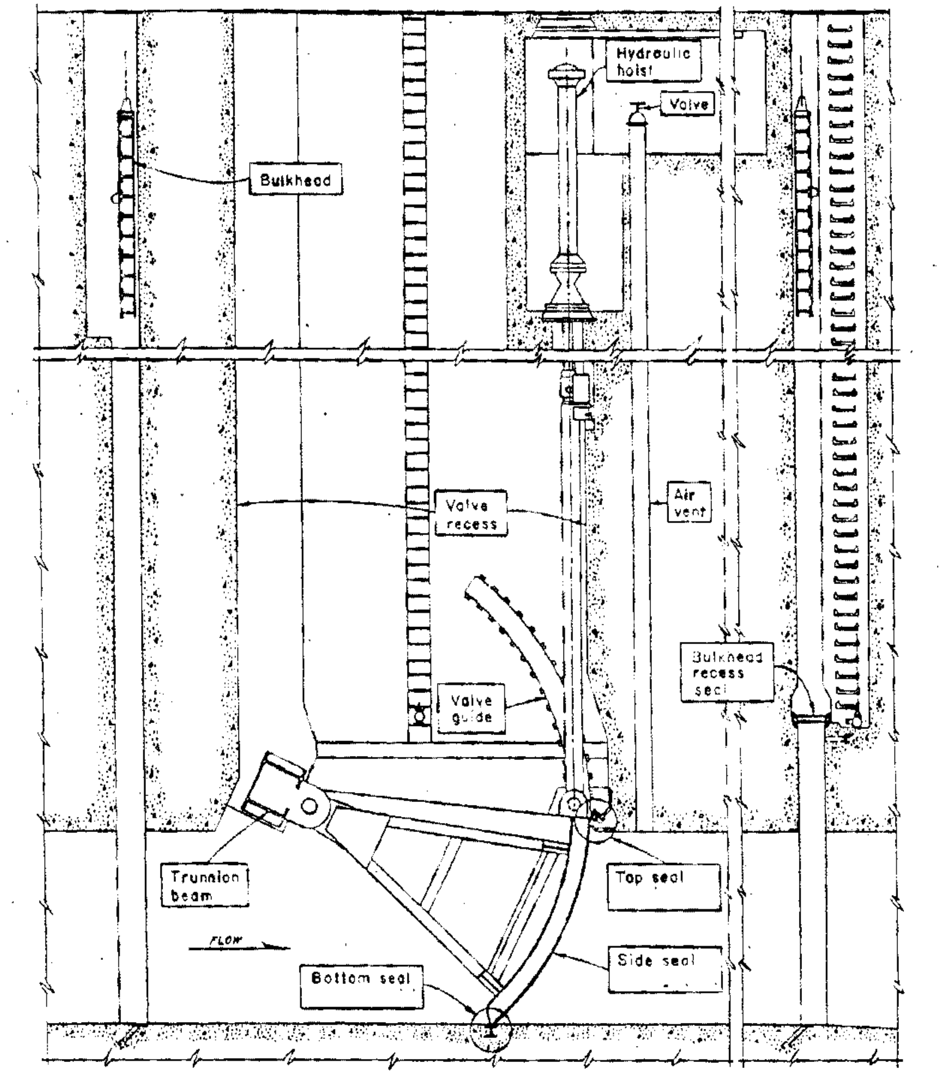


Figure B–39. Plate 39: Culvert tainter valve hydraulic cylinder bell crank plan & elevations



CULVERT TAINTER VALVE
MACHINERY HOIST
ELEVATION

PLATE - 40

Figure B–40. Plate 40: Culvert tainter valve machinery hoist elevation

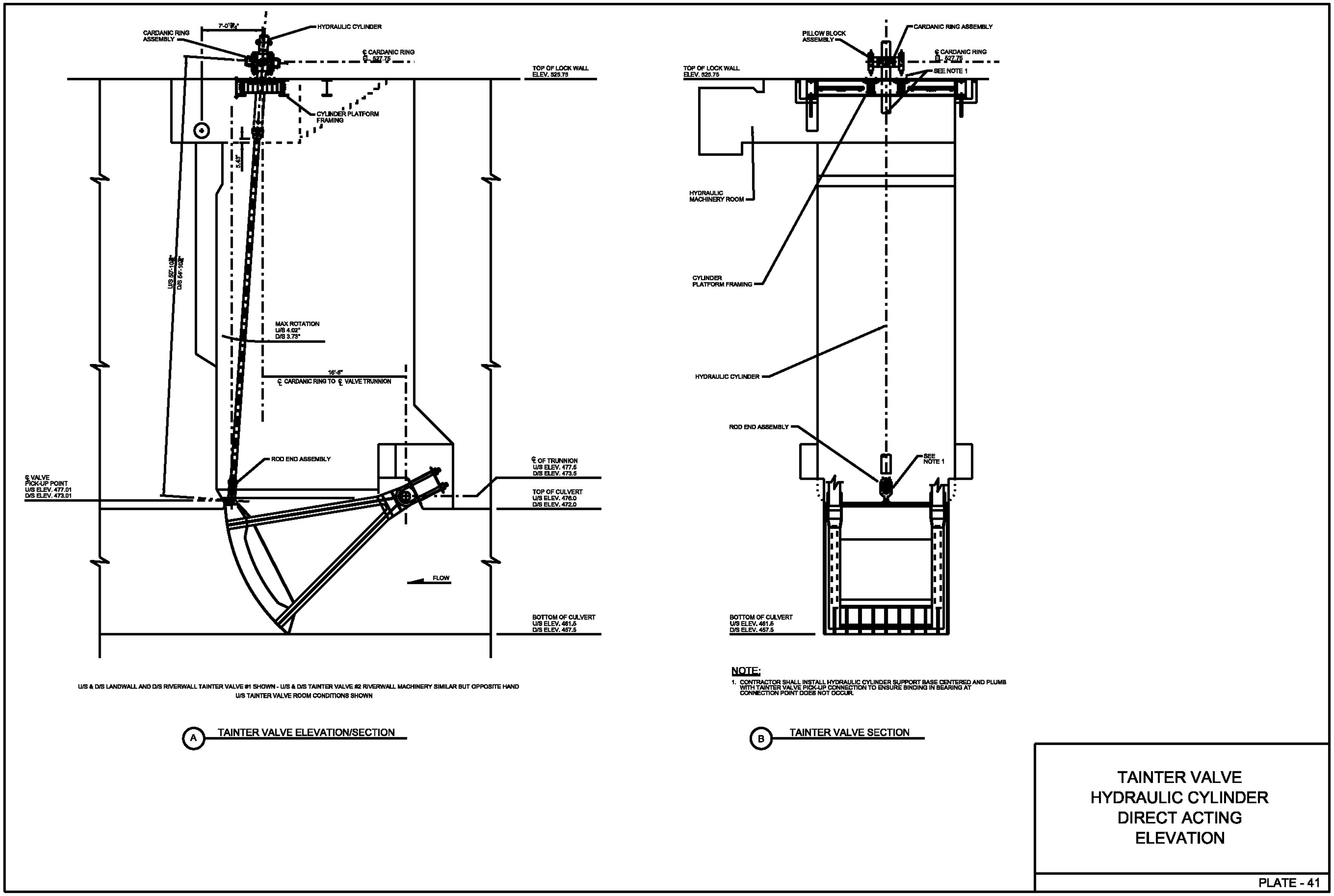


Figure B–41. Plate 41: Tainter valve hydraulic cylinder direct acting

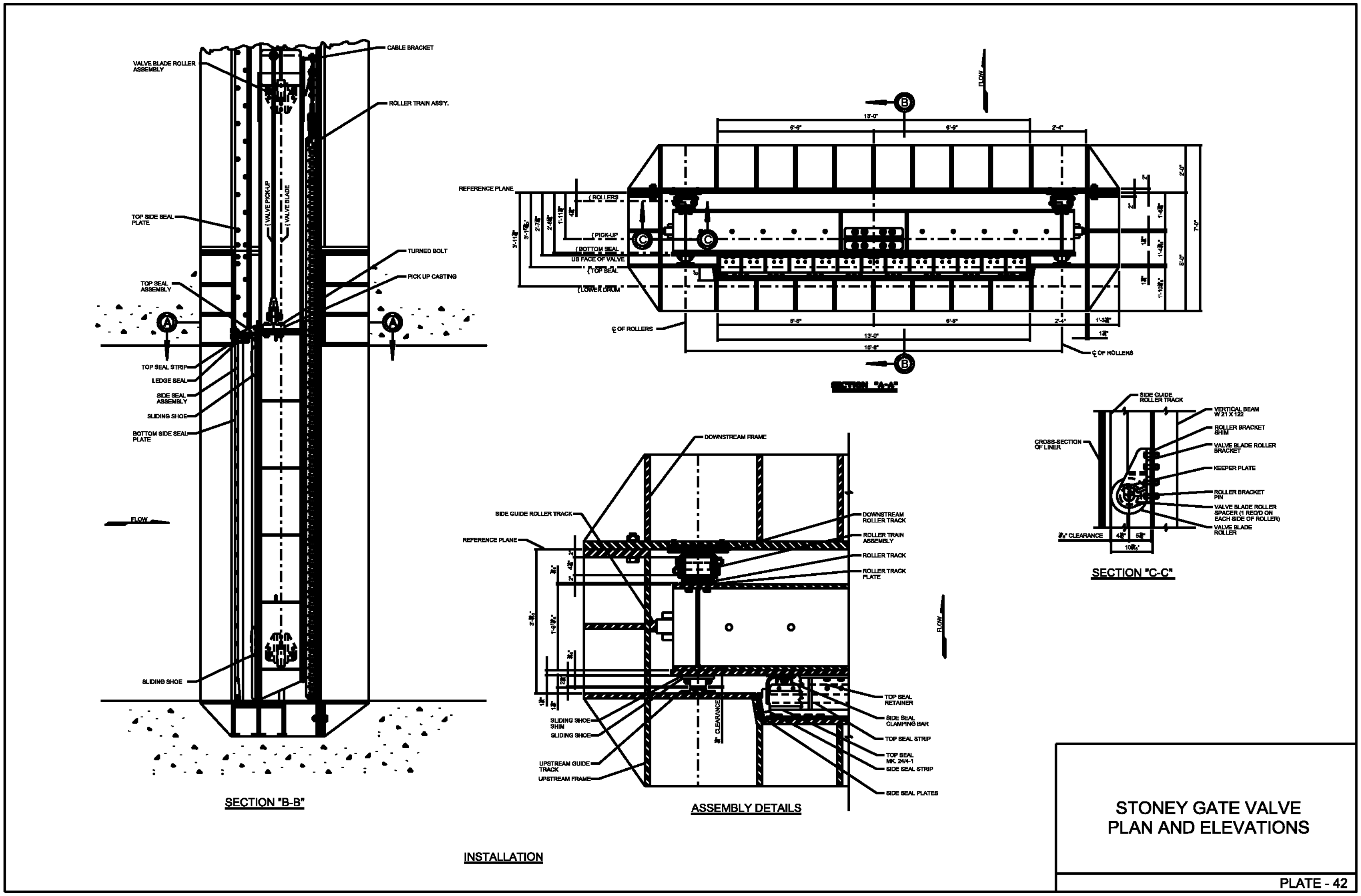


Figure B–42. Plate 42: Stoney gate valve plan and elevations

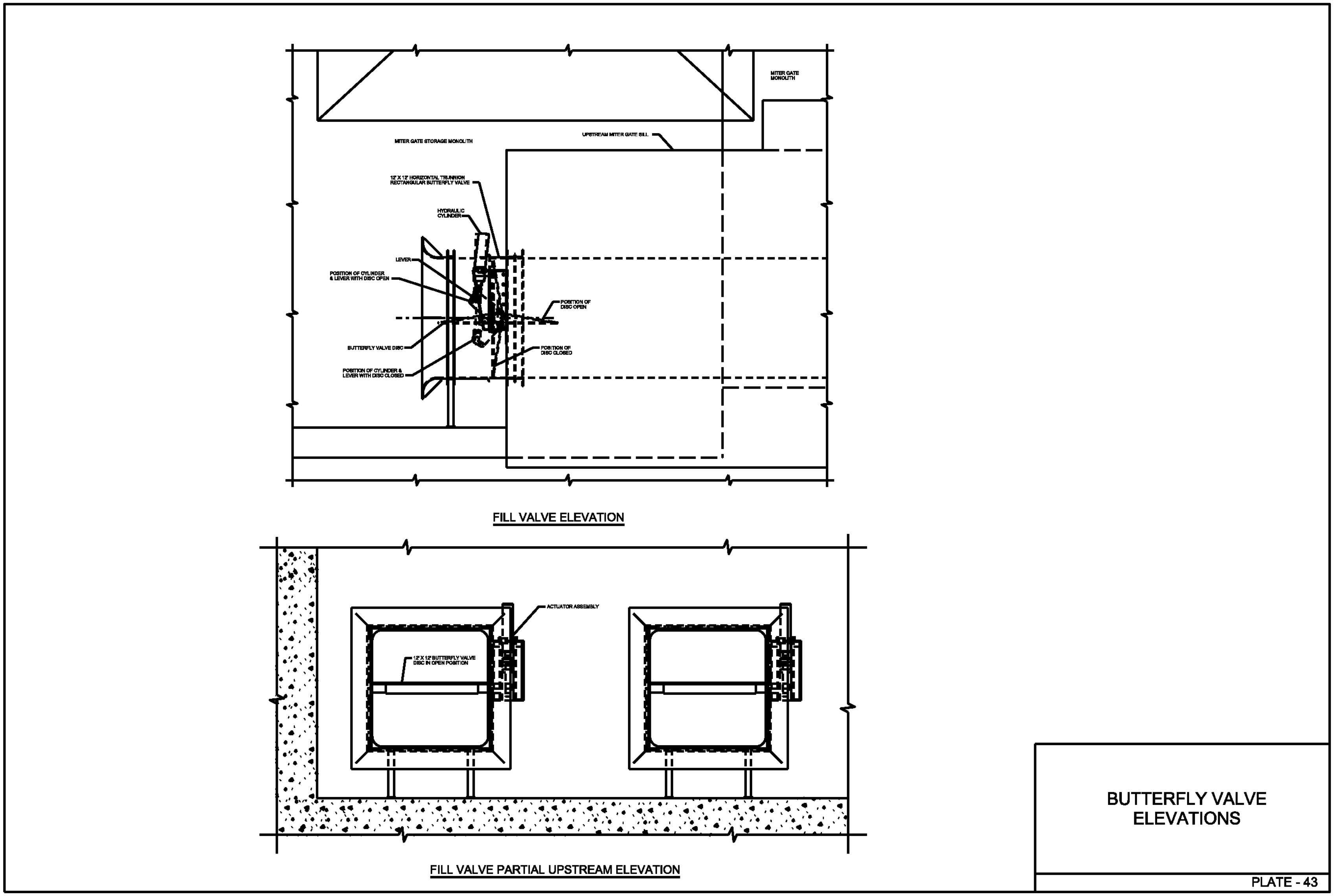


Figure B–43. Plate 43: Butterfly valve elevations

B–8. Vertical lift gates

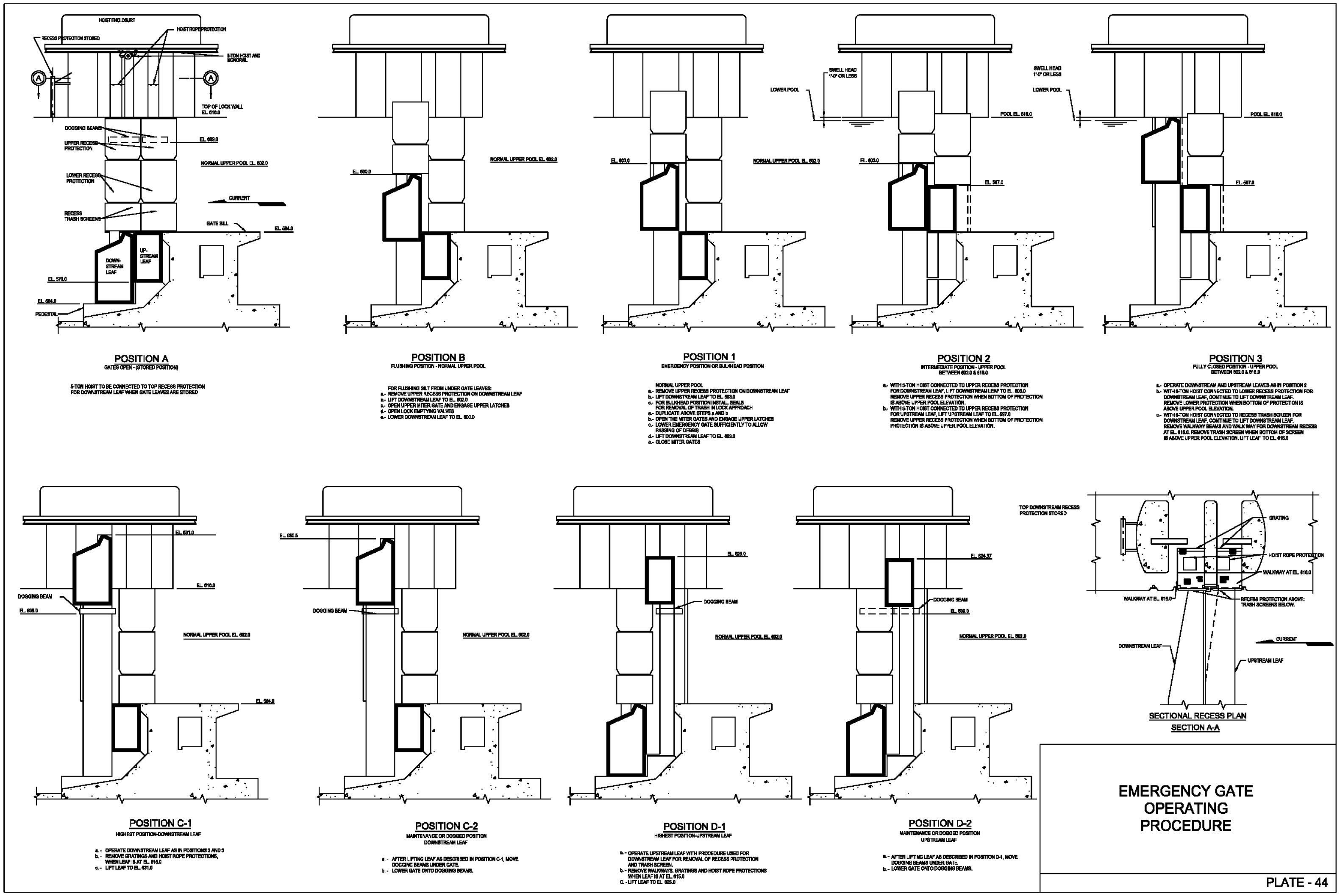


Figure B–44. Plate 44: Emergency gate operating procedure

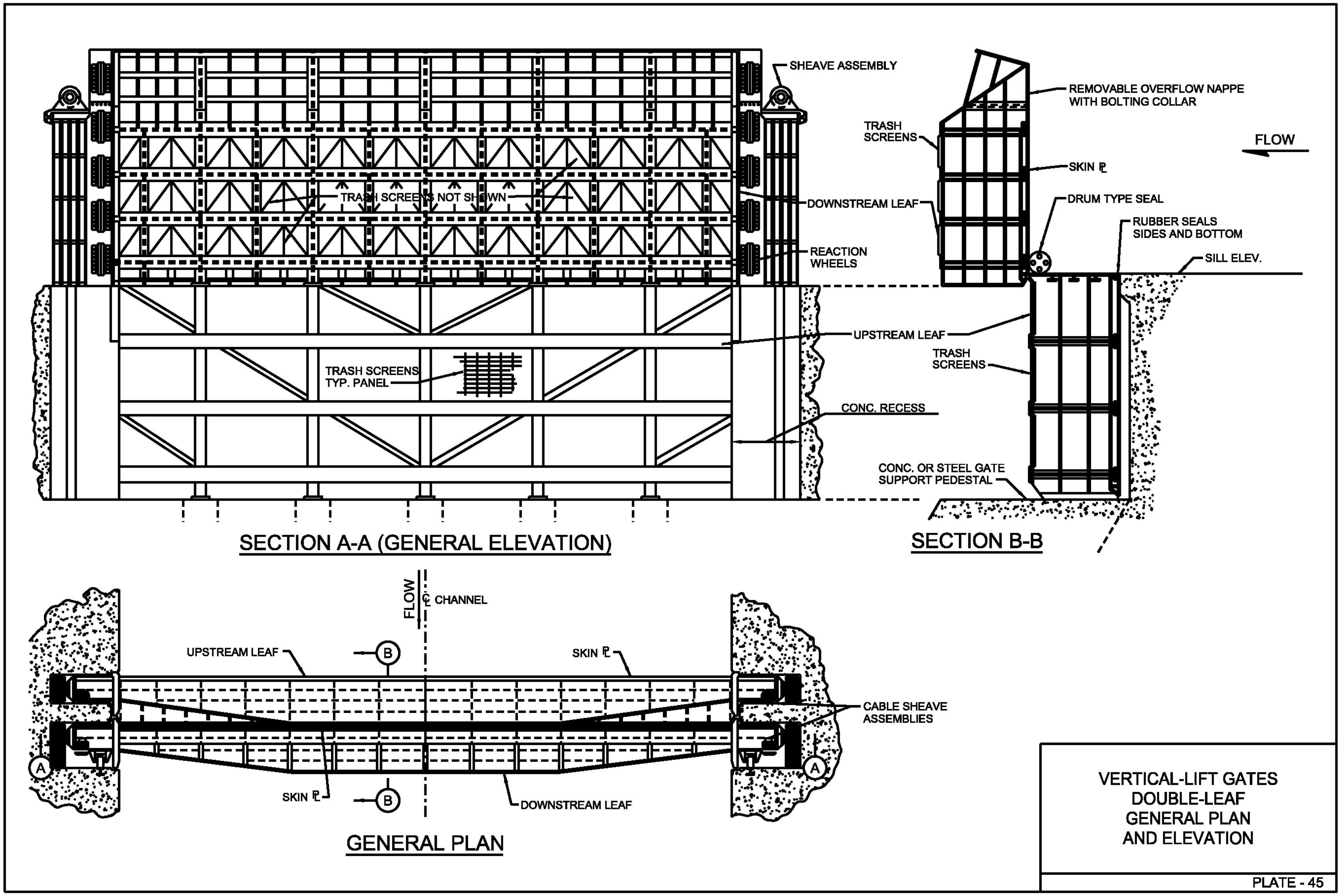


Figure B–45. Plate 45: Vertical-lift gates, double-leaf, general plan, and elevation

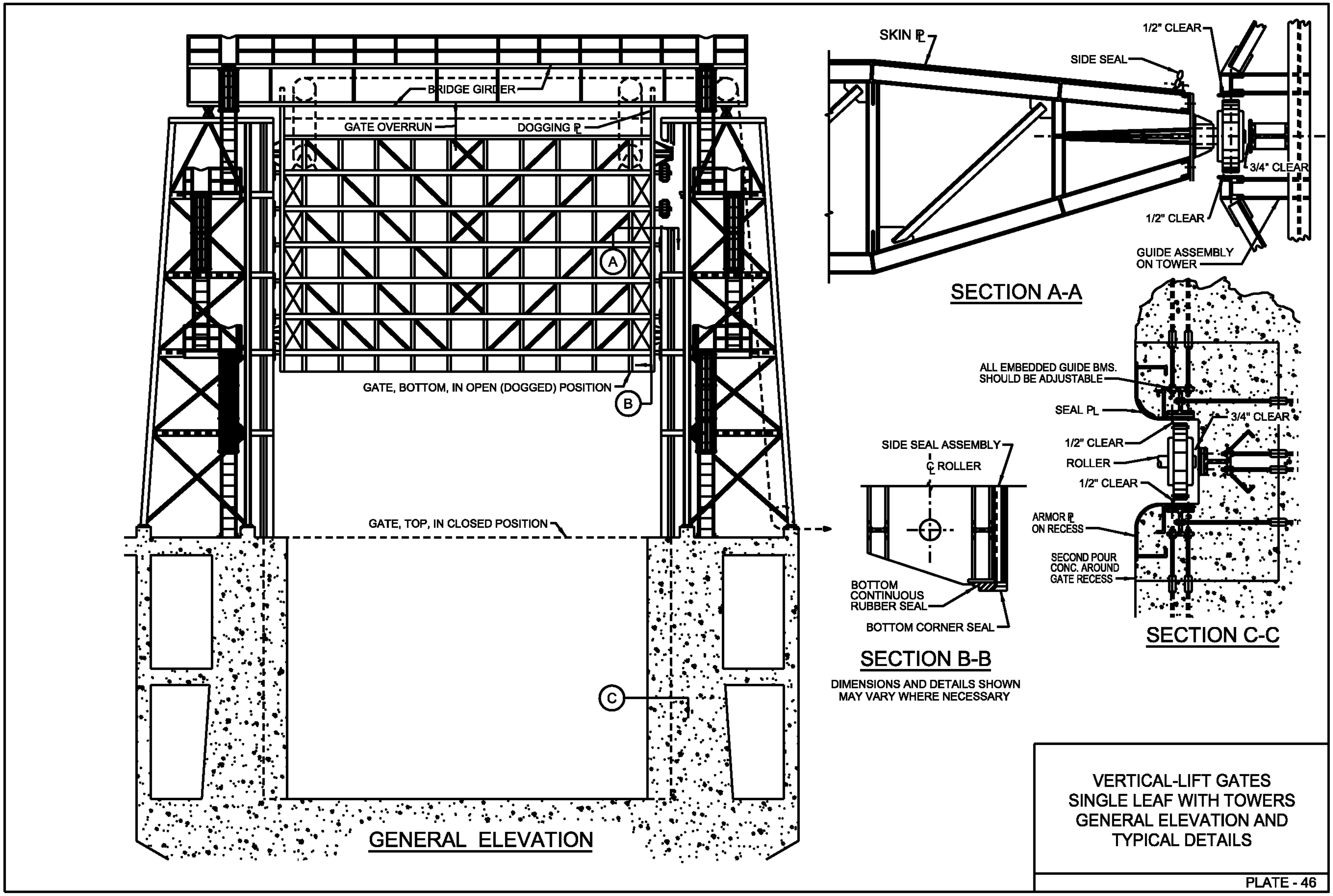


Figure B–46. Plate 46: Vertical-lift gates, single leaf with towers, general elevation, and typical details

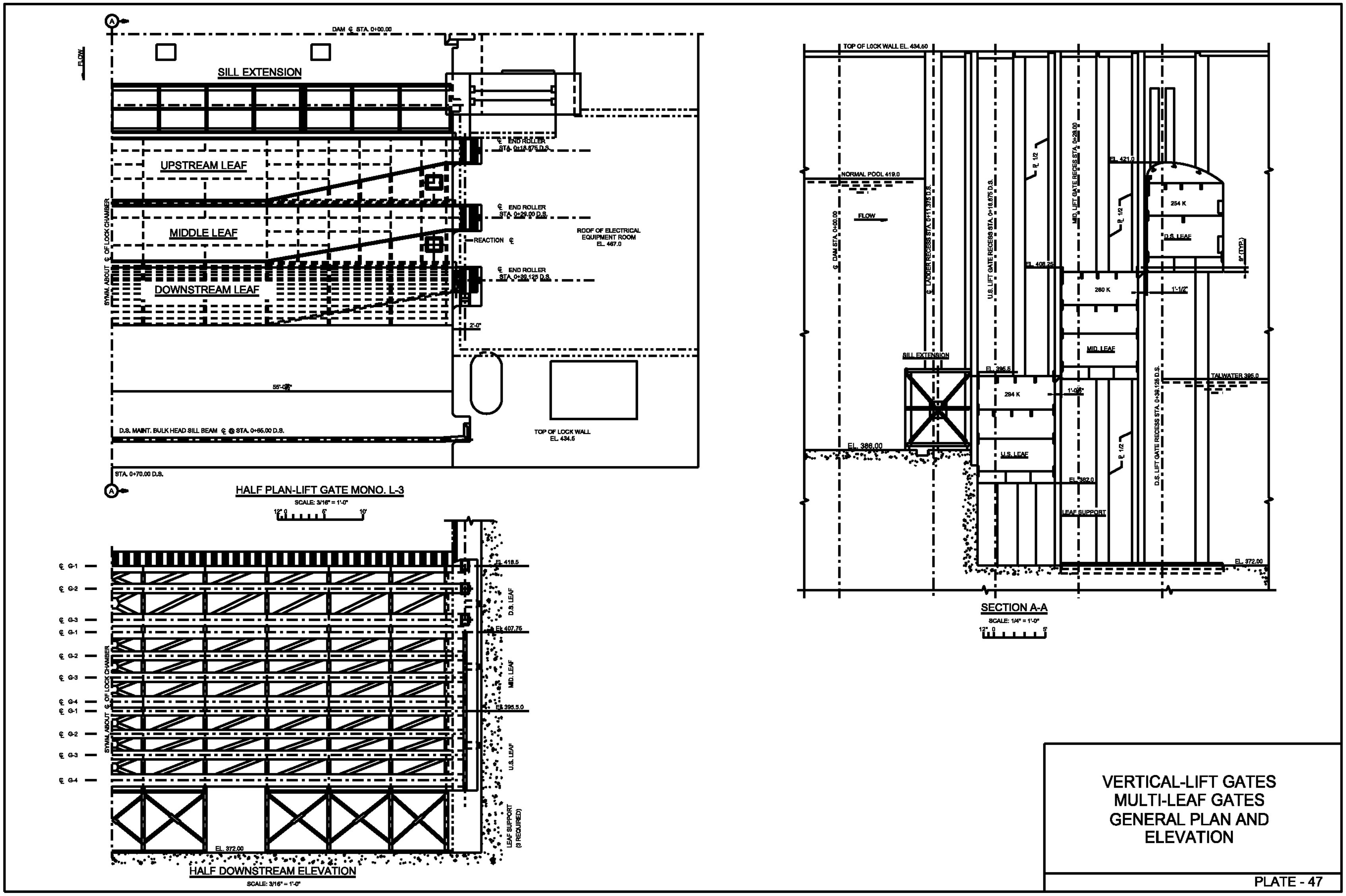


Figure B–47. Plate 47: Vertical-lift gates, multi-leaf gates, general plan, and elevation

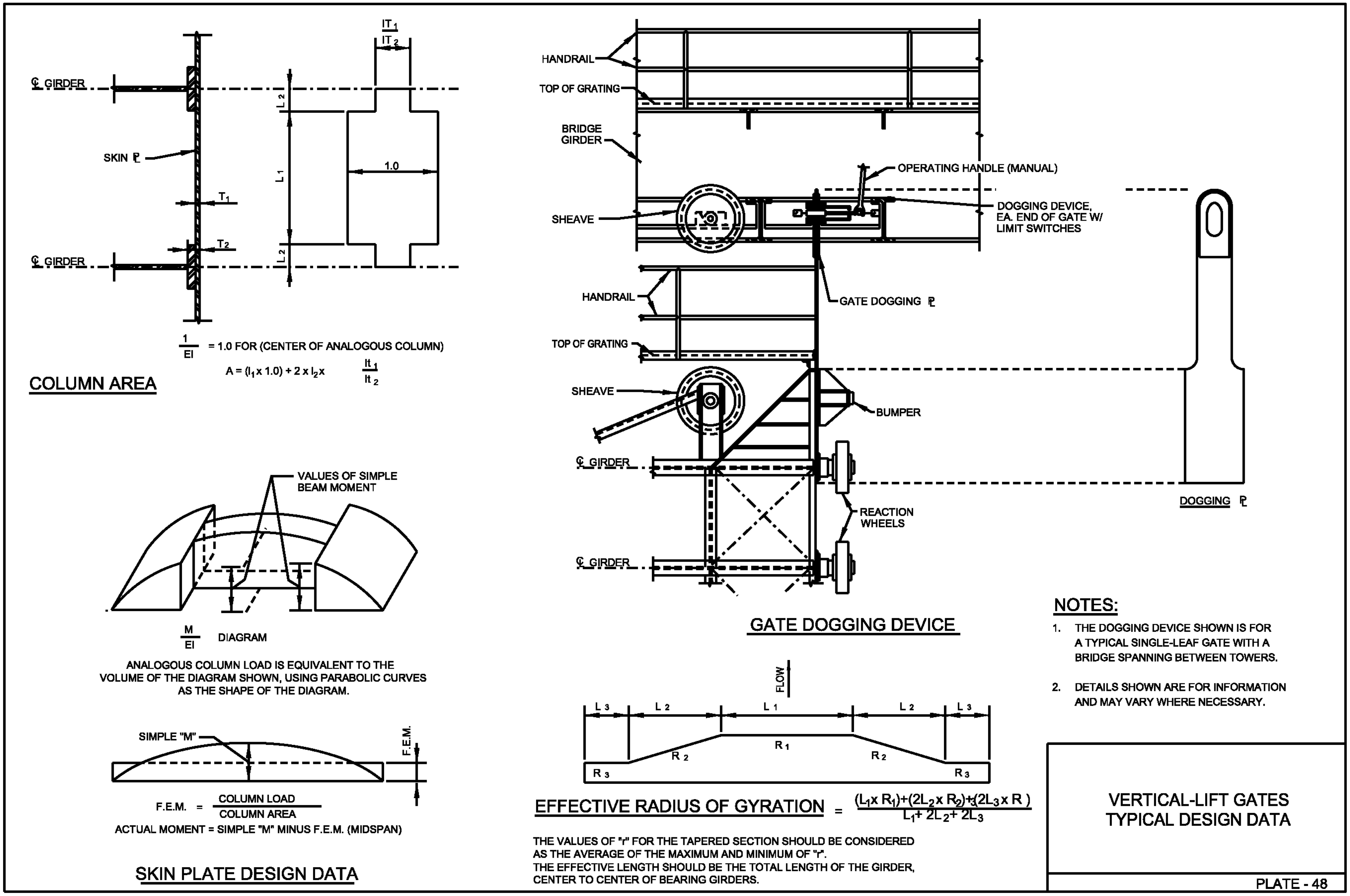


Figure B–48. Plate 48: Vertical-lift gates, typical design data

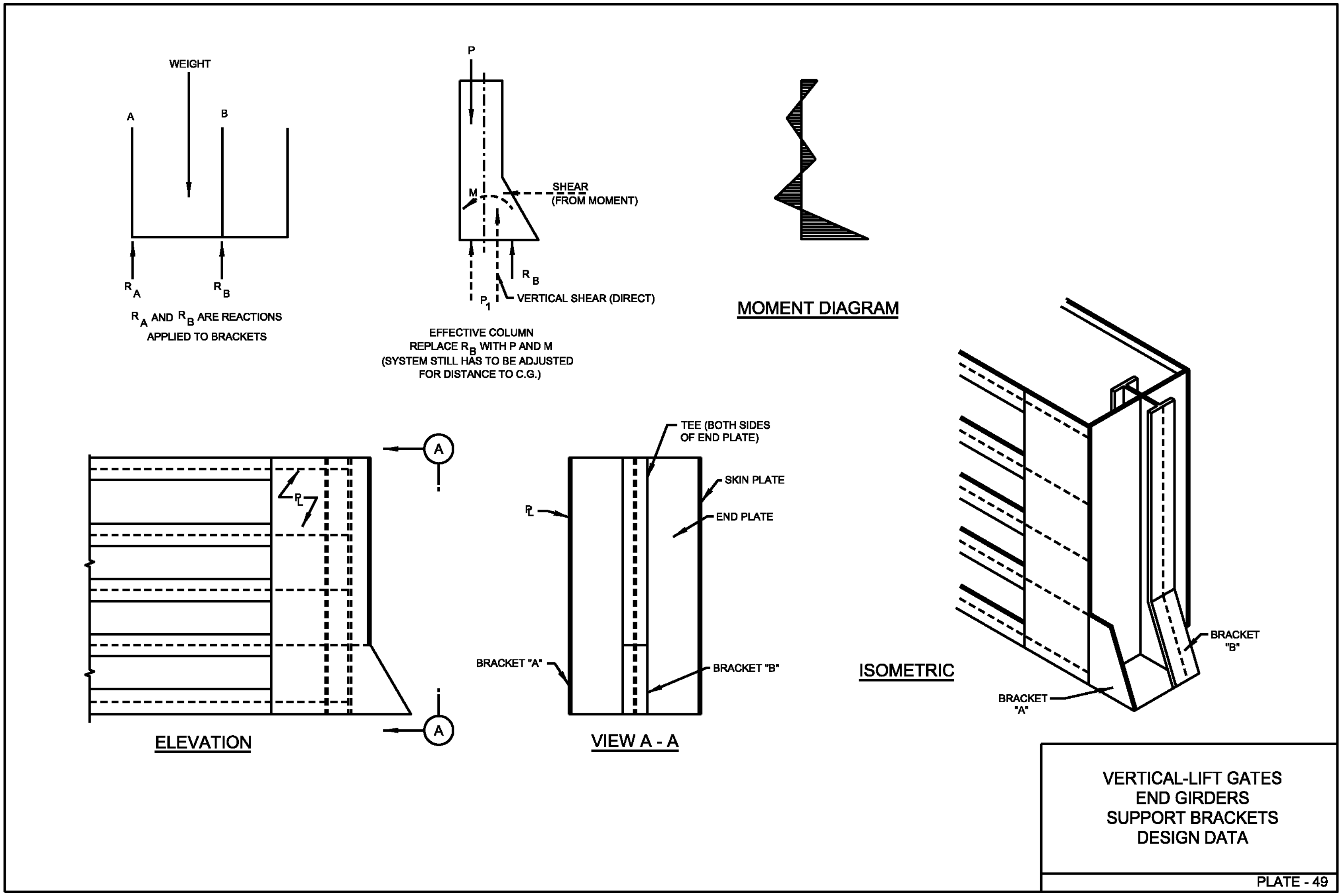


Figure B–49. Plate 49: Vertical-lift gates, end girders, support brackets, design data

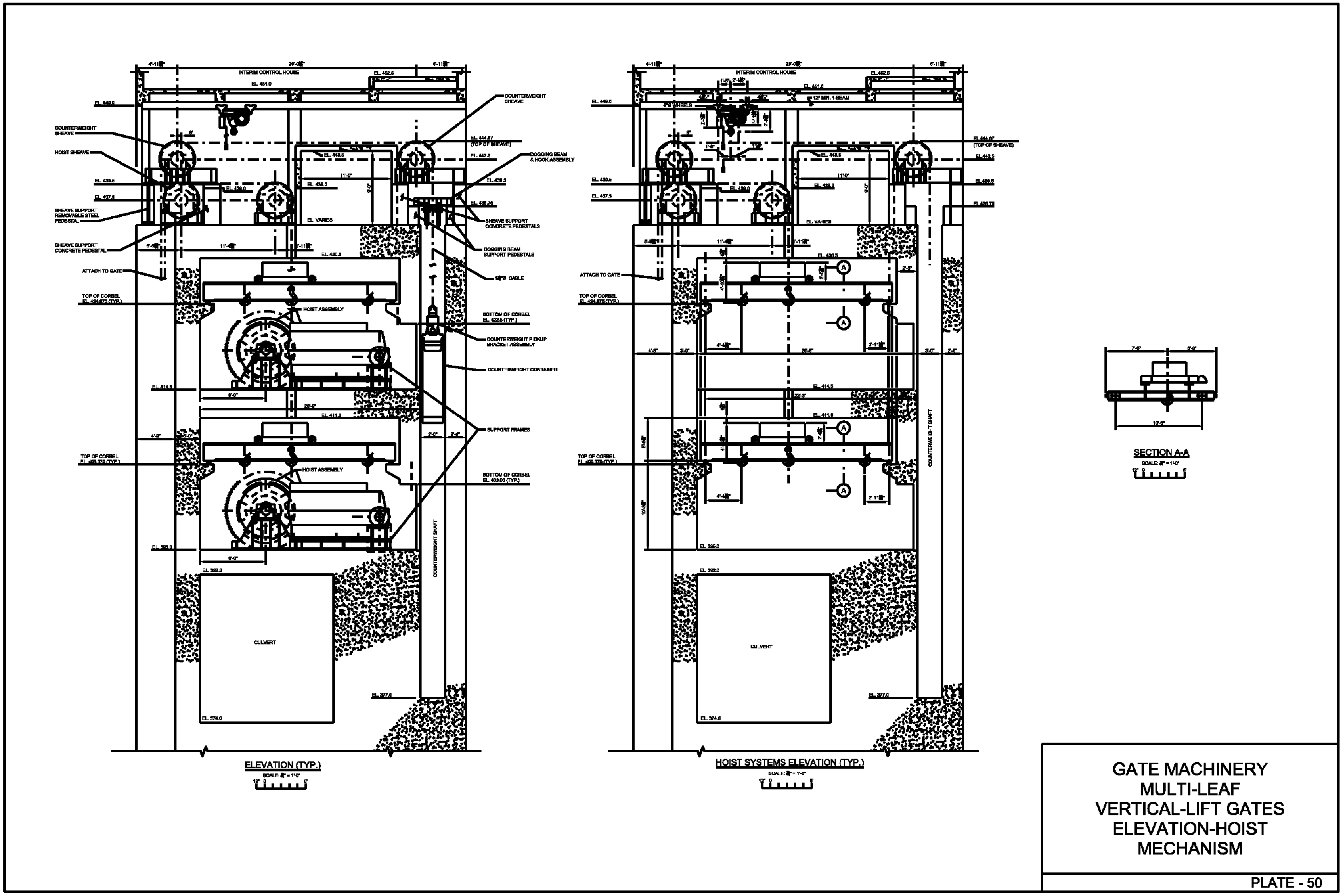
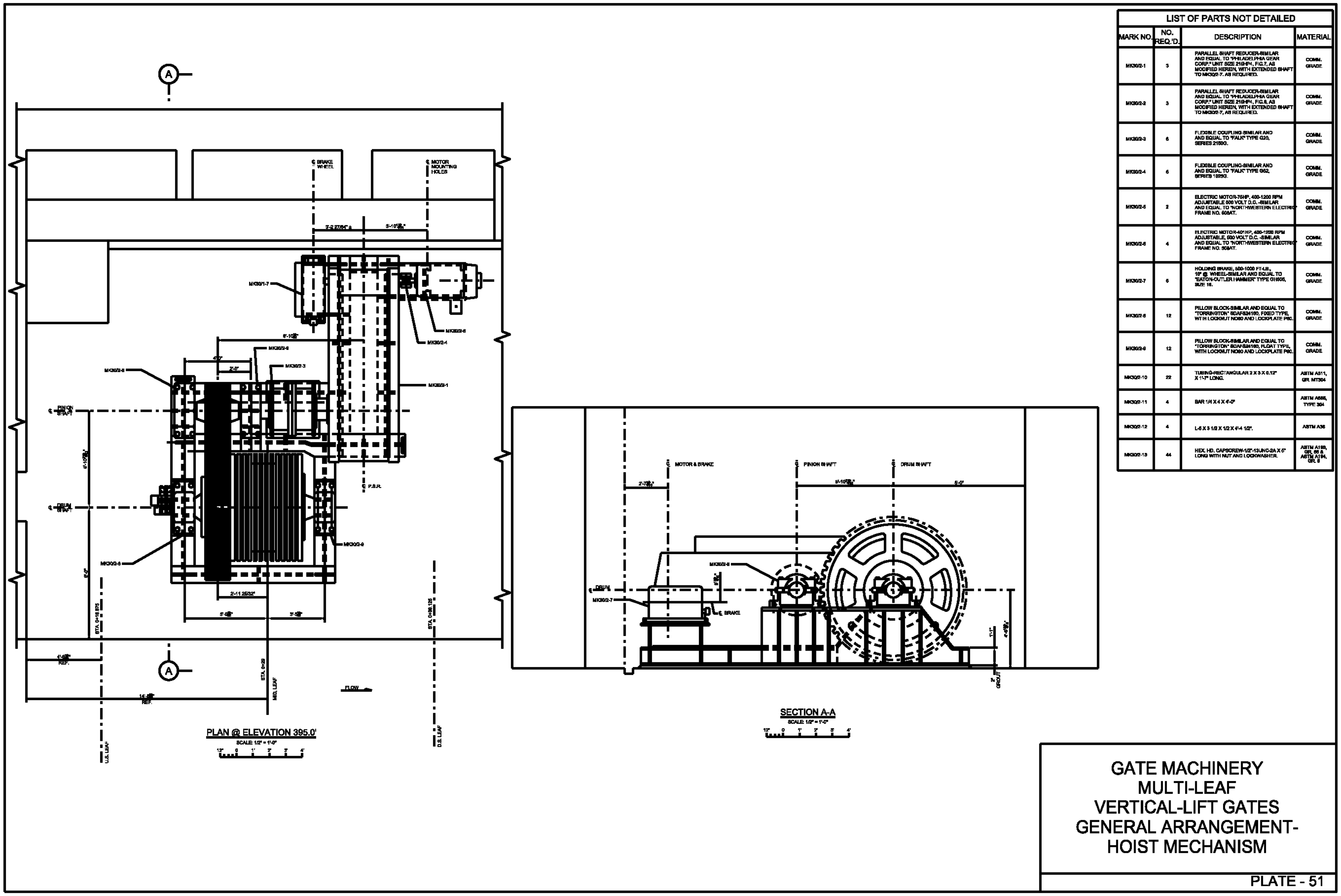


Figure B–50. Plate 50: Gate machinery, multi-leaf, vertical-lift gates, elevation-hoist mechanism



LIST OF PARTS NOT DETAILED			
MARK NO.	NO. REQ.'D.	DESCRIPTION	MATERIAL
MK30/2-1	3	PARALLEL SHAFT REDUCER-SIMILAR AND EQUAL TO "PHILADELPHIA GEAR CORP." UNIT SIZE 216HP4, FIG.7, AS MODIFIED HEREIN, WITH EXTENDED SHAFT TO MK30/2-7. AS REQUIRED.	COMM. GRADE
MK30/2-2	3	PARALLEL SHAFT REDUCER-SIMILAR AND EQUAL TO "PHILADELPHIA GEAR CORP." UNIT SIZE 216HP4, FIG.8, AS MODIFIED HEREIN, WITH EXTENDED SHAFT TO MK30/2-7, AS REQUIRED.	COMM. GRADE
MK30/2-3	6	FLEXIBLE COUPLING-SIMILAR AND AND EQUAL TO "FALK" TYPE G20, SERIES 2150G.	COMM. GRADE
MK30/2-4	6	FLEXIBLE COUPLING-SIMILAR AND AND EQUAL TO "FALK" TYPE G52, SERIES 1025G.	COMM. GRADE
MK30/2-5	2	ELECTRIC MOTOR-75HP, 400-1200 RPM ADJUSTABLE 500 VOLT D.C. -SIMILAR AND EQUAL TO "NORTHWESTERN ELECTRIC" FRAME NO. 508AT.	COMM. GRADE
MK30/2-6	4	ELECTRIC MOTOR-401HP, 400-1200 RPM ADJUSTABLE, 500 VOLT D.C. -SIMILAR AND EQUAL TO "NORTHWESTERN ELECTRIC" FRAME NO. 508AT.	COMM. GRADE
MK30/2-7	6	HOLDING BRAKE, 500-1000 FT-LB., 16" ⌀ WHEEL-SIMILAR AND EQUAL TO "EATON-CUTLER HAMMER" TYPE GH505, SIZE 16.	COMM. GRADE
MK30/2-8	12	PILLOW BLOCK-SIMILAR AND EQUAL TO "TORRINGTON" SDAFS24160, FIXED TYPE, WTIH LOCKNUT NO80 AND LOCKPLATE P80.	COMM. GRADE
MK30/2-9	12	PILLOW BLOCK-SIMILAR AND EQUAL TO "TORRINGTON" SDAFS24160, FLOAT TYPE, WITH LOCKNUT NO80 AND LOCKPLATE P80.	COMM. GRADE
MK30/2-10	22	TUBING-RECTANGULAR 2 X 3 X 0.12" X 1'-7" LONG.	ASTM A511, GR. MT304
MK30/2-11	4	BAR 1/4 X 4 X 4'-0"	ASTM A666, TYPE 304
MK30/2-12	4	L-6 X 3 1/2 X 1/2 X 4'-4 1/2".	ASTM A36
MK30/2-13	44	HEX. HD. CAPSCREW-1/2"-13UNC-2A X 5" LONG WITH NUT AND LOCKWASHER.	ASTM A193, GR. B6 & ASTM A194, GR. 6

Figure B–51. Plate 51: Gate machinery, multi-leaf vertical-lift gates, general arrangement-hoist mechanism

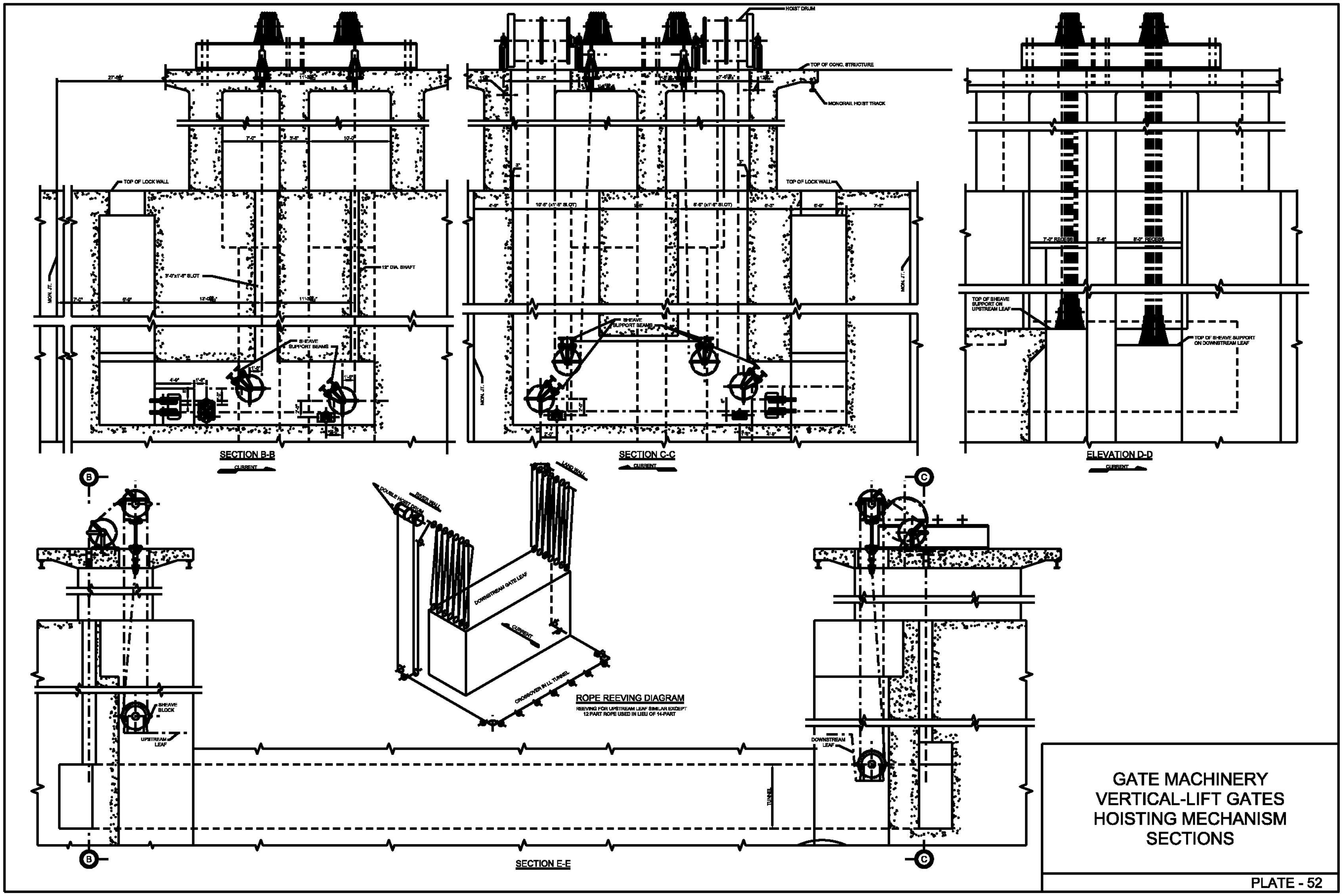


Figure B–52. Plate 52: Gate machinery, vertical-lift gates, hoisting mechanism sections

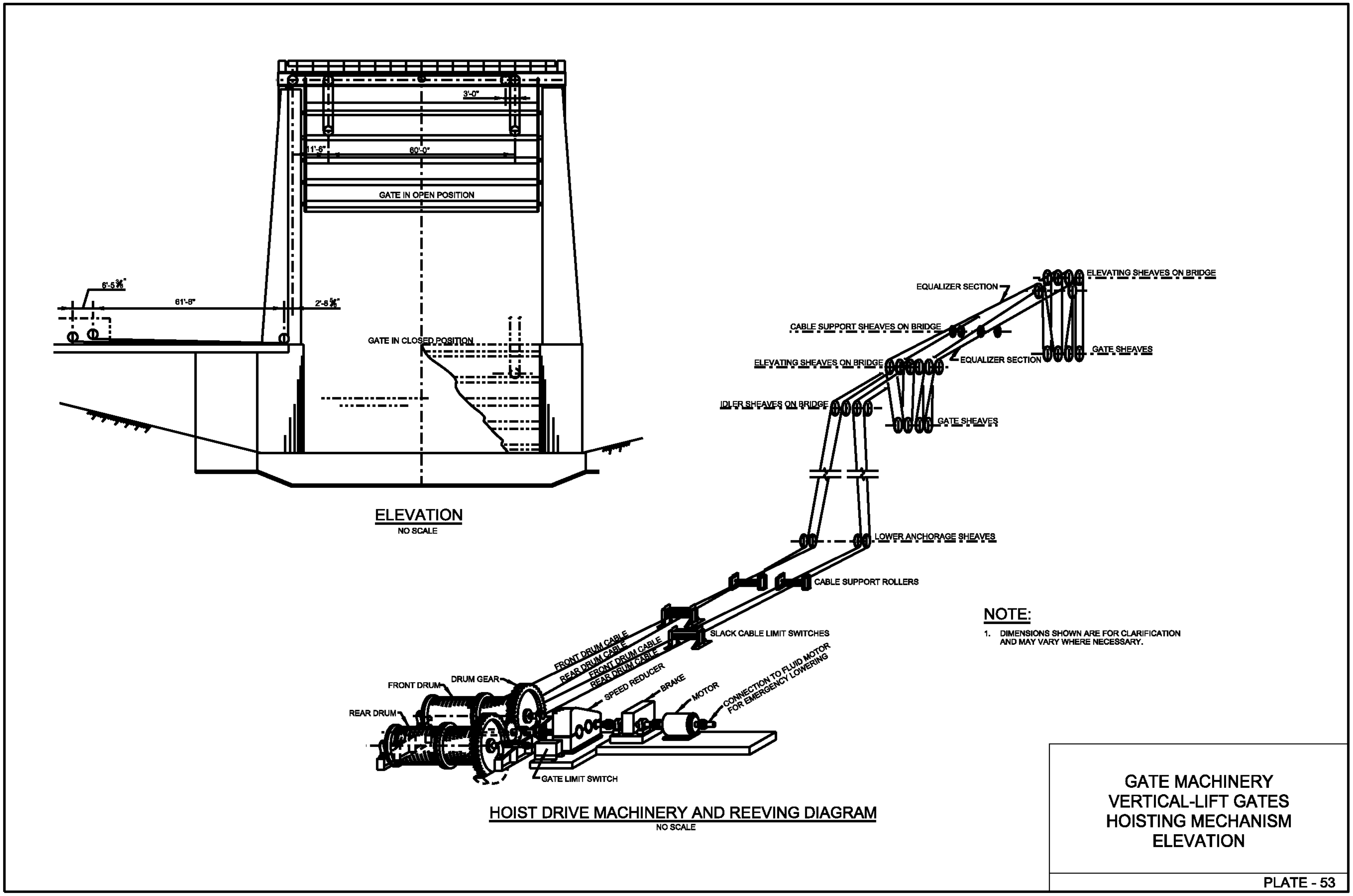


Figure B–53. Plate 53: Gate machinery, vertical-lift gates, hoisting mechanism elevation

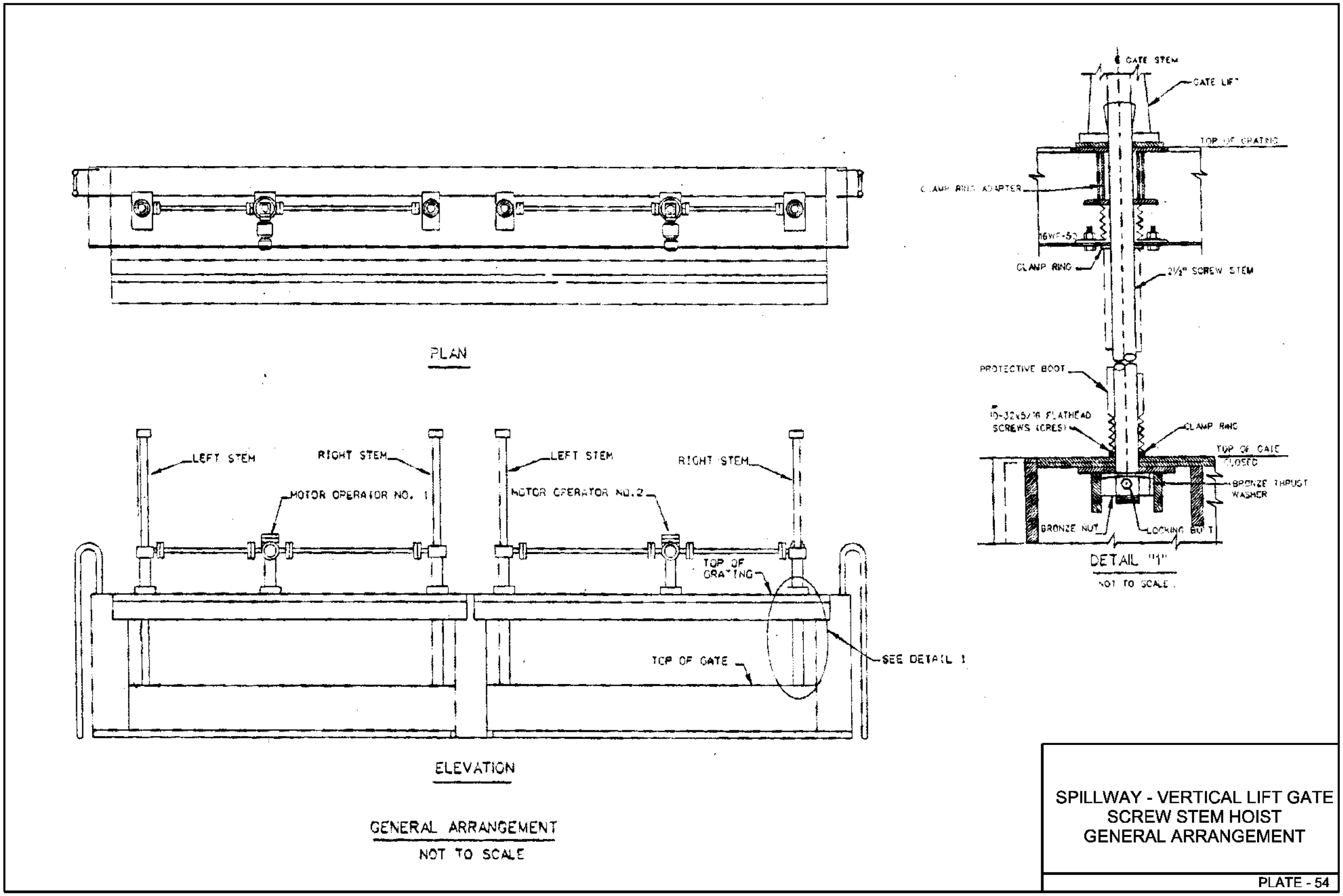


Figure B–54. Plate 54: Spillway – vertical lift gate, screw stem hoist general arrangement

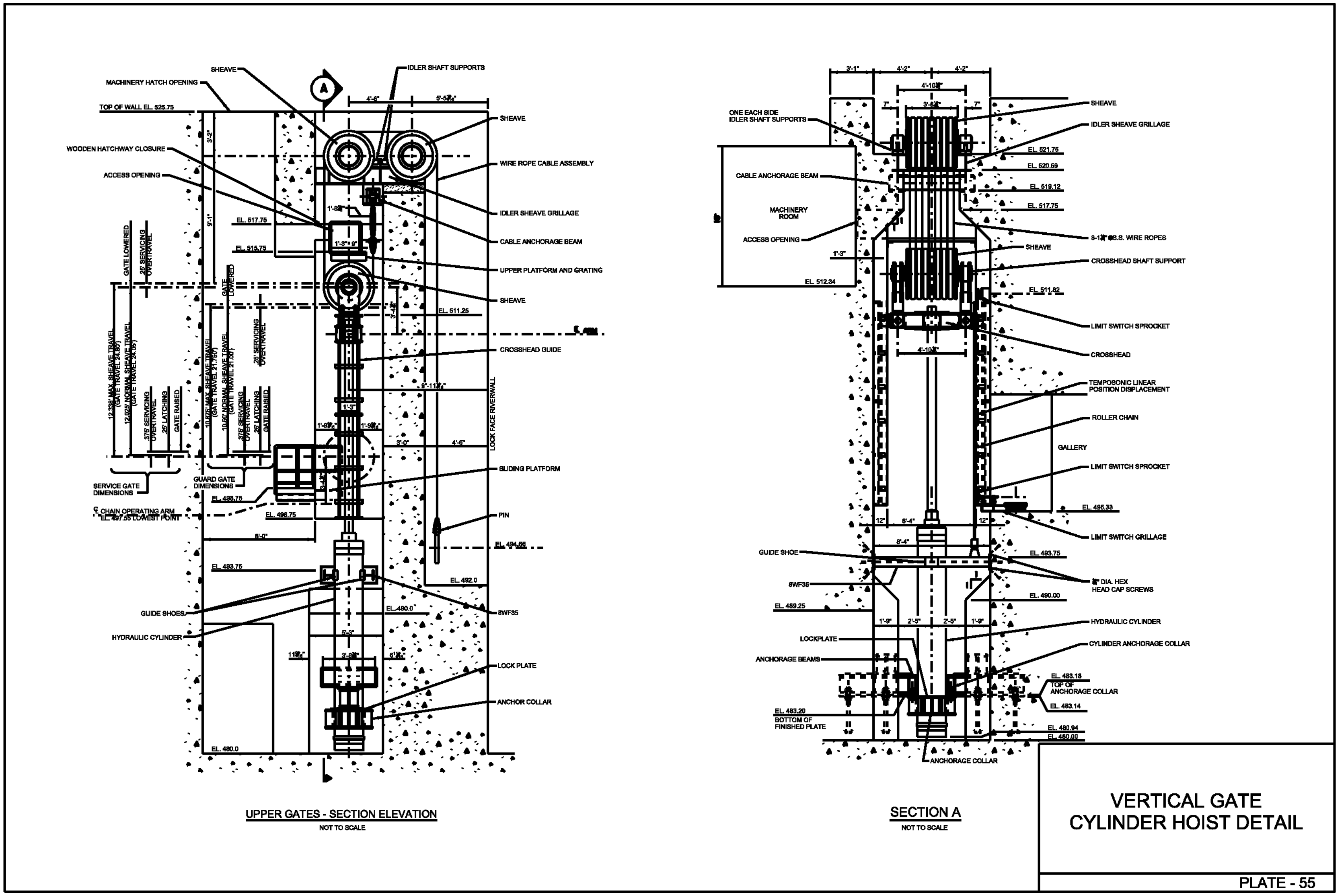
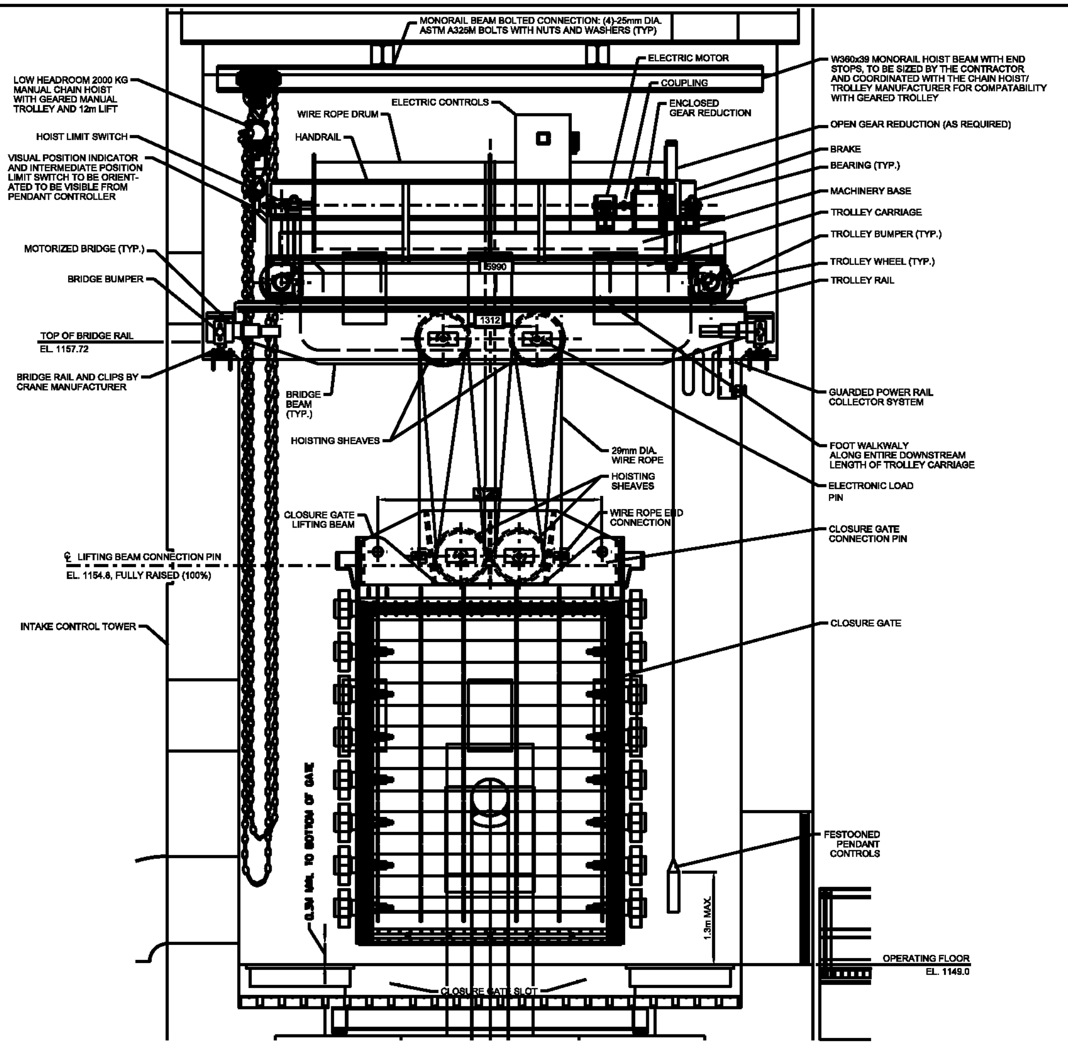


Figure B–55. Plate 55: Vertical gate cylinder hoist detail



BRIDGE CRANE ELEVATION

NOTES:

1. THE DIMENSIONS SHOWN ARE APPROXIMATE. THE CONTRACTOR SHALL BE RESPONSIBLE TO COORDINATE WITH ALL EQUIPMENT MANUFACTURER'S DIMENSIONS OF FURNISHED EQUIPMENT FOR INSTALLATION AND LAYOUT.
2. ALL DIMENSIONS ENCLOSED IN RECTANGLE ARE DEPENDENT UPON THE OVERHEAD BRIDGE CRANE MANUFACTURER'S DESIGN AND SHALL BE COORDINATED AND IDENTIFIED IN THE SHOP DRAWINGS FOR APPROVAL. SHEAVES SHALL BE STANDARD MANUFACTURER'S PRODUCTS AND SUITABLE FOR THE INTENDED LOADS.
3. THE CONTRACTOR SHALL BE RESPONSIBLE TO ADJUST THE LOCATION OF THE HOISTING SHEAVES AND WIRE ROPE CONNECTIONS FOR THE GATE TO HANG VERTICALLY DURING HOISTING OPERATIONS.
4. THE CRANE MANUFACTURER SHALL DESIGN AND FURNISH A LOAD PIN IN THE CRANE REEVING SYSTEM TO CONTINUOUSLY MONITOR LOAD DURING HOISTING OPERATIONS. THE LOAD PIN SHALL BE EQUIPPED WITH ELECTRIC RELAYS AND INCORPORATED INTO THE CRANE CONTROL CIRCUIT TO TERMINATE CRANE OPERATION IN THE EVENT OF UNDERLOAD (SLACK CABLE) AND OVERLOAD.
5. THE CRANE MANUFACTURER SHALL DESIGN AND FURNISH TWO (2) CLOSURE GATE LIFTING BEAMS SIMILAR AS SHOWN HEREIN. ANY PROPOSED MODIFICATIONS TO THE CLOSURE GATE CONNECTION DIMENSIONS OR LOCATION SHALL BE COORDINATED AND SUBMITTED IN THE SHOP.
6. THE BRIDGE CRANE WIRE ROPE DRUM AND HOISTING SHEAVE SIZES AND LOCATIONS SHALL BE DEPENDENT UPON THE CRANE MANUFACTURER'S DESIGN. MINIMUM BENDING RADIUS FOR THE WIRE ROPE SHALL NOT BE EXCEEDED AND IN ACCORDANCE WITH THE SPECIFICATIONS. THE DRUM LENGTH AND DIAMETER SHALL BE DESIGNED TO REEVE THE ENTIRE LENGTH OF WIRE ROPE NECESSARY TO ACHIEVE THE REQUIRED LIFT AND MAINTAIN SPECIFIED FLEET ANGLES WITHOUT THE WIRE ROPE INTERFERING WITH THE CRANE BRIDGE, CLOSURE GATE SLOT AT THE OPERATING FLOOR, OR ANY PORTION OF THE INTAKE CONTROL TOWER STRUCTURE.
7. FABRICATE AND FURNISH TWO (2) COMPLETE AND FULLY FUNCTIONAL CLOSURE GATE LIFTING BEAM ASSEMBLIES. ONE LIFTING BEAM ASSEMBLY SHALL BE MAINTAINED AS A SPARE AND PREPARED FOR LONG-TERM STORAGE ON SITE.
8. THE CONTRACTOR SHALL FURNISH SUFFICIENT LENGTH OF SPARE WIRE ROPE ON SPOOL(S) TO COMPLETELY REPLACE THE WIRE ROPE FURNISHED WITH THE BRIDGE CRANE. WIRE ROPE SHALL BE PREPARED FOR LONG-TERM STORAGE ON SITE.
9. THE CHAIN HOIST TROLLEY MANUFACTURER SHALL FURNISH A MONORAIL HOIST BEAM SUITABLE FOR THE TROLLEY OPERATION AND SIZED TO PROVIDE A MAXIMUM BEAM DEFLECTION OF 5mm WITH THE DESIGN LOAD LOCATED AT THE END OF MONORAIL BEAM TRAVEL. THE CONTRACTOR SHALL FURNISH AND INSTALL THE MONORAIL HOIST BEAM WITH AN ASTM A325M BOLTED CONNECTION TO THE GATE TOWER ROOF BEAMS. THE CONTRACTOR SHALL DRILL AND INSTALL (8)-25mm DIA. BOLTS, NUTS AND WASHERS THROUGH THE FLANGE INTERFACE (EACH SIDE) OF EACH ROOF BEAM TO ESTABLISH THE CONNECTION. THE BEAMS SHALL BE FIELD DRILLED FOR THE INSTALLATION TO LOCATE THE MONORAIL IN THE APPROXIMATE POSITION AND TO MAXIMIZE ACCESSIBILITY FOR OVERHEAD BRIDGE CRANE MAINTENANCE.

CRANE DESIGN CRITERIA		
RATED CAPACITY	1112 KN	250,000 lbs
HOISTING SPEED	5.0-19.1 mm/s	0.98 - 3.75 ft/min
LIFTING BEAM TRAVEL	61 m	200 ft
LIFTING BEAM UPPER LIMIT - CL PIN	1154.6 m	3784.4 ft
LIFTING BEAM LOWER LIMIT - CL PIN	1095.8 m	3591.5 ft
MAX. HOIST MOTOR POWER	7.4 kw	10 HP
MAX. BRIDGE ENDTRUCK MOTOR POWER	3.0 kw	4 HP
MAX. TROLLEY MOTOR POWER	3.0 kw	4 HP
TROLLEY MAX. TRAVEL	1.43 m	4.69 ft
TROLLEY MAX. SPEED	5.0 -10.0 mm/s	0.98 - 1.97 ft/min
TROLLEY MAX. SPAN	2.07 m	6.8 ft
BRIDGE MAX. TRAVEL	2.49 m	8.18 ft
BRIDGE MAX. SPEED	5.0 - 13.0 mm/s	0.98 - 2.56 ft/min
BRIDGE MAX. SPAN	7.48 m	24.54 ft

TRACTOR GATE DETAIL

PLATE - 56

Figure B–56. Plate 56: Tractor gate detail

B–9. Tainter gates

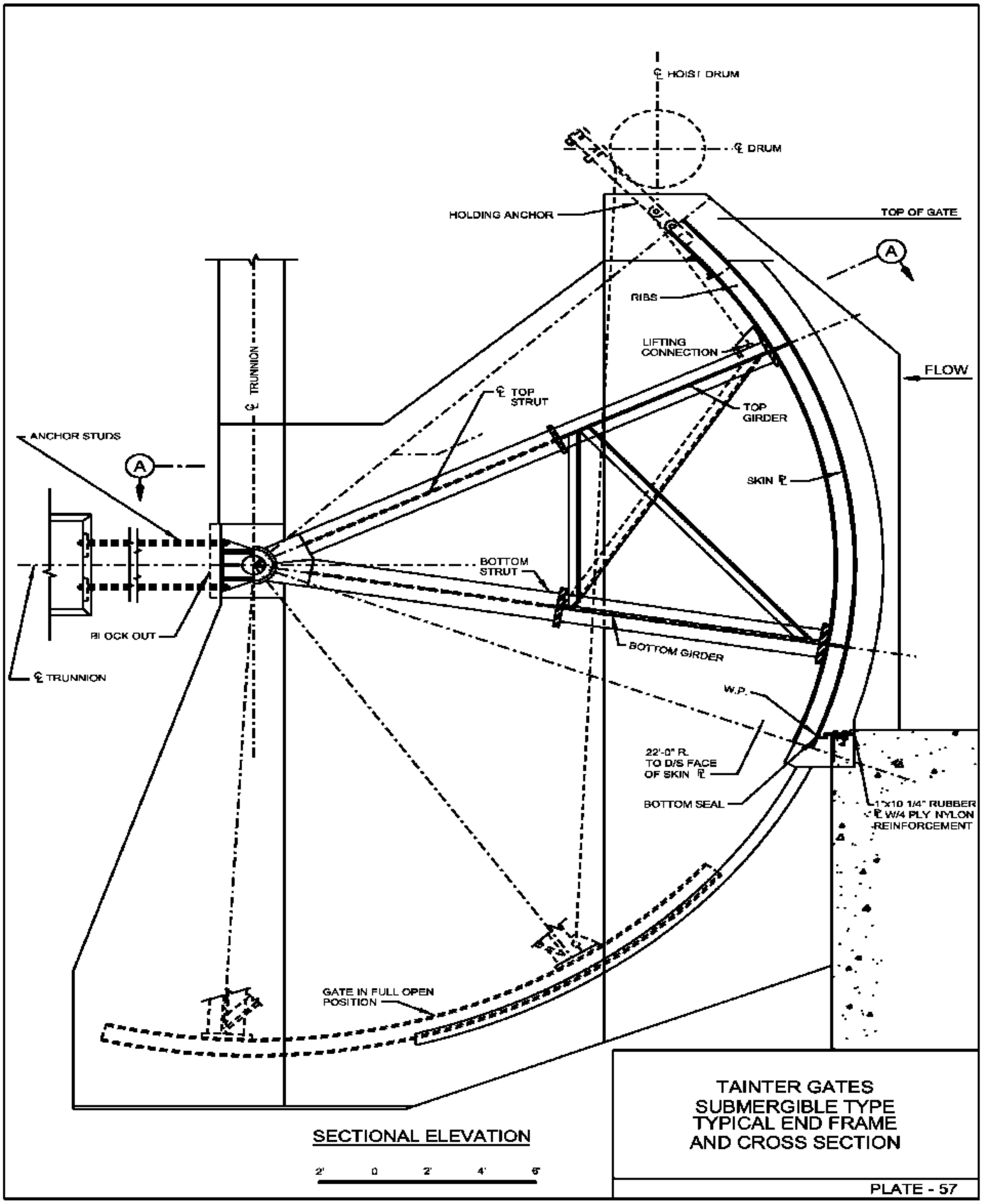


Figure B–57. Plate 57: Tainter gates, submergible type, typical end frame and cross section

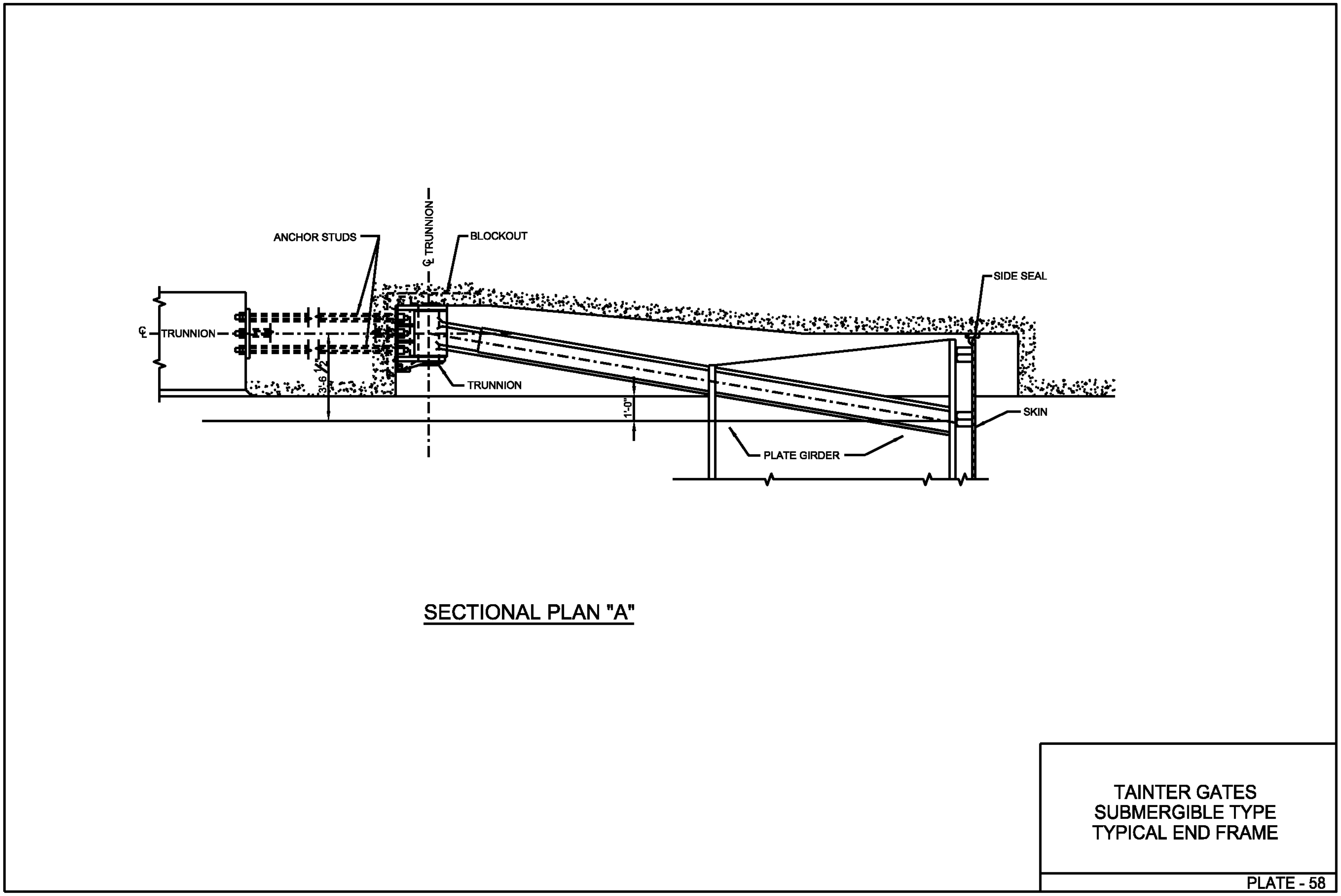


Figure B–58. Plate 58: Tainter gates, submergible type, typical end frame

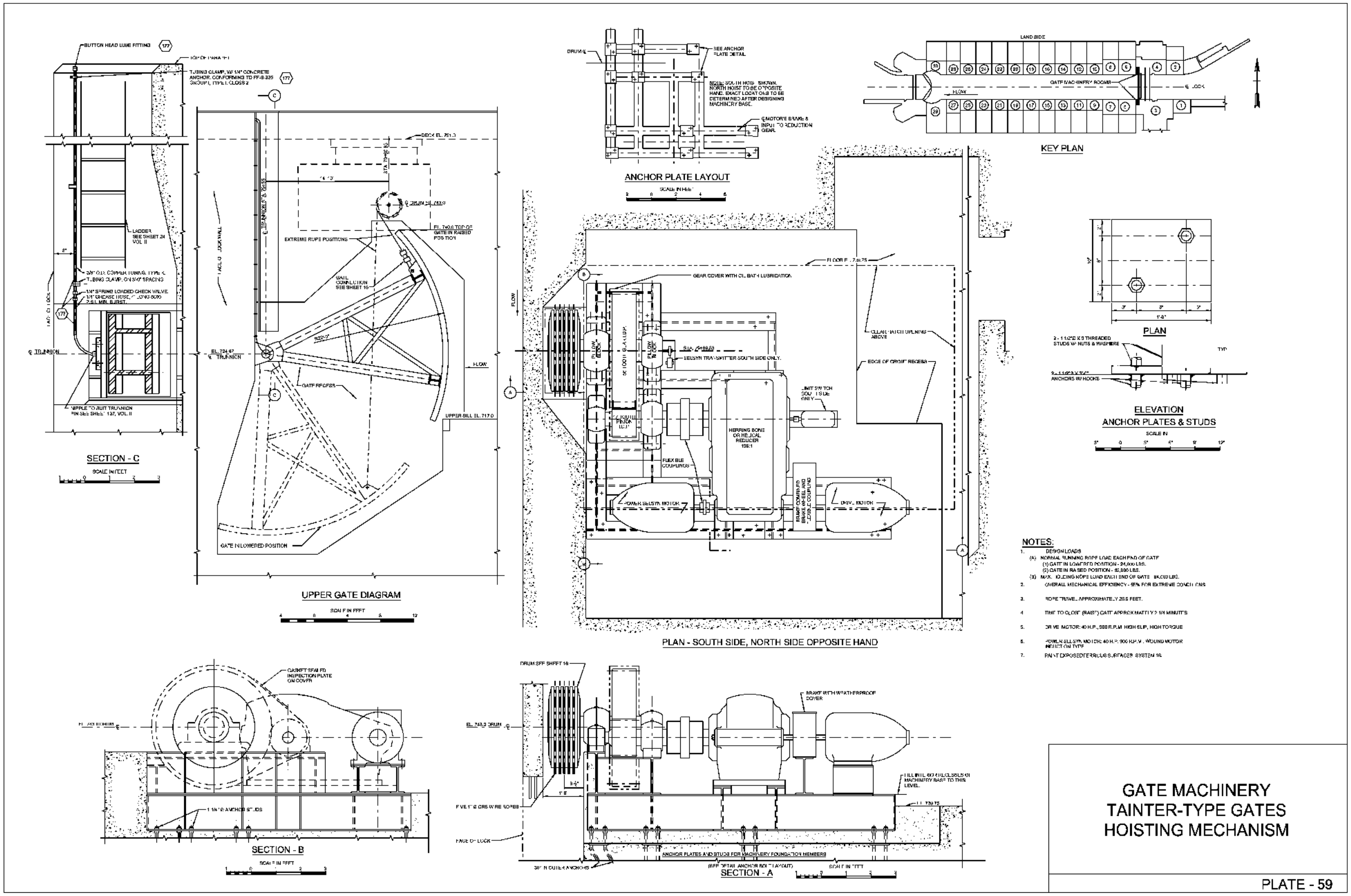


Figure B–59. Plate 59: Gate machinery, tainter-type gates, hoisting mechanism

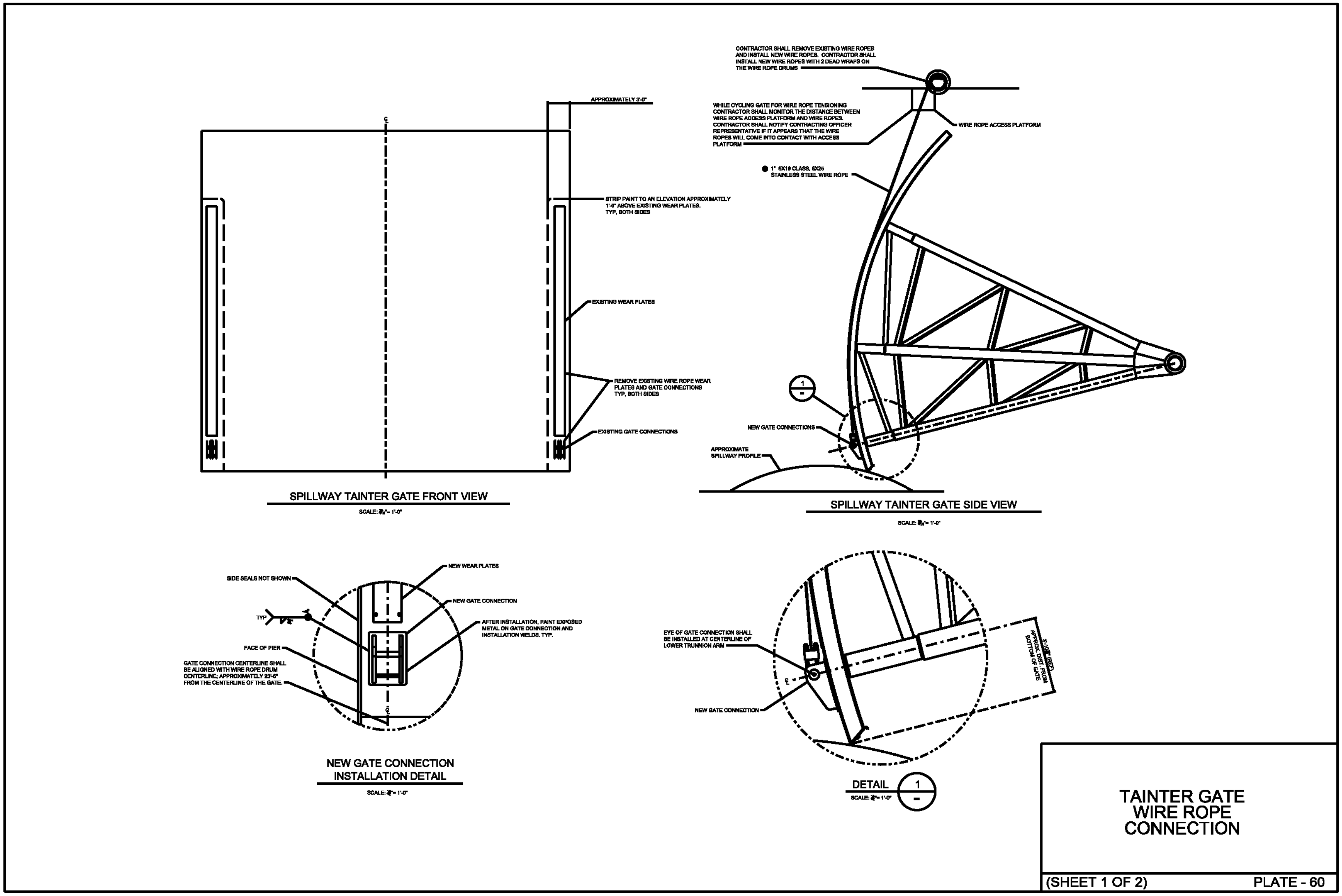


Figure B–60. Plate 60: Tainter gate wire rope connection (sheet 1 of 2)

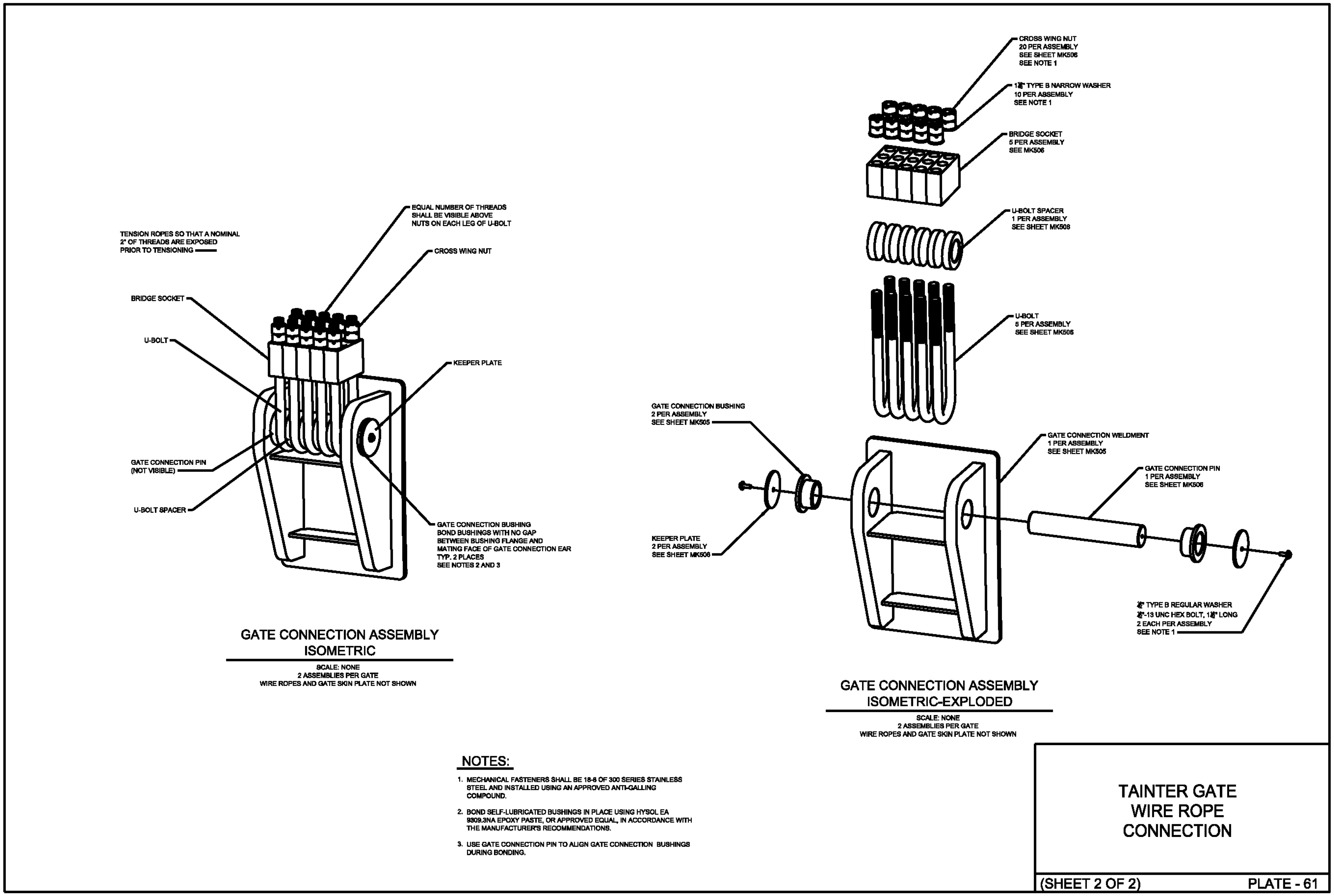


Figure B–61. Plate 61: Tainter gate wire rope connection (sheet 2 of 2)

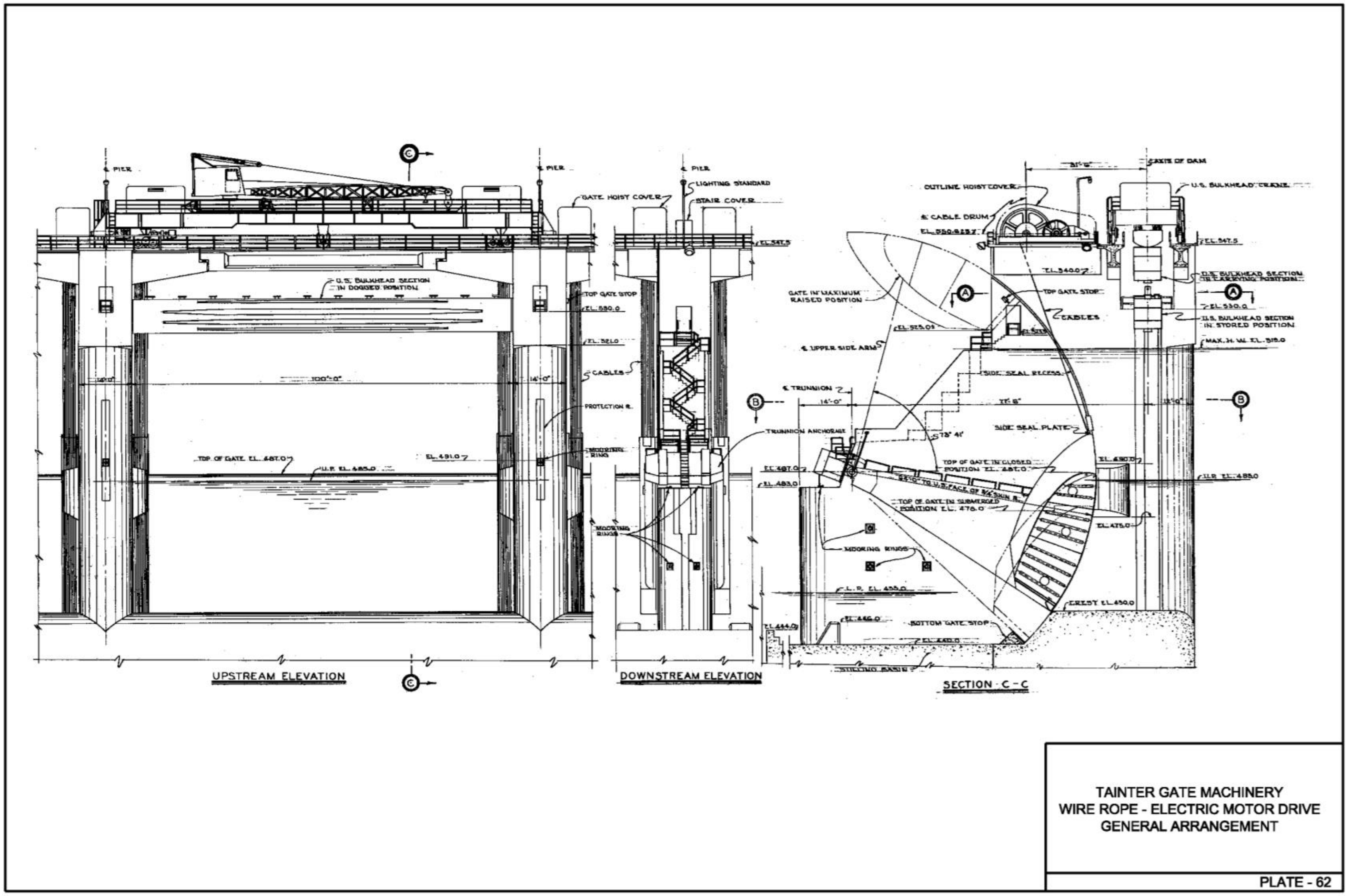
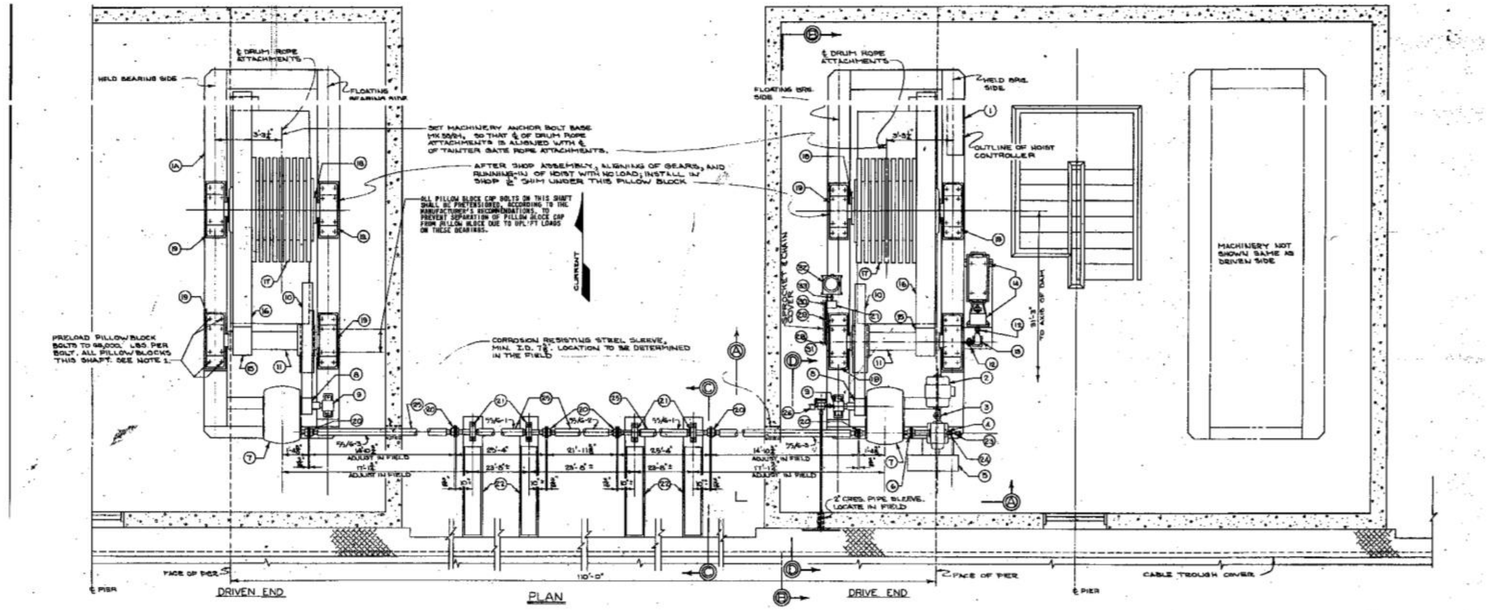


Figure B–62. Plate 62: Tainter gate machinery, wire rope-electric motor drive, general arrangement



MARK	ITEM	DESCRIPTION
1	MACHINERY BASE - DRIVE END	SEE DWG. NO. 55/7
1A	MACHINERY BASE - DRIVEN END	SEE DWG. NO. 55/8 .
2	HOIST MOTOR	25 HP @ 1800 R.P.M. 3 PHASE, 60 CYCLE, 460 V., 284 TS FRAME, DRIPPROOF, 8 REQ'D.
3	FLEXIBLE COUPLING	PHILADELPHIA GEAR, TYPE K, SIZE 3, OR EQUAL, 8 REQ'D.
4	WORM GEAR REDUCER	10.8 : 1 RATIO - PHILADELPHIA GEAR WORKS' TYPE A, SIZE 675, OR EQUAL, 8 REQ'D. WITH EXTENDED SHAFTS FOR CONNECTING TO 5, 7, 24
5	BRAKE	10" WHEEL 150 LB. FT. TORQUE, CONTINUOUS DUTY WITH WATER-TIGHT ENCLOSURE - WESTINGHOUSE TYPE TMH1035 OR EQUAL, 8 REQ'D.
6	FLEXIBLE COUPLING	PHILADELPHIA GEAR, TYPE K, SIZE 2½ OR EQUAL. 8 REQ'D.
7	DOUBLE REDUCER	PARALLEL SHAFT REDUCER, 34.2:1 RATIO. PHILADELPHIA GEAR WORKS HELICAL REDUCER UNIT 320, OR EQUAL, 8 REQ'D. WITH DOUBLE EXTENDED INPUT SHAFT AS PER. SPECS., 8 REQ'D WITH SINGLE STD. INPUT SHAFT, SEE 55/5 FOR OUTPUT SHAFT
8	REDUCER PINION	SEE DWG. NO. 55/5.
9	PILLOW BLOCK	CAST STEEL WITH SPHERICAL ROLLER BEARINGS, TORRINGTON SAFS-22309, WITH SPLIT STABILIZING RING, AND BRG. NO. [illegible] OR EQUAL, 16 REQ'D.
10	SMALL BULL GEAR	SEE DWG. NO. 55/5.
11	LG. BULL GEAR PINION SHAFT	SEE DWG. NO. 55/5.
12	FLEXIBLE COUPLING	BOSTON GEAR FCB825, OR EQUAL. 16 REQ'D.
13	SPIRAL GEAR SPEED REDUCER	PHILADELPHIA GEAR WORKS TYPE 3H38T, 1.84:1 RATIO, OR EQUAL. 8 REQ'D.
14	LIMIT SWITCH WITH INTERMITTENT MOTION DRIVE UNIT	CUTLER-HAMMER INC'S. BULLETIN 17020, OR EQUAL. 8 REQ'D.
15	LARGE BULL GEAR PINION	SEE DWG. NO. 55/5.
16	LARGE BULL GEAR	SEE DWG. NO. 55/5.
17	ROPE DRUM	SEE DWG. NO. 55/3.
18	LARGE BULL GEAR AND ROPE DRUM SHAFT	SEE DWG. NO. 55/3.
19	PILLOW BLOCK	CAST STEEL WITH SPHERICAL ROLLER BEARINGS, TORRINGTON SAFS-22236, OR EQUAL, ONE END CLOSED, WITH SPLIT STABILIZING RING AND BRG. NO. 150 [illegible], 64 REQ'D.
20	FLEXIBLE COUPLING	PHILADELPHIA GEAR WORKS, TYPE EX, SIZE 2, OR EQUAL. 48 REQ'D.
21	PILLOW BLOCK	CAST STEEL HOUSING, SELF ALIGNING, SELF LUBRICATING, LINKBELT NO. 3247 PT8, OR EQUAL, 32 REQ'D.
22	DRIVE SHAFT SUPPORT	SEE DWG. 55/6.
23	REVOLUTION COUNTER	TOP READING, DURANT MFG. CO. MODEL 5-CS-7-4-L, OR EQUAL, TO SUBTRACT WHEN REVERSED. ROTATION FOR INCREASING NUMBERS WHEN GATE IS RAISED. PROVIDE PEDESTAL ON MACHINERY BASE FOR MOUNTING COUNTER. 8 REQ'D.
24	FLEXIBLE COUPLING	BOSTON GEAR FCB815, OR EQUAL. 8 REQ'D.
25	DRIVE SHAFT	SEE DWG. 55/6.
26	GEARED-ROTARY LIMIT SWITCH	GENERAL ELECTRIC NO. CR115-E1Z101, OR EQUAL. 8 REQ'D.
27	WORM GEAR REDUCER	15:1 RATIO, BOSTON GEAR U113 OR EQUAL, 8 REQD.
28	SPROCKET	SINGLE WIDTH, 16 TEETH, NO. 40, 1/2" PITCH. BOSTON GEAR HKSB16-1 OR EQUAL, 8 REQD.
29	CHAIN	SINGLE WIDTH, NO. 40, 1/2" PITCH. BOSTON GEAR CO. OR EQUAL, 8 REQD.
30	SPROCKET	SINGLE WIDTH, 15 TEETH, NO. 40, 1/2" PITCH. BOSTON GEAR HKSB15-1 OR EQUAL, 8 REQD.
31	EXTENDED SHAFT	SEE DWG. NO. 55/5.
32	SELSYN SYSTEM TRANSMITTER	SEE GATE HOIST ELECTRICAL EQUIPMENT SCHEDULE, DWG. 55/15.
33	COUPLING	MARK 55/D-13, DWG. 55/8.

TAINTER GATE MACHINERY
WIRE ROPE - ELECTRIC MOTOR DRIVE
ASSEMBLY - PLAN

PLATE - 63

Figure B–63. Plate 63: Tainter gate machinery, wire rope-electric motor drive, assembly – plan

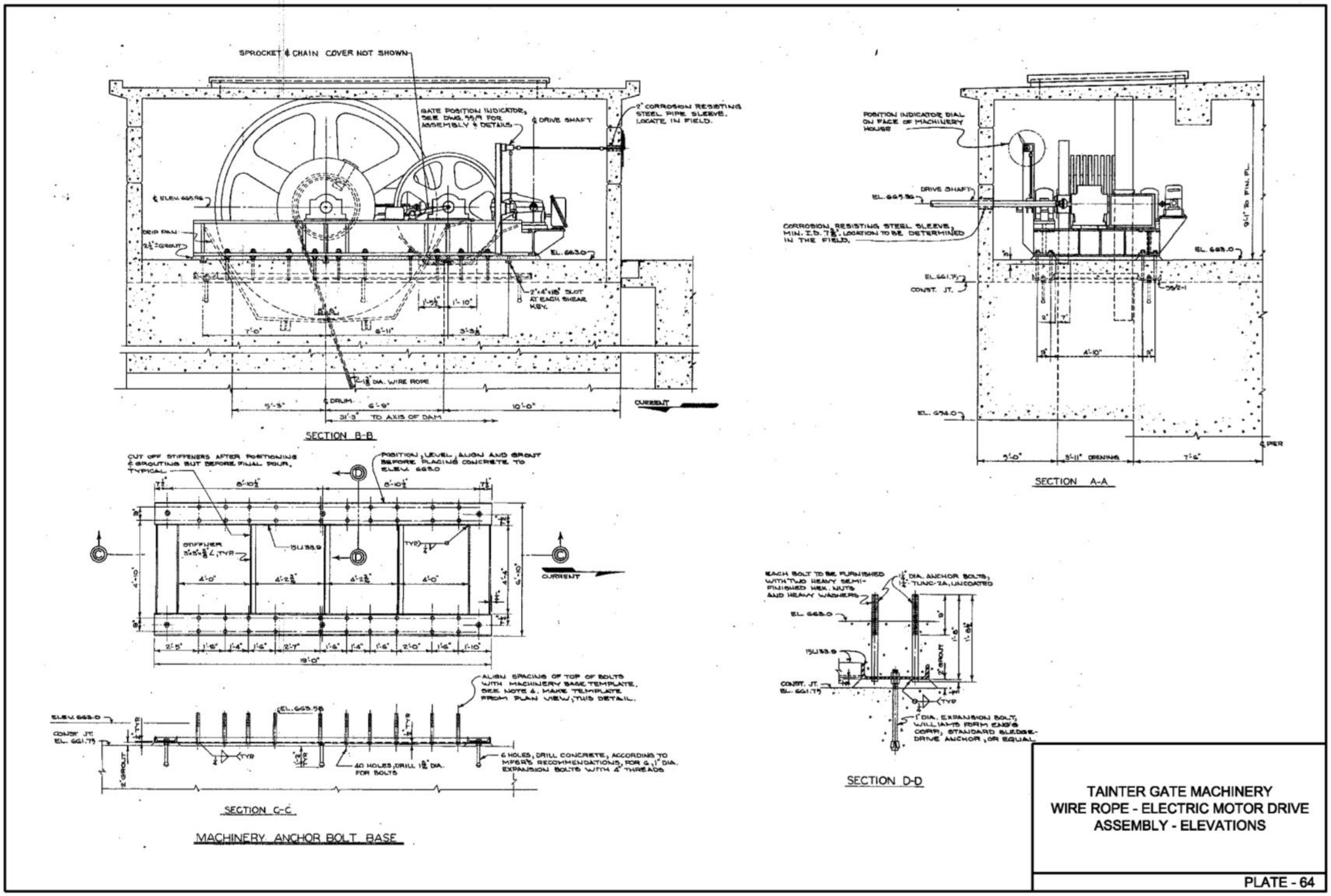


Figure B–64. Plate 64: Tainter gate machinery, wire rope-electric motor drive, assembly – elevations

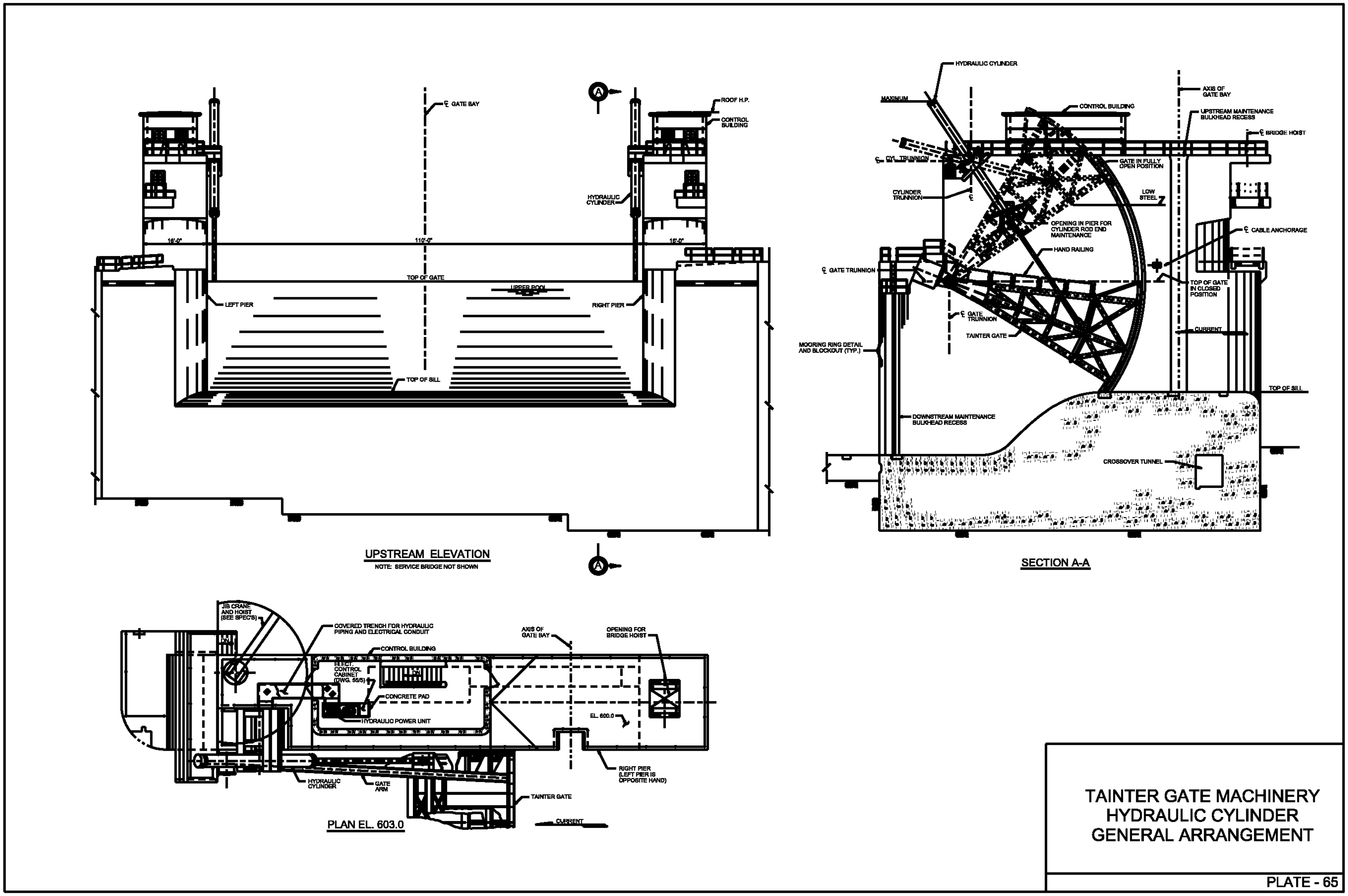


Figure B–65. Plate 65: Tainter gate machinery, hydraulic cylinder, general arrangement

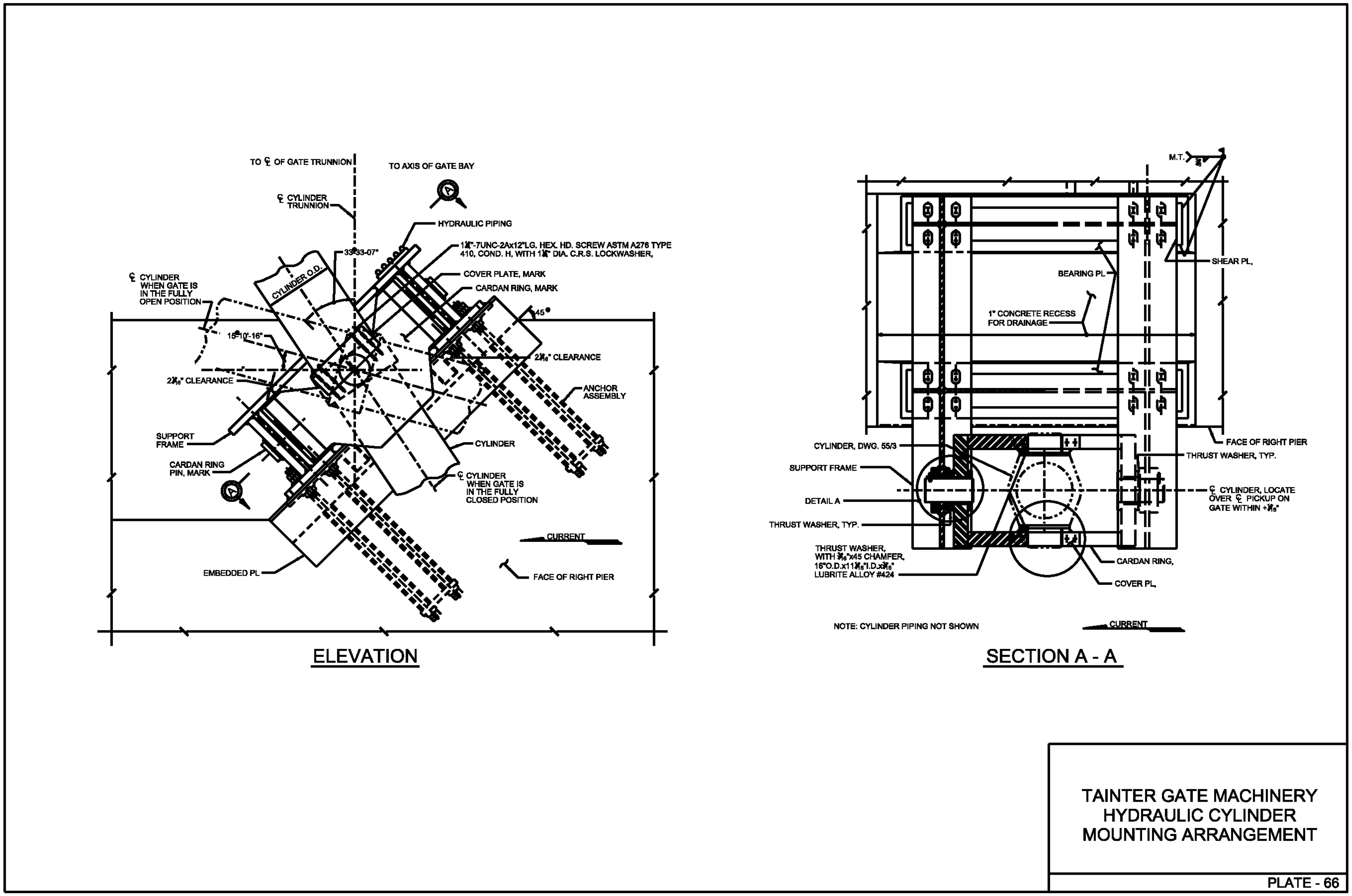


Figure B–66. Plate 66: Tainter gate machinery, hydraulic cylinder, mounting arrangement

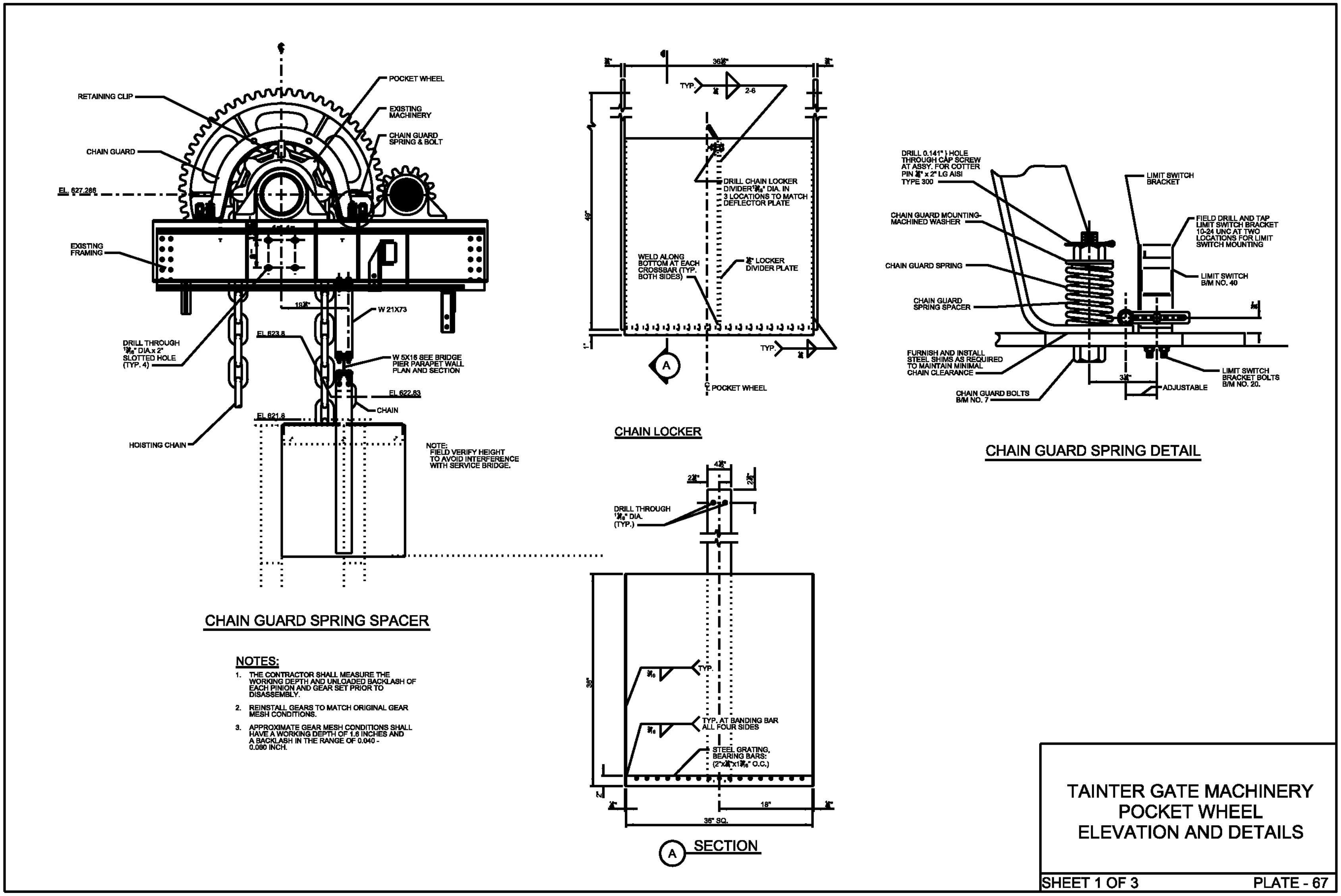


Figure B–67. Plate 67: Tainter gate machinery, pocket wheel, elevation, and details (sheet 1 of 3)

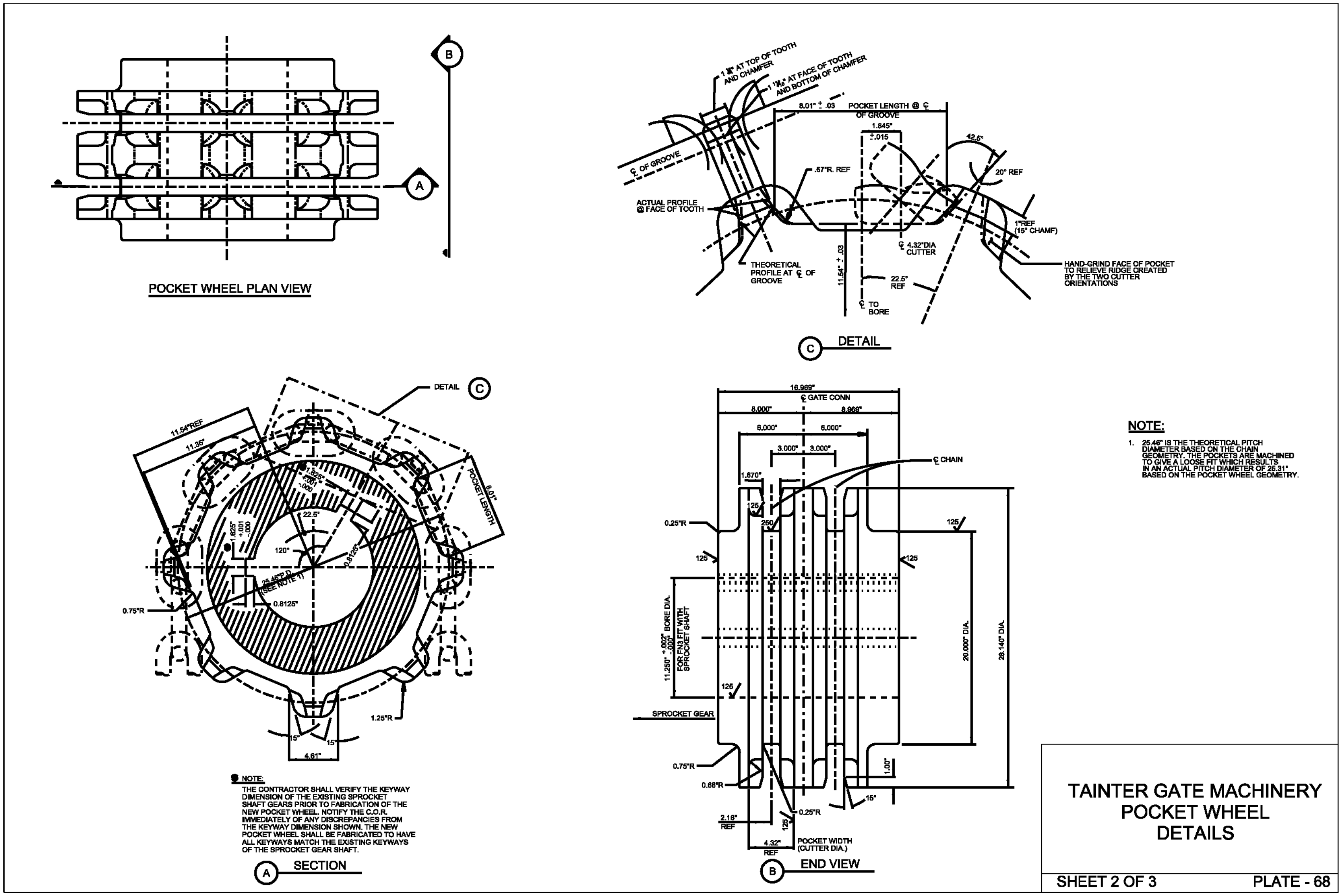


Figure B–68. Plate 68: Tainter gate machinery, pocket wheel, details (sheet 2 of 3)

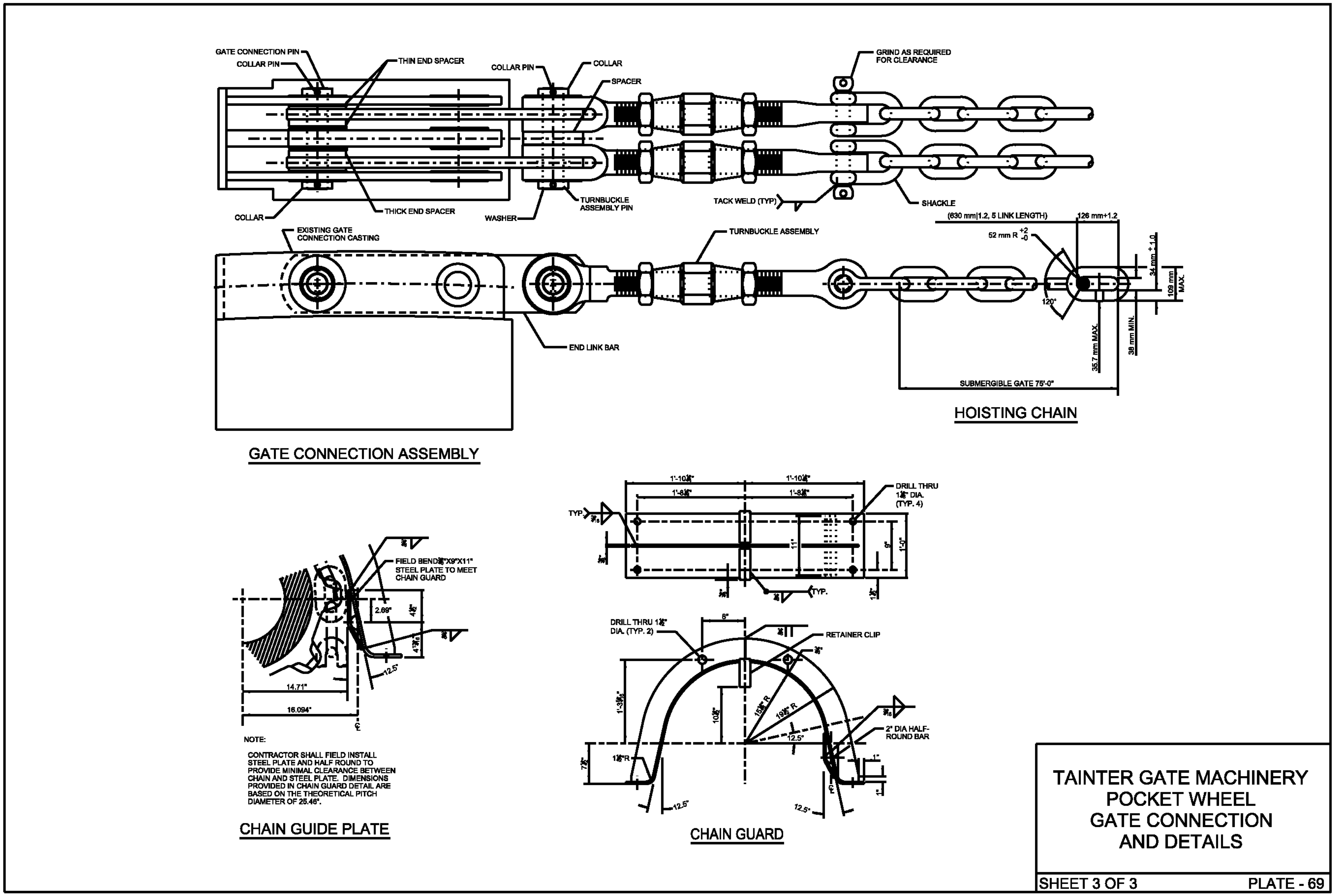


Figure B–69. Plate 69: Tainter gate machinery, pocket wheel gate connection and details (sheet 3 of 3)

B–10. Wicket gates

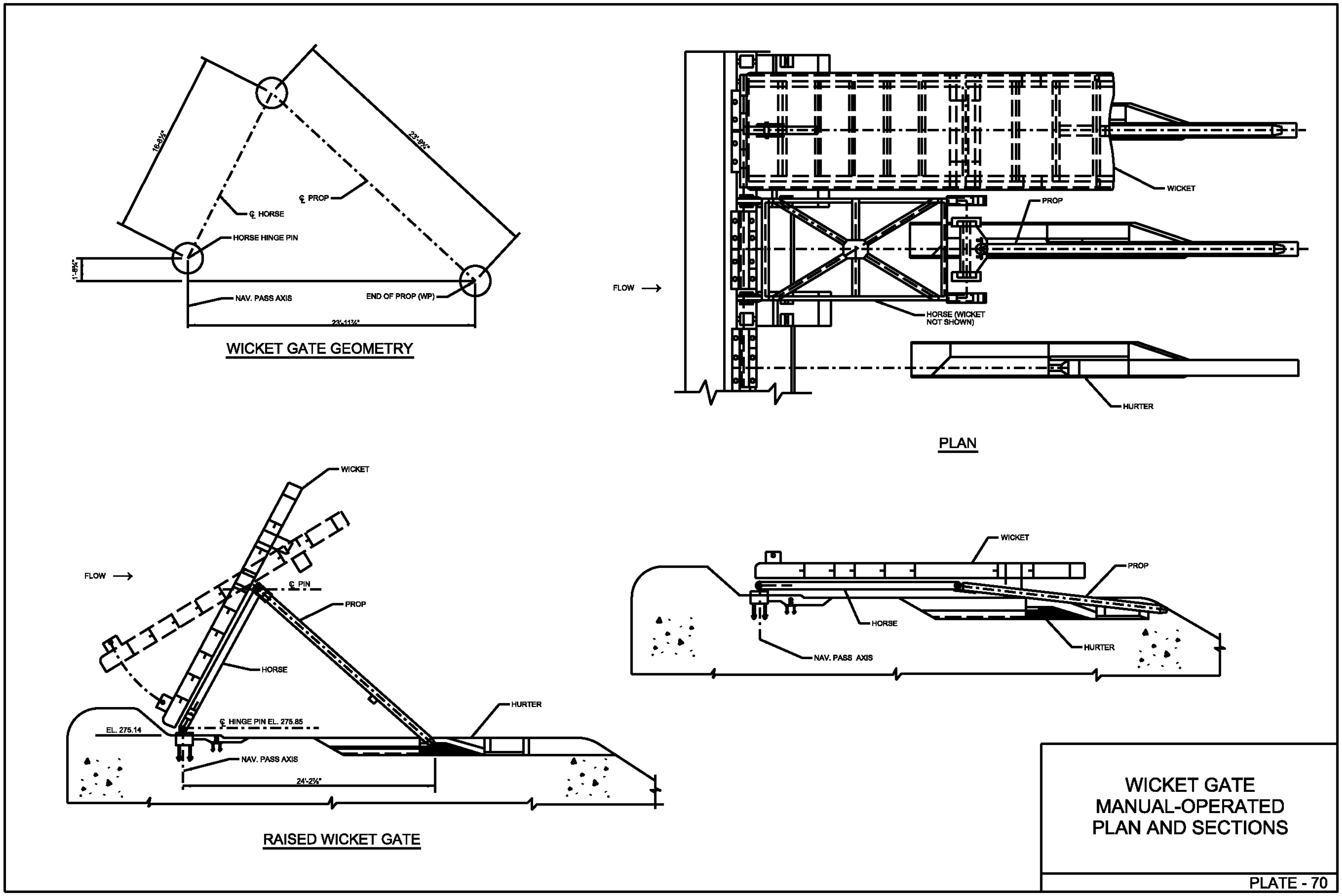


Figure B–70. Plate 70: Wicket gate manual operated plan and sections

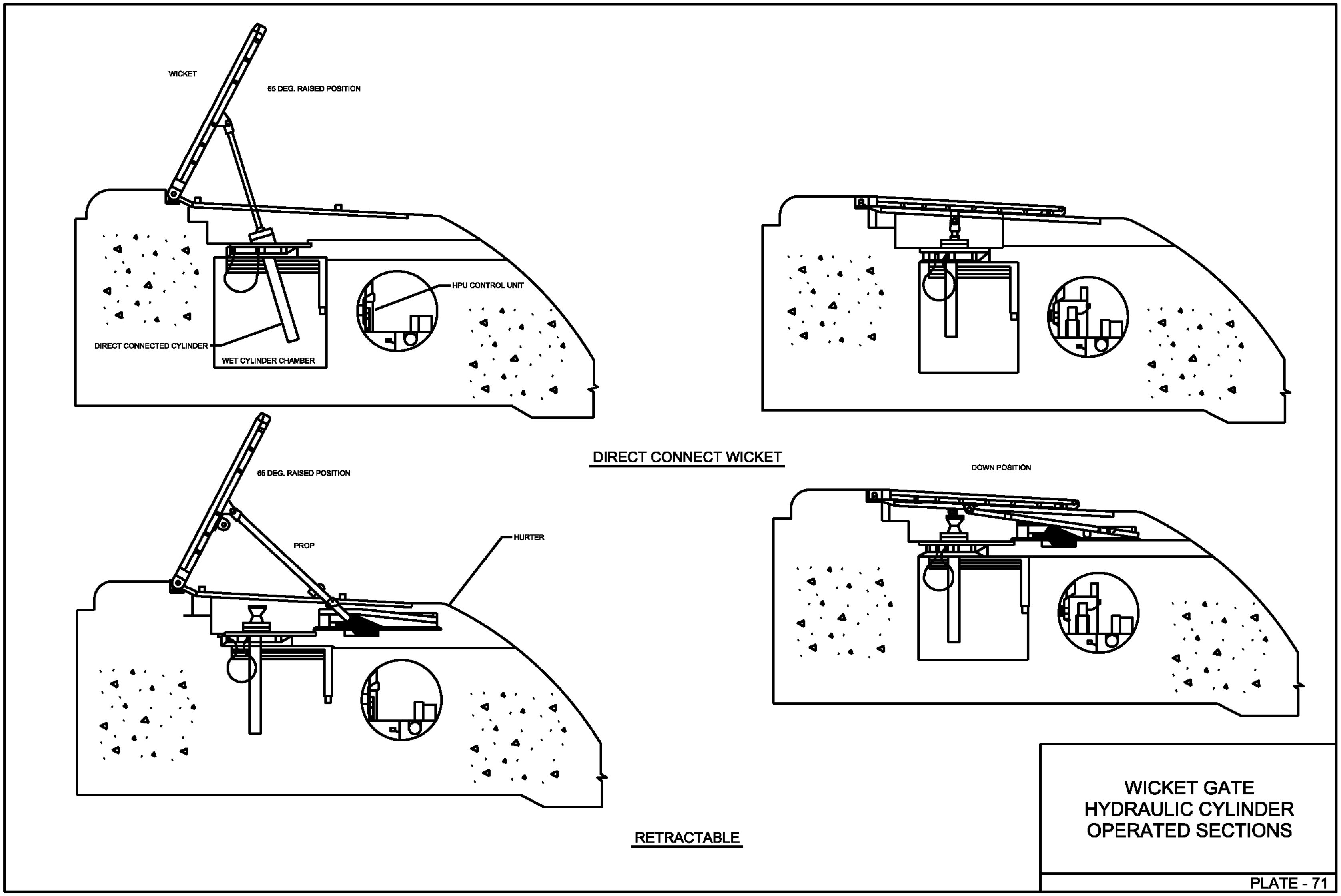


Figure B–71. Plate 71: Wicket gate hydraulic cylinder operated sections

B–11. Hinged crest gates

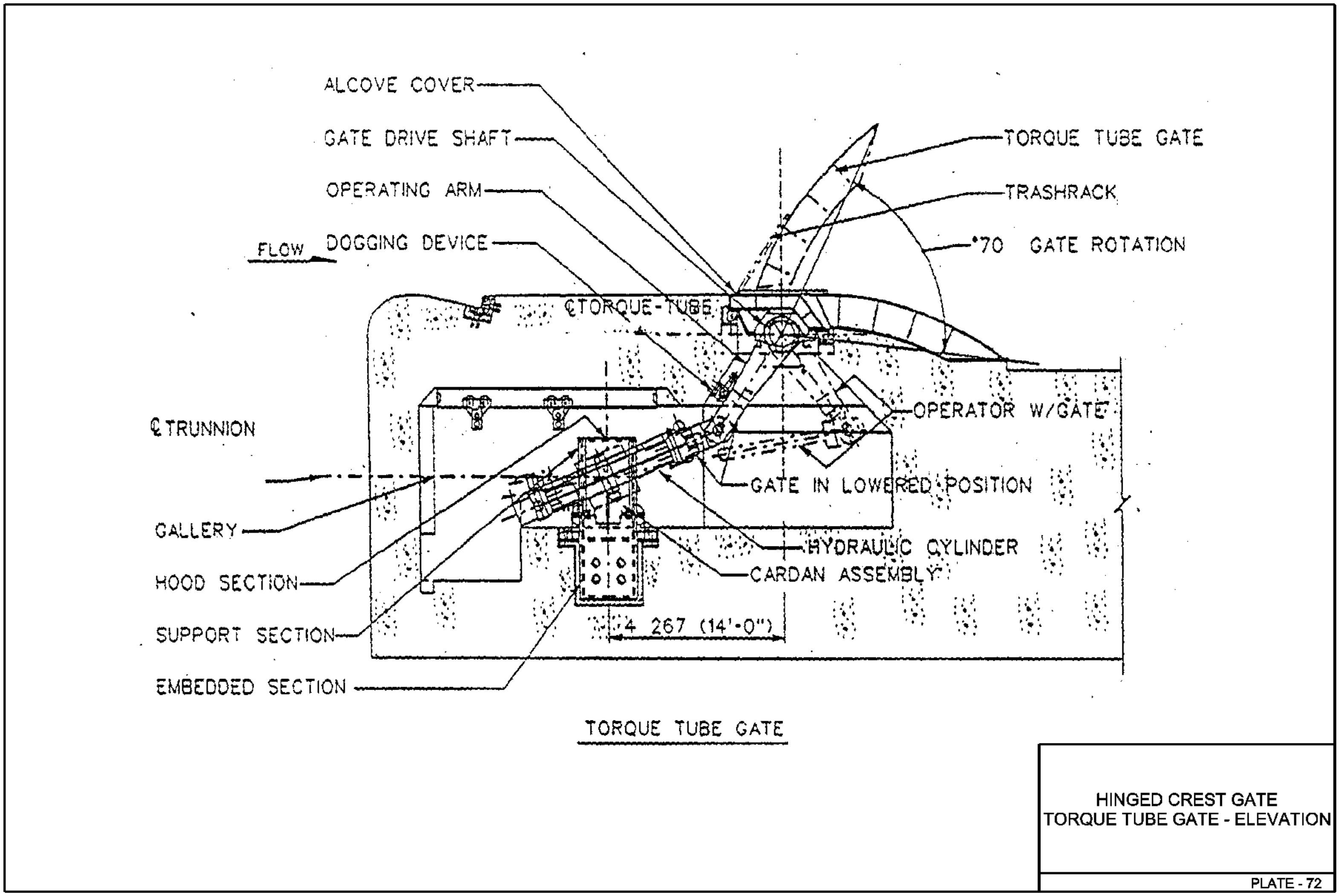


Figure B–72. Plate 72: Hinged crest gate, torque tube gate – elevation

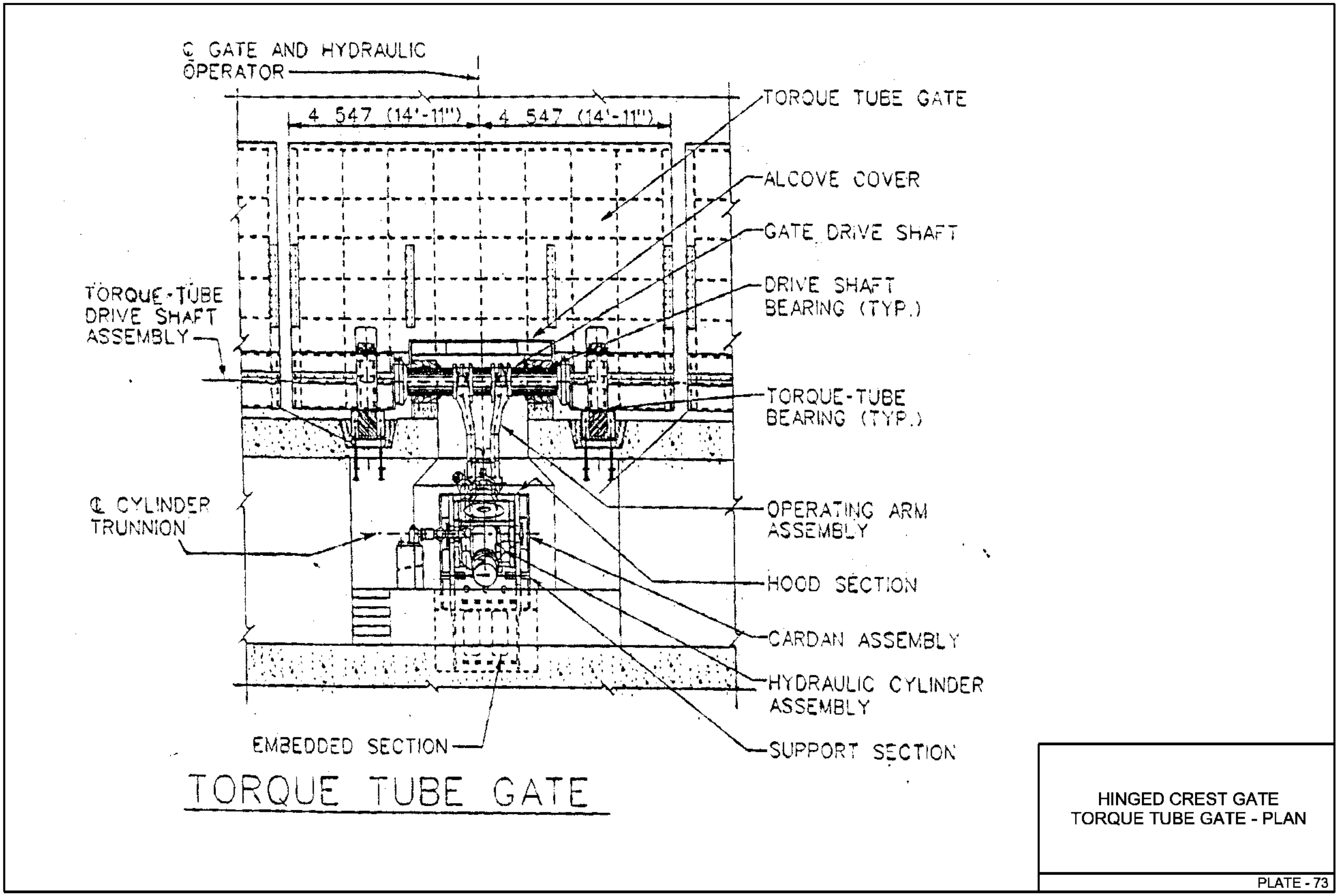


Figure B–73. Plate 73: Hinged crest gate, torque tube gate – plan

B–12. Other systems – cathodic protection

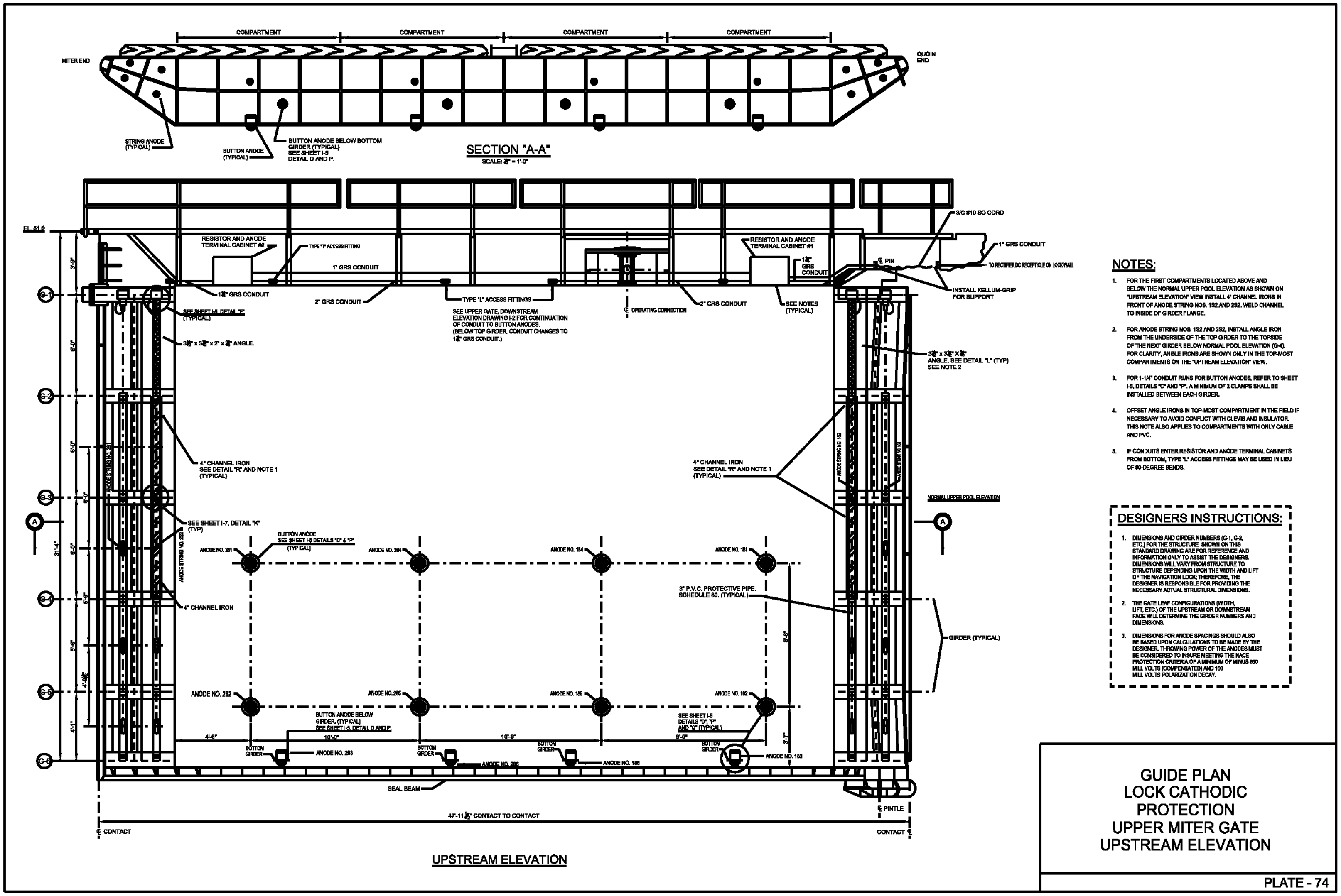


Figure B–74. Plate 74: Guide plan, lock cathodic protection, upper miter gate, upstream elevation

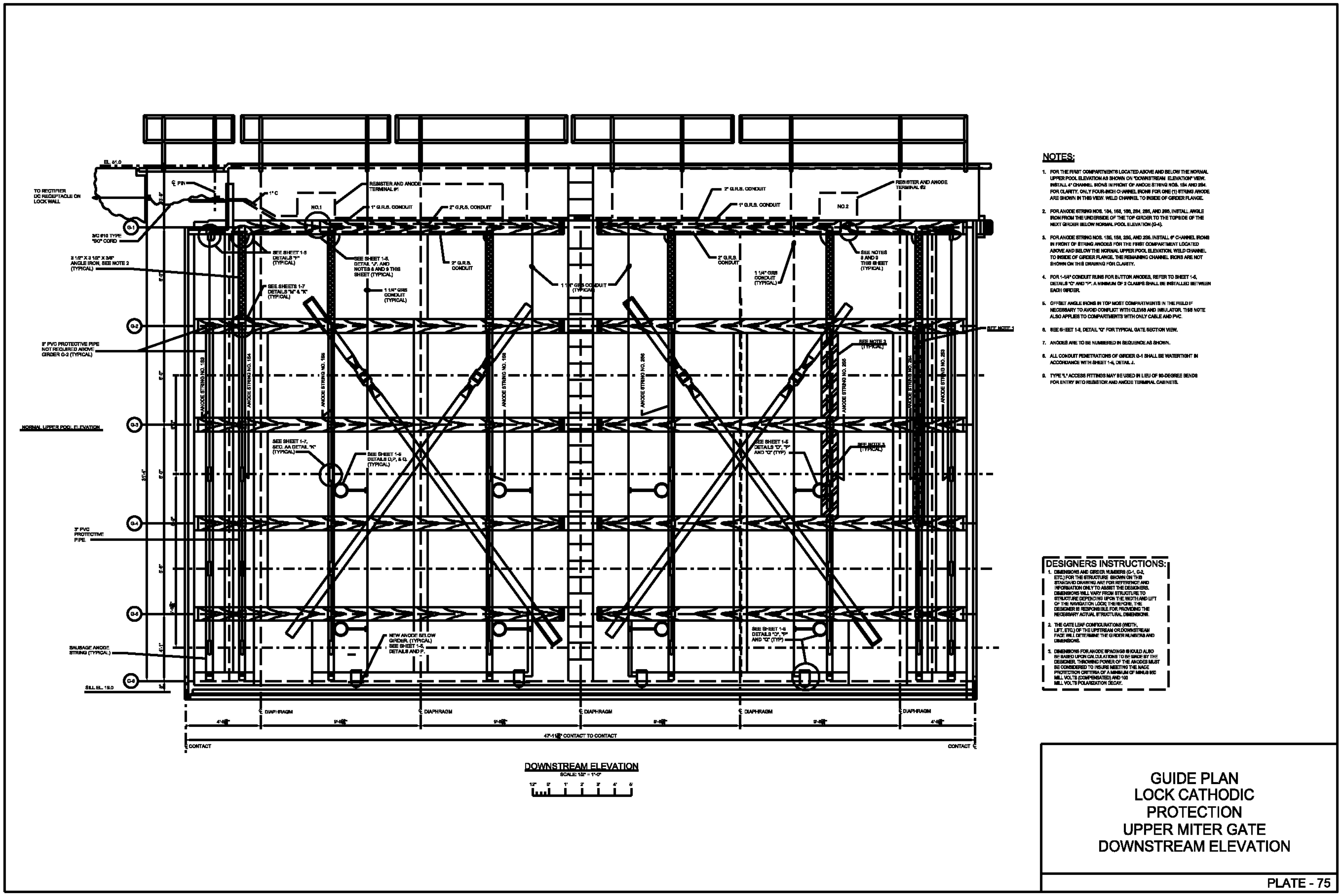


Figure B–75. Plate 75: Guide plan, lock cathodic protection, upper miter gate, downstream elevation

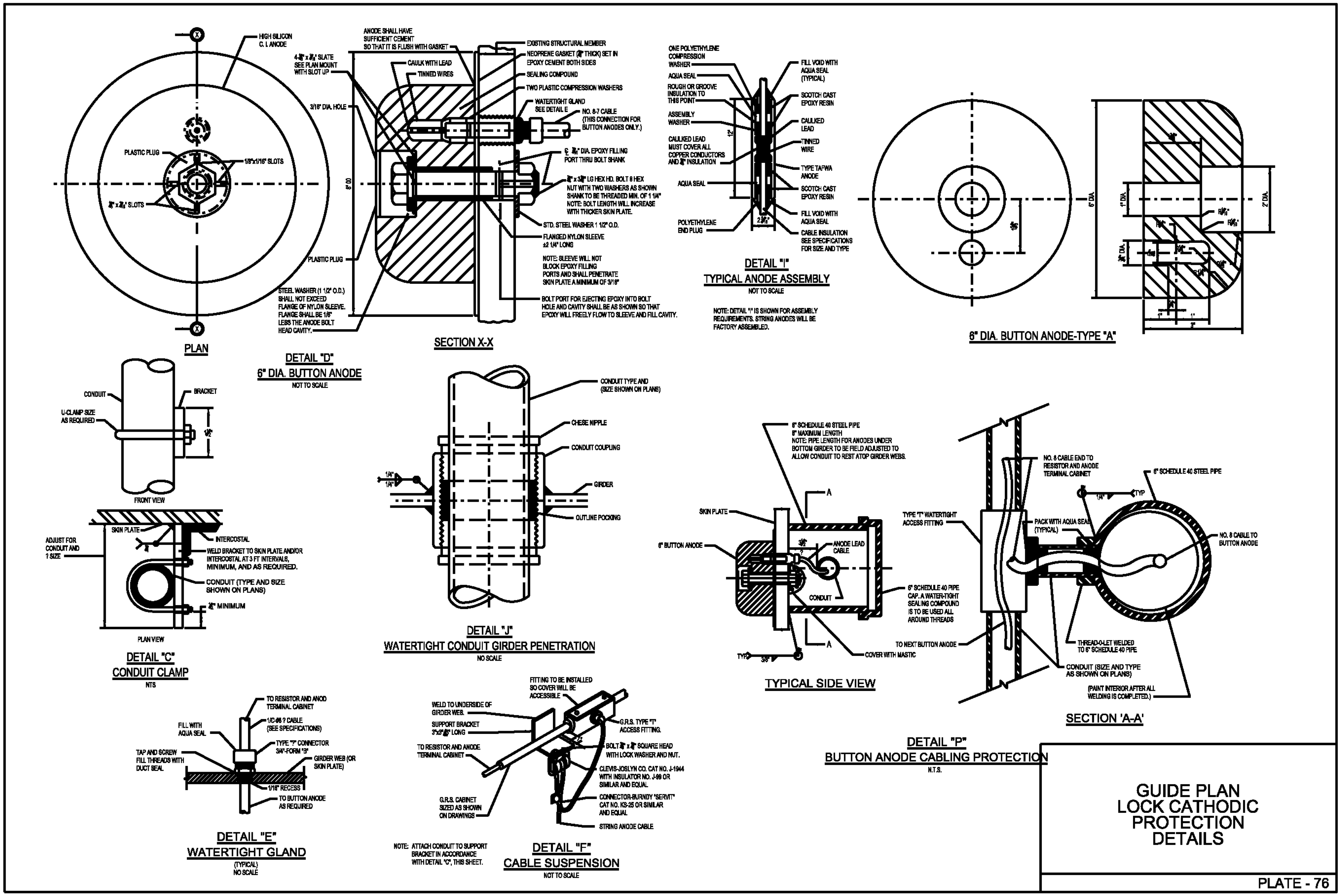


Figure B–76. Plate 76: Guide plan, lock cathodic protection details

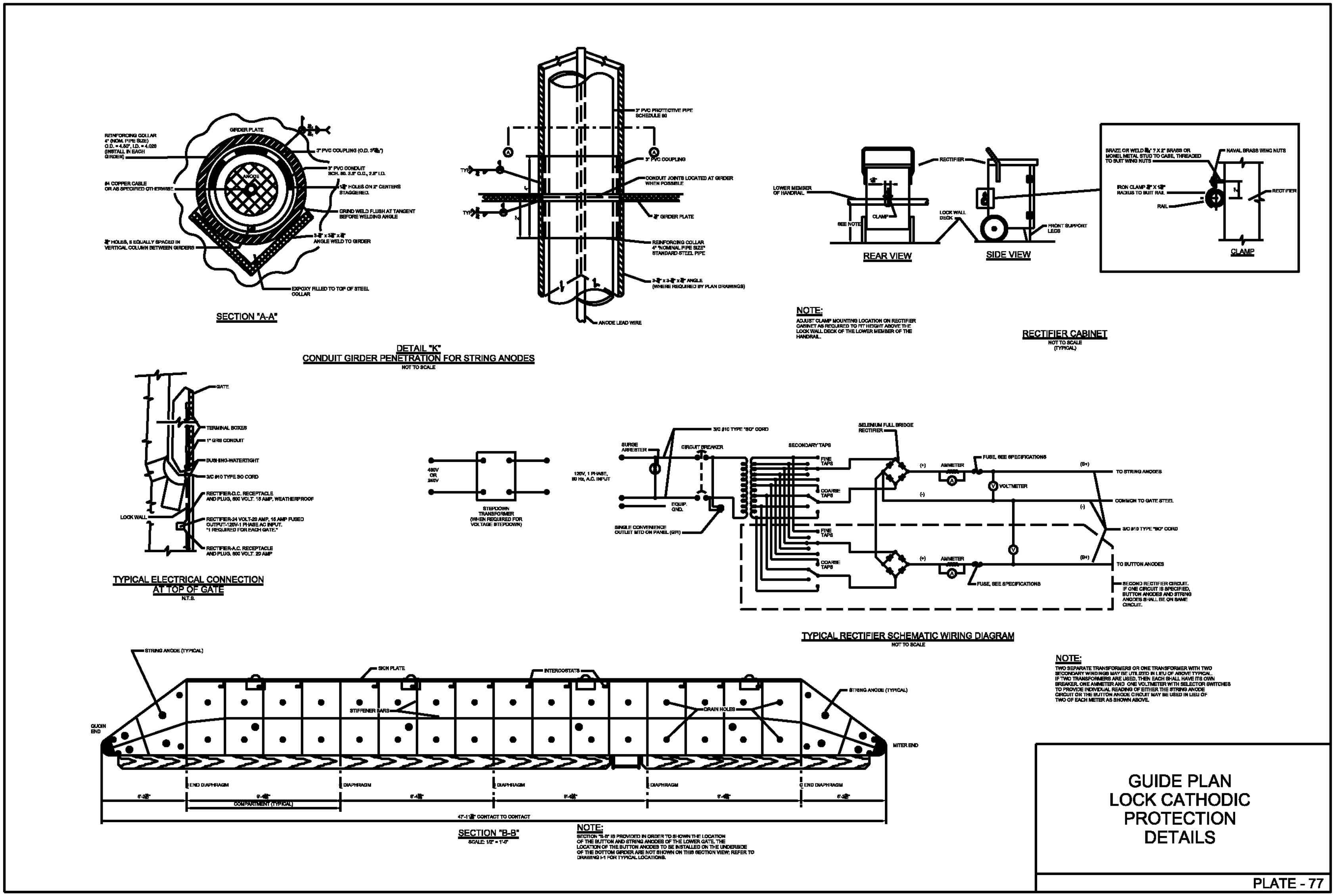


Figure B–77. Plate 77: Guide plan, lock cathodic protection details

B–13. Electrical

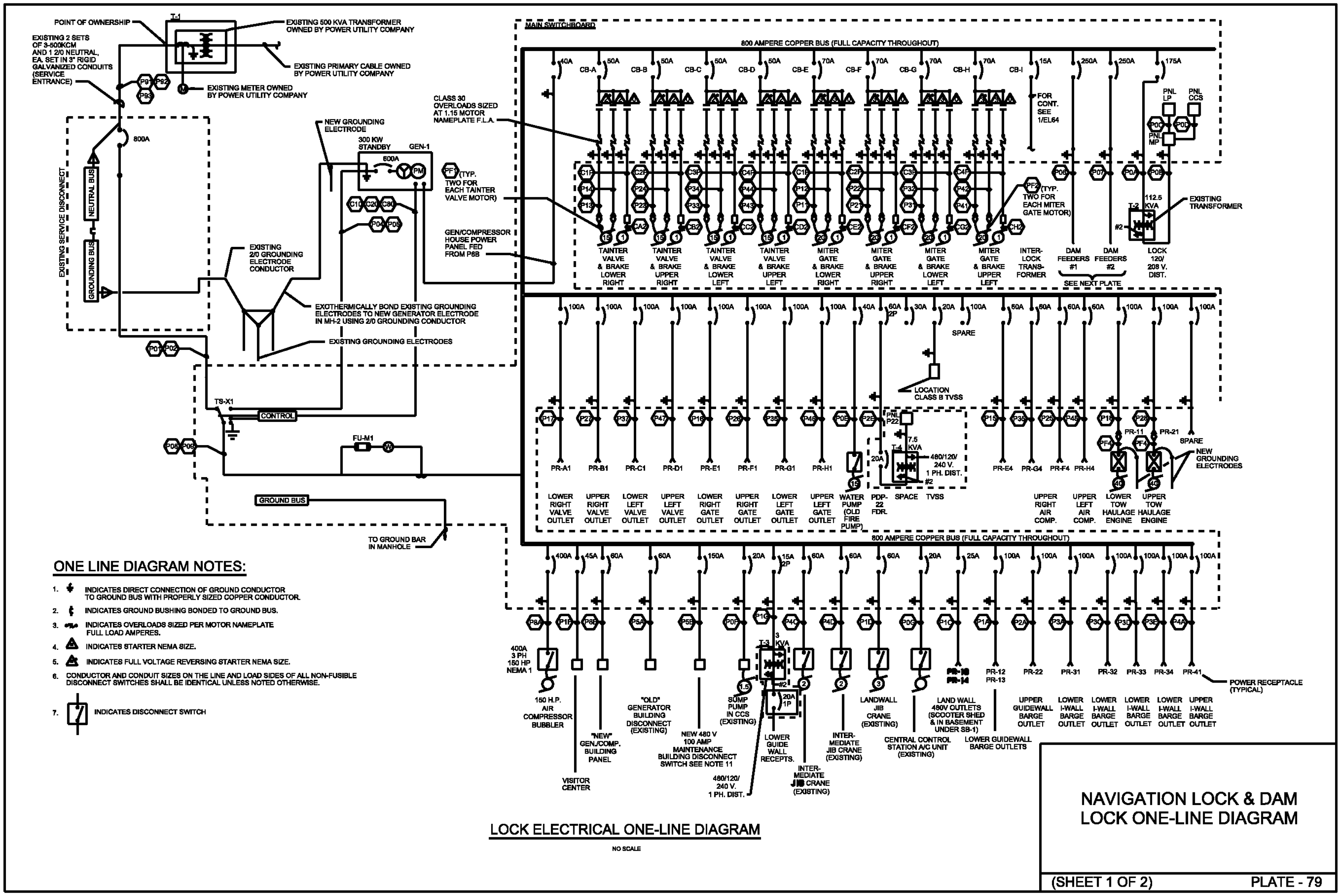


Figure B–78. Plate 78: Navigation lock & dam, lock one-line diagram (sheet 1 of 2)

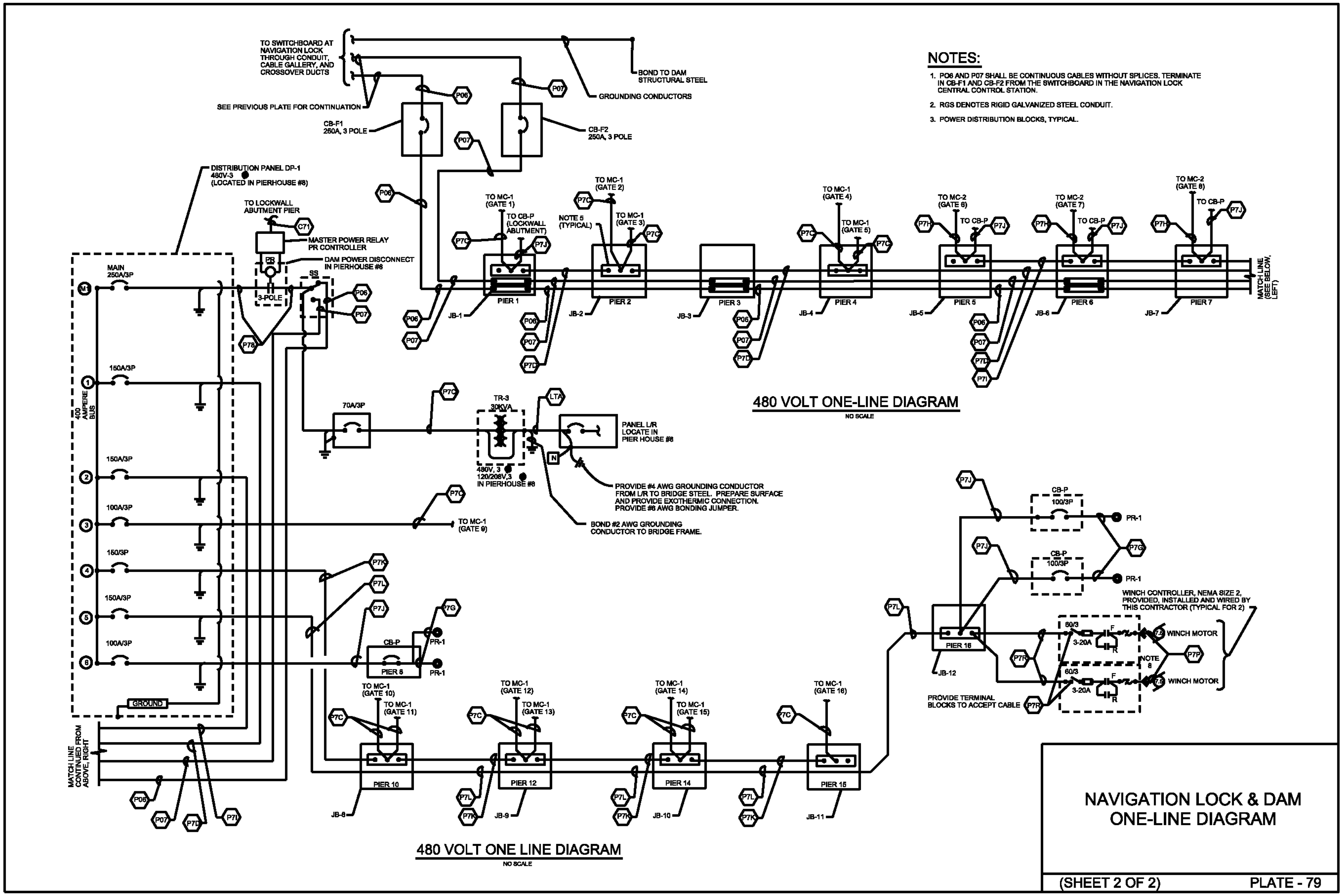


Figure B–79. Plate 79: Navigation lock & dam, one-line diagram (sheet 2 of 2)

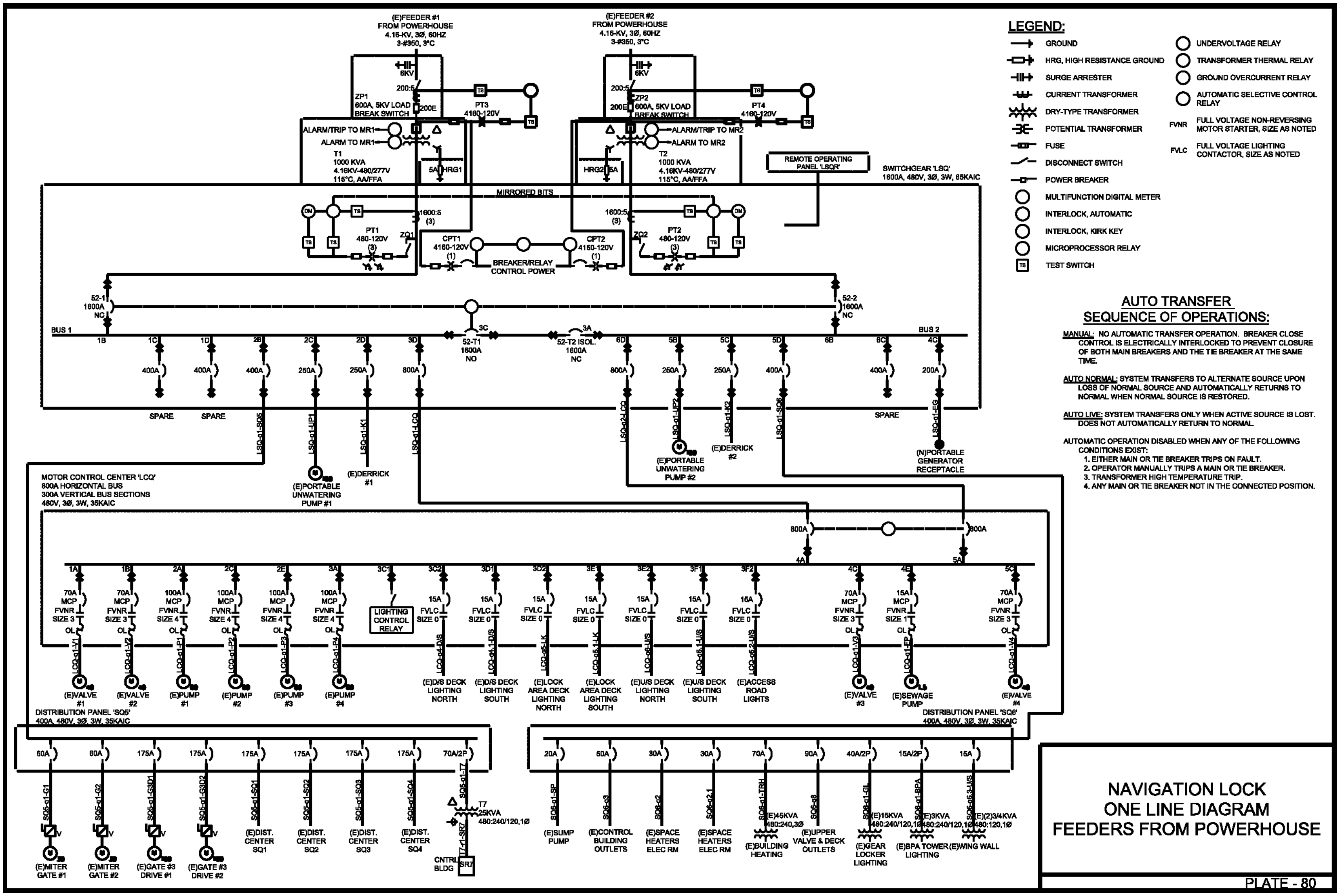


Figure B–80. Plate 80: Navigation lock, one-line diagram, feeders from powerhouse

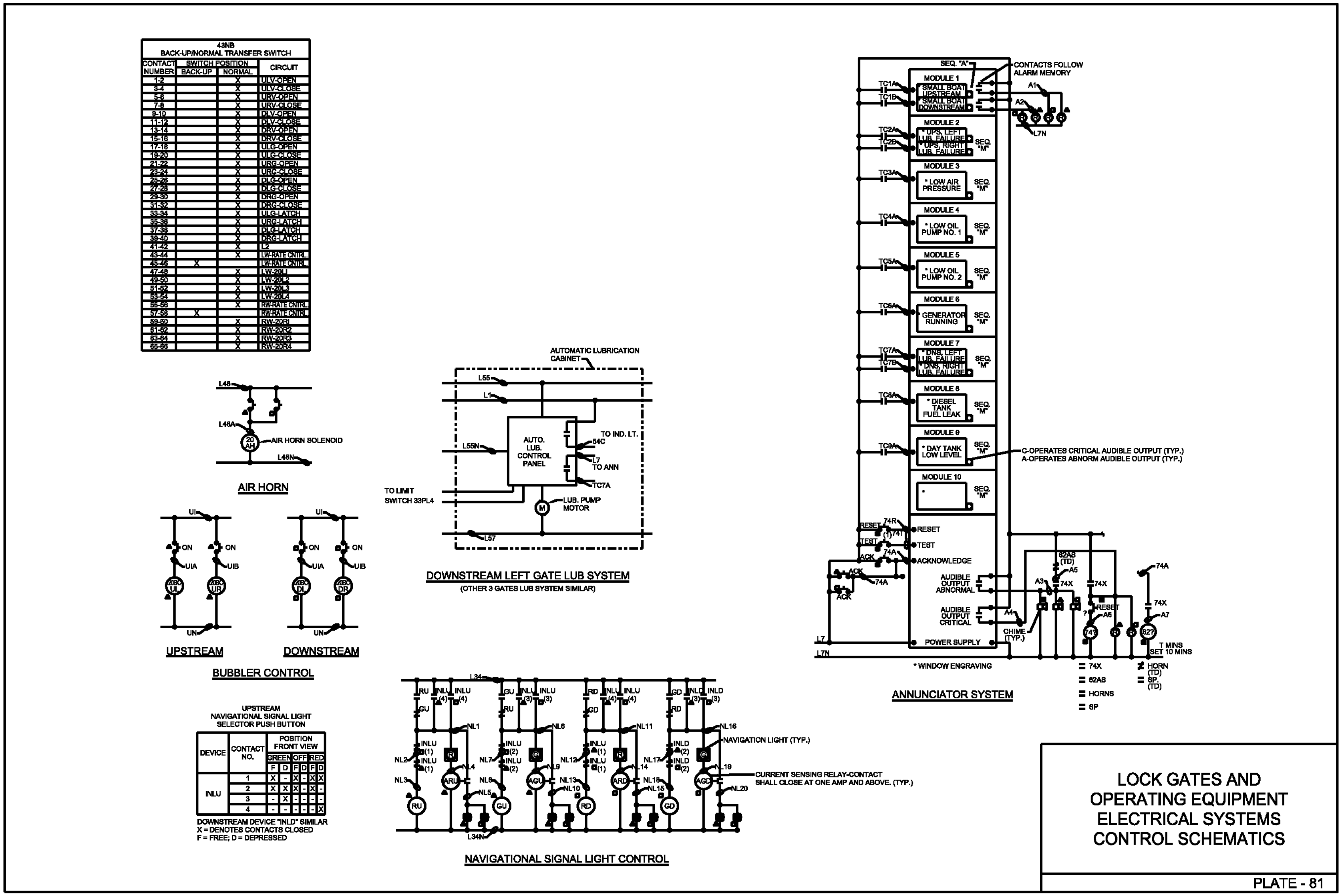


Figure B–81. Plate 81: Lock gates and operating equipment, electrical systems, control schematics

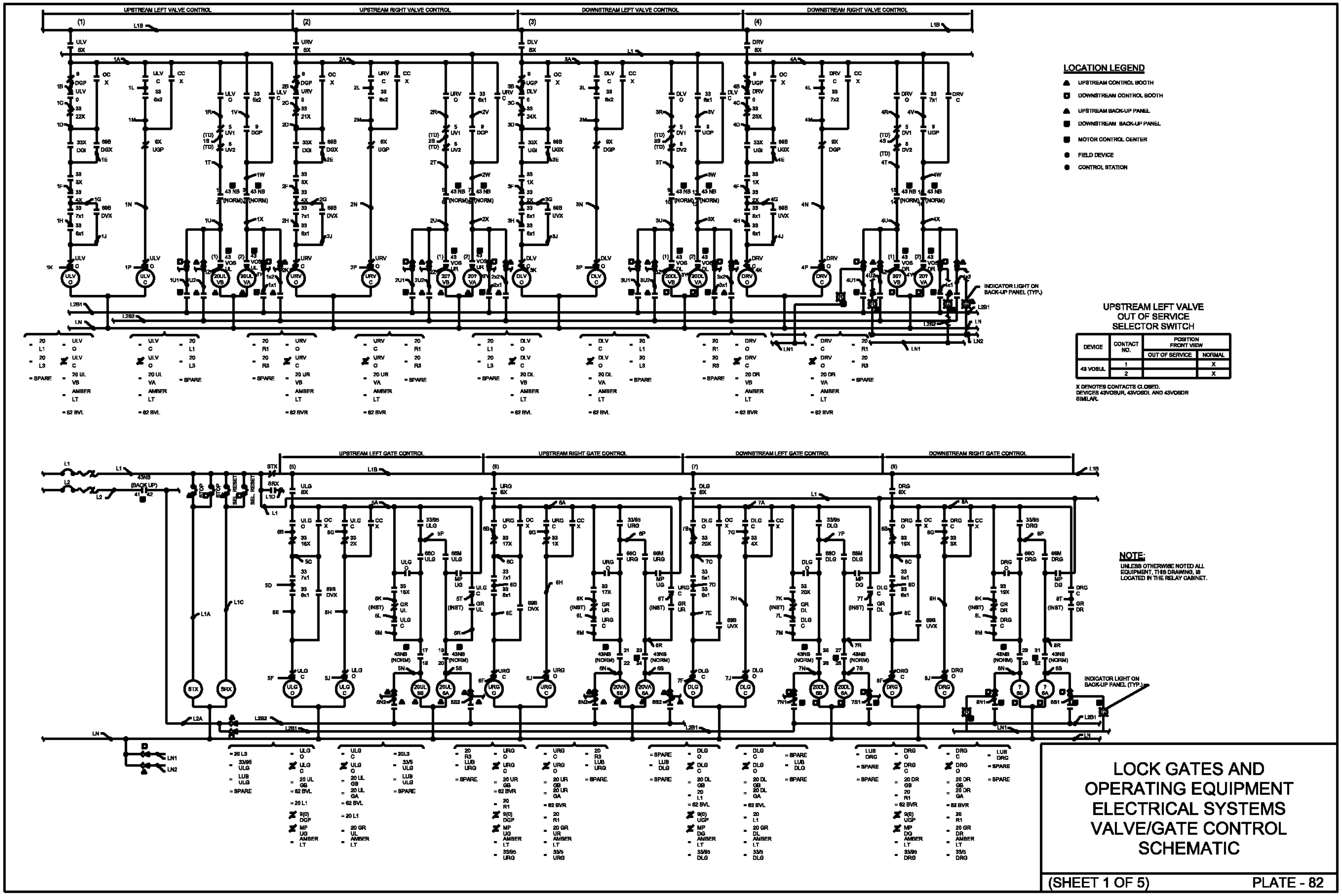


Figure B–82. Plate 82: Lock gates and operating equipment, electrical systems, valve/gate control schematic (sheet 1 of 5)

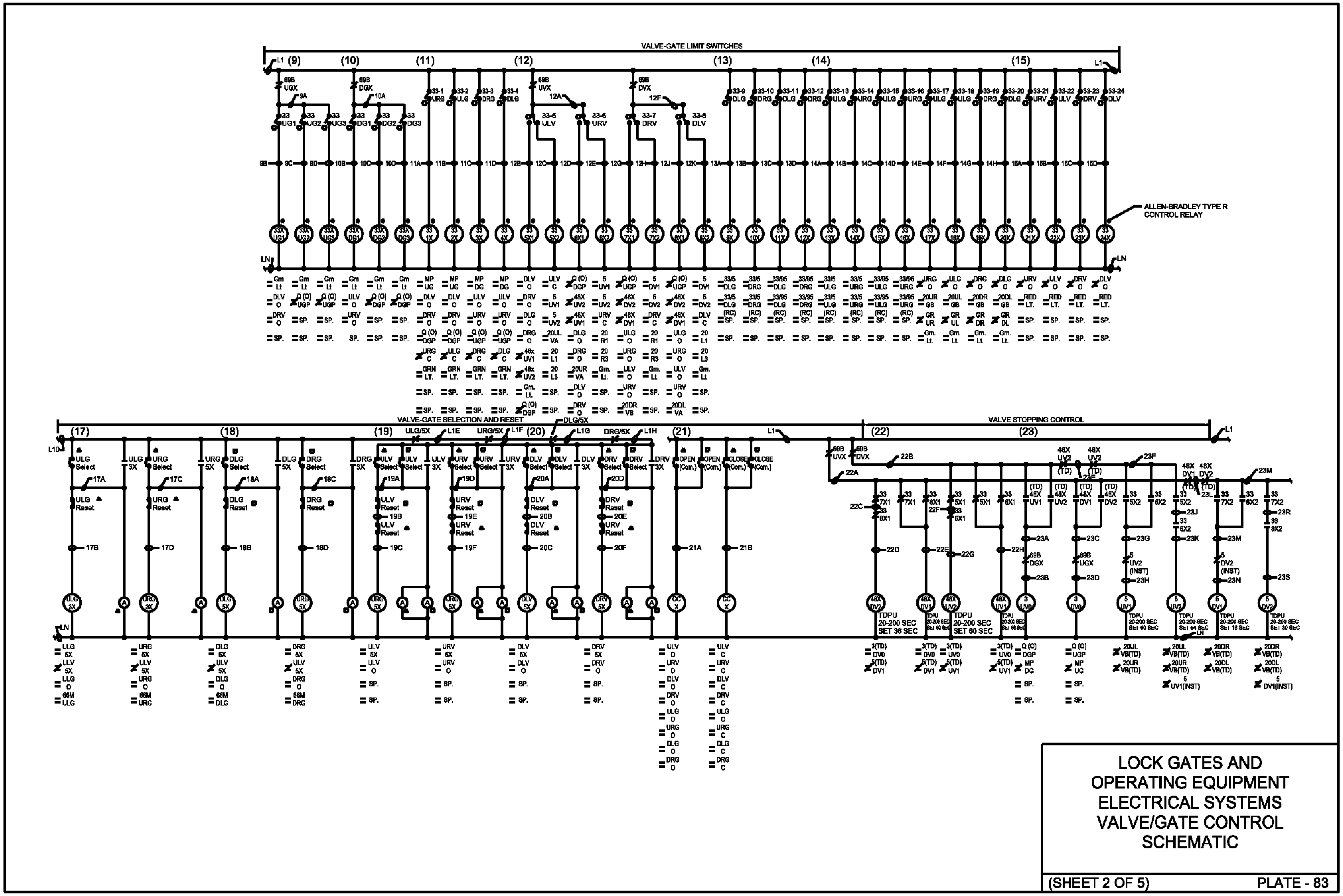


Figure B–83. Plate 83: Lock gates and operating equipment, electrical systems, valve/gate control schematic (sheet 2 of 5)

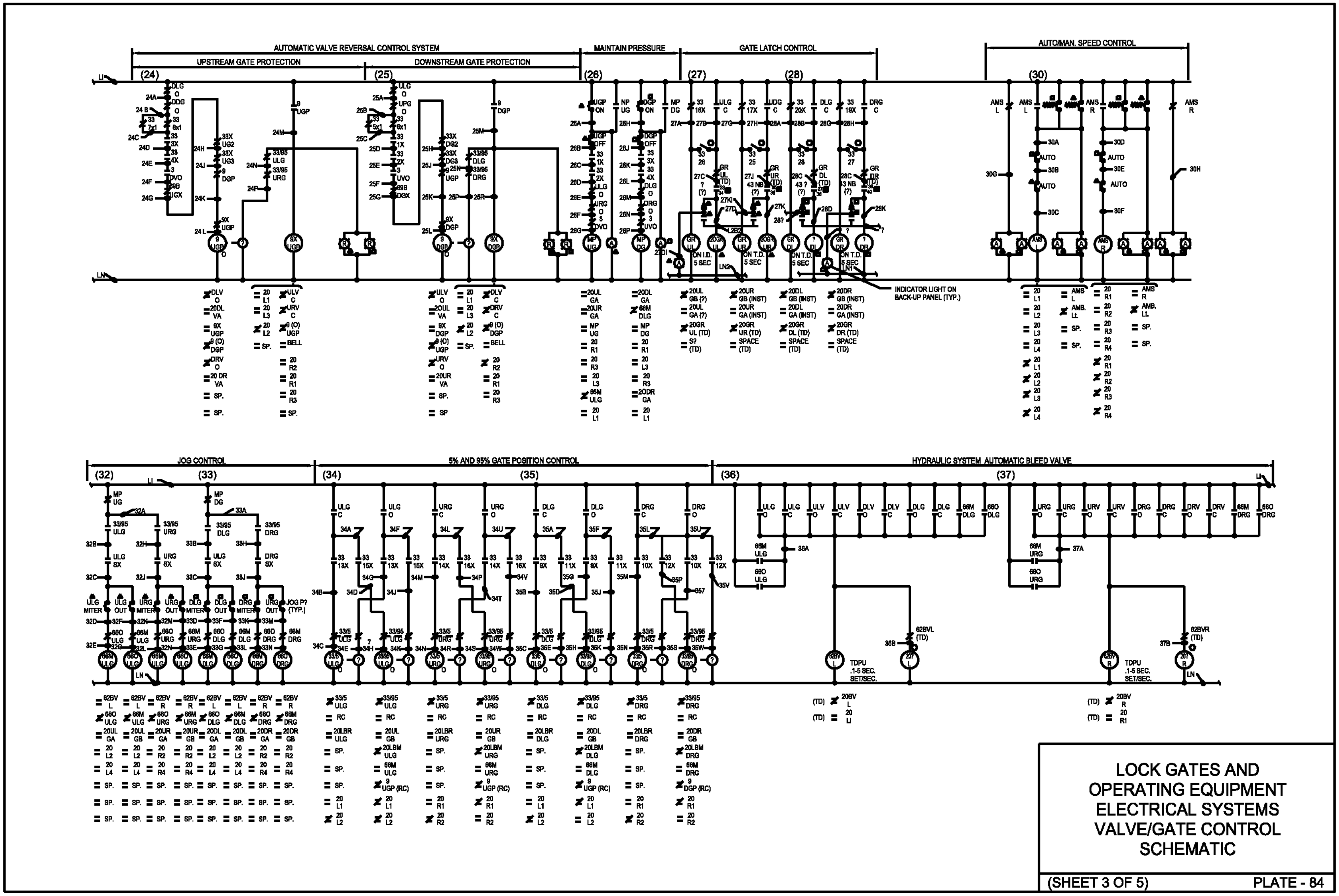
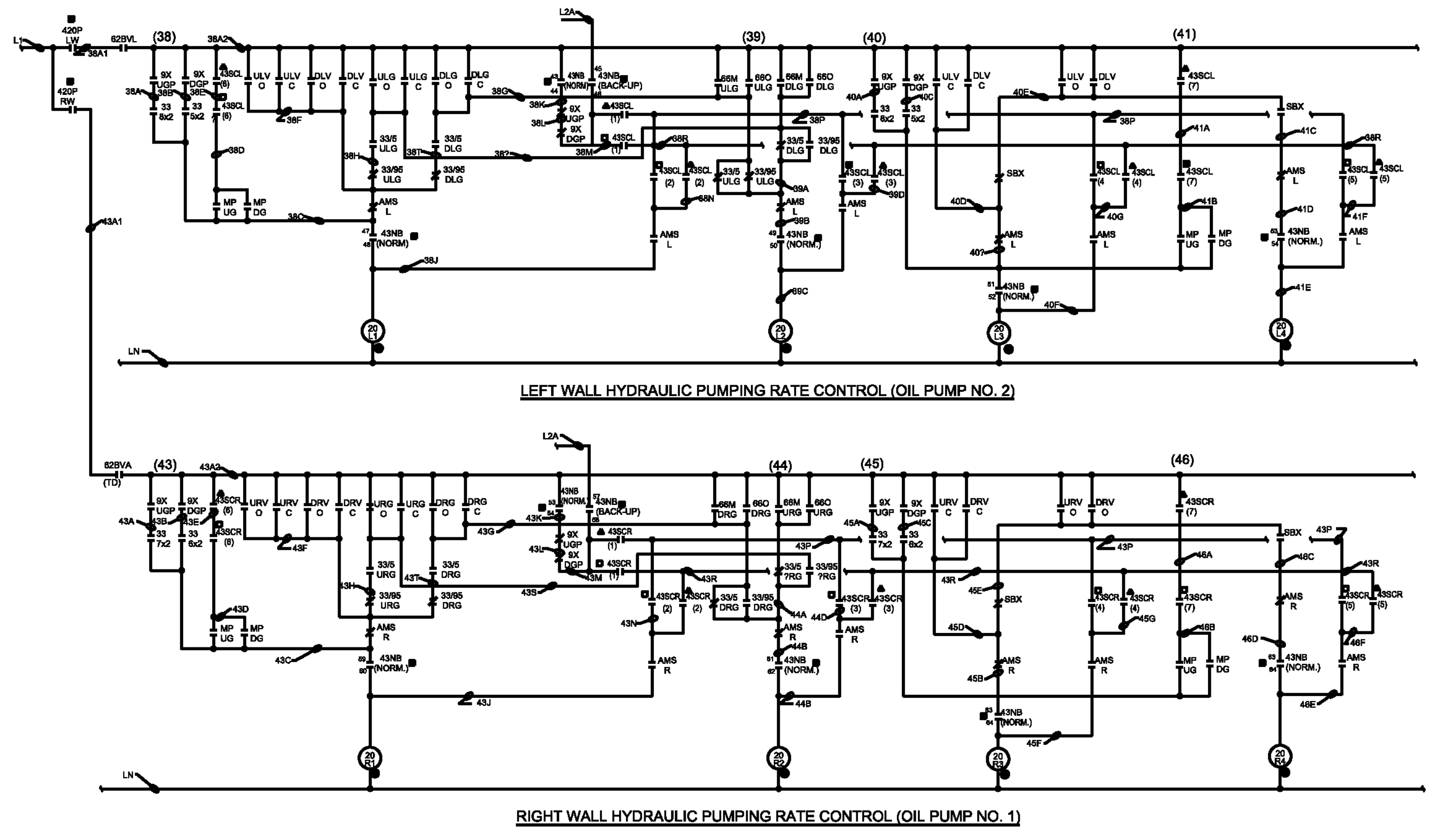


Figure B–84. Plate 84: Lock gates and operating equipment, electrical systems, valve/gate control schematic (sheet 3 of 5)



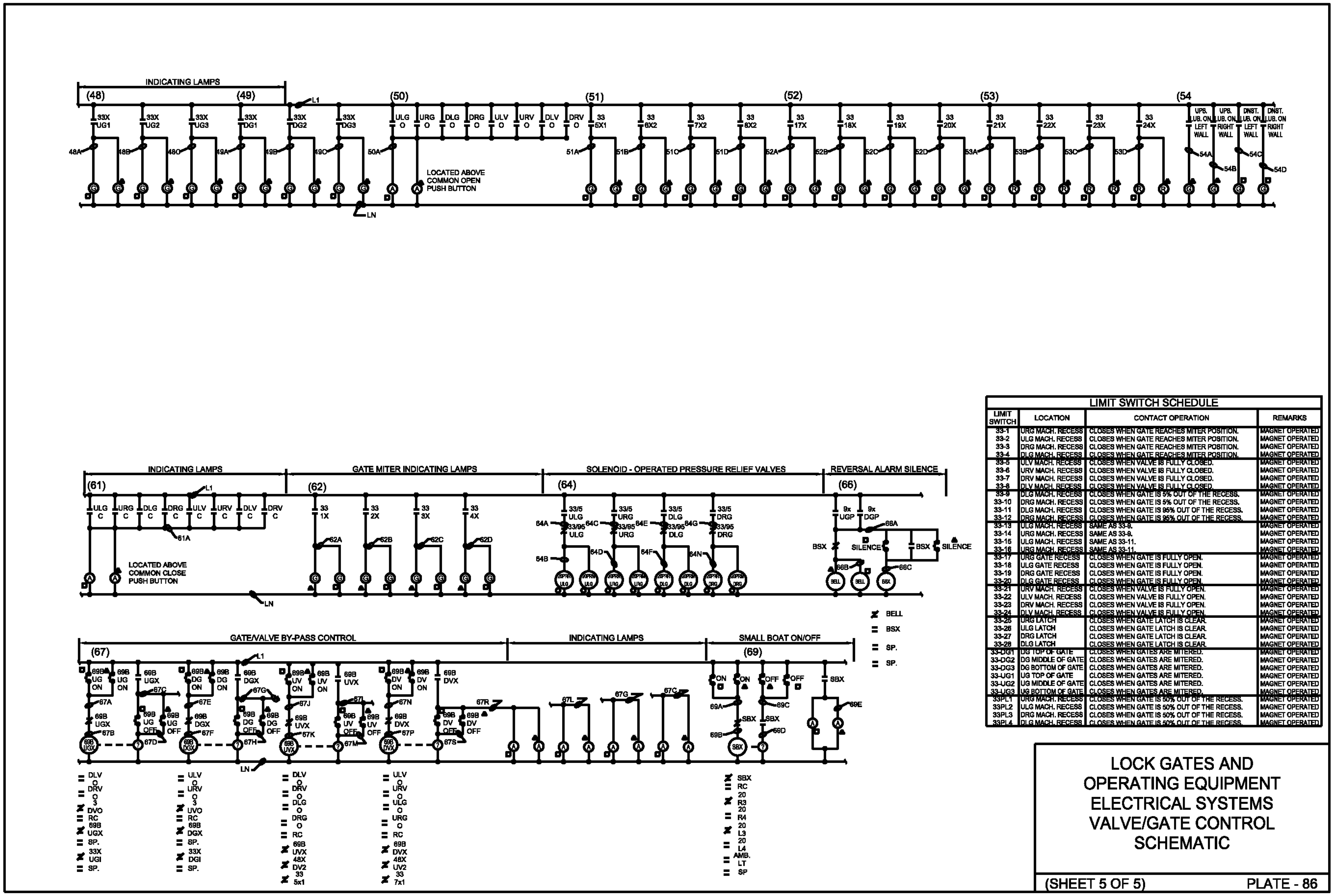
43SCR	RIGHT WALL GATE-VALVE SPEED CONTROL SWITCH		GATE FAST	GATE SLOW	NEUT.	VALVE SLOW	VALVE FAST	BLACK PISTOL GRIP HANDLE
		1			X			
		2	X			X	X	
		3		X				ALL POSITIONS MAINTAINED
		4					X	
		5				X		
		6			X			
		7			X			
		8			X			

43SCL SIMILAR
X DENOTES CONTACTS CLOSED

LOCK GATES AND OPERATING EQUIPMENT ELECTRICAL SYSTEMS VALVE/GATE CONTROL SCHEMATIC

(SHEET 4 OF 5) PLATE - 85

Figure B–85. Plate 85: Lock gates and operating equipment, electrical systems, valve/gate control schematic (sheet 4 of 5)



LIMIT SWITCH SCHEDULE

LIMIT SWITCH	LOCATION	CONTACT OPERATION	REMARKS
33-1	URG MACH. RECESS	CLOSES WHEN GATE REACHES MITER POSITION.	MAGNET OPERATED
33-2	ULG MACH. RECESS	CLOSES WHEN GATE REACHES MITER POSITION.	MAGNET OPERATED
33-3	DRG MACH. RECESS	CLOSES WHEN GATE REACHES MITER POSITION.	MAGNET OPERATED
33-4	DLG MACH. RECESS	CLOSES WHEN GATE REACHES MITER POSITION.	MAGNET OPERATED
33-5	ULV MACH. RECESS	CLOSES WHEN VALVE IS FULLY CLOSED.	MAGNET OPERATED
33-6	URV MACH. RECESS	CLOSES WHEN VALVE IS FULLY CLOSED.	MAGNET OPERATED
33-7	DRV MACH. RECESS	CLOSES WHEN VALVE IS FULLY CLOSED.	MAGNET OPERATED
33-8	DLV MACH. RECESS	CLOSES WHEN VALVE IS FULLY CLOSED.	MAGNET OPERATED
33-9	DLG MACH. RECESS	CLOSES WHEN GATE IS 5% OUT OF THE RECESS.	MAGNET OPERATED
33-10	DRG MACH. RECESS	CLOSES WHEN GATE IS 5% OUT OF THE RECESS.	MAGNET OPERATED
33-11	DLG MACH. RECESS	CLOSES WHEN GATE IS 95% OUT OF THE RECESS.	MAGNET OPERATED
33-12	DRG MACH. RECESS	CLOSES WHEN GATE IS 95% OUT OF THE RECESS.	MAGNET OPERATED
33-13	ULG MACH. RECESS	SAME AS 33-9.	MAGNET OPERATED
33-14	URG MACH. RECESS	SAME AS 33-9.	MAGNET OPERATED
33-15	ULG MACH. RECESS	SAME AS 33-11.	MAGNET OPERATED
33-16	URG MACH. RECESS	SAME AS 33-11.	MAGNET OPERATED
33-17	URG GATE RECESS	CLOSES WHEN GATE IS FULLY OPEN.	MAGNET OPERATED
33-18	ULG GATE RECESS	CLOSES WHEN GATE IS FULLY OPEN.	MAGNET OPERATED
33-19	DRG GATE RECESS	CLOSES WHEN GATE IS FULLY OPEN.	MAGNET OPERATED
33-20	DLG GATE RECESS	CLOSES WHEN GATE IS FULLY OPEN.	MAGNET OPERATED
33-21	URV MACH. RECESS	CLOSES WHEN VALVE IS FULLY OPEN.	MAGNET OPERATED
33-22	ULV MACH. RECESS	CLOSES WHEN VALVE IS FULLY OPEN.	MAGNET OPERATED
33-23	DRV MACH. RECESS	CLOSES WHEN VALVE IS FULLY OPEN.	MAGNET OPERATED
33-24	DLV MACH. RECESS	CLOSES WHEN VALVE IS FULLY OPEN.	MAGNET OPERATED
33-25	URG LATCH	CLOSES WHEN GATE LATCH IS CLEAR.	MAGNET OPERATED
33-26	ULG LATCH	CLOSES WHEN GATE LATCH IS CLEAR.	MAGNET OPERATED
33-27	DRG LATCH	CLOSES WHEN GATE LATCH IS CLEAR.	MAGNET OPERATED
33-28	DLG LATCH	CLOSES WHEN GATE LATCH IS CLEAR.	MAGNET OPERATED
33-DG1	DG TOP OF GATE	CLOSES WHEN GATES ARE MITERED.	MAGNET OPERATED
33-DG2	DG MIDDLE OF GATE	CLOSES WHEN GATES ARE MITERED.	MAGNET OPERATED
33-DG3	DG BOTTOM OF GATE	CLOSES WHEN GATES ARE MITERED.	MAGNET OPERATED
33-UG1	UG TOP OF GATE	CLOSES WHEN GATES ARE MITERED.	MAGNET OPERATED
33-UG2	UG MIDDLE OF GATE	CLOSES WHEN GATES ARE MITERED.	MAGNET OPERATED
33-UG3	UG BOTTOM OF GATE	CLOSES WHEN GATES ARE MITERED.	MAGNET OPERATED
33PL1	URG MACH. RECESS	CLOSES WHEN GATE IS 50% OUT OF THE RECESS.	MAGNET OPERATED
33PL2	ULG MACH. RECESS	CLOSES WHEN GATE IS 50% OUT OF THE RECESS.	MAGNET OPERATED
33PL3	DRG MACH. RECESS	CLOSES WHEN GATE IS 50% OUT OF THE RECESS.	MAGNET OPERATED
33PL4	DLG MACH. RECESS	CLOSES WHEN GATE IS 50% OUT OF THE RECESS.	MAGNET OPERATED

Figure B–86. Plate 86: Lock gates and operating equipment, electrical systems, valve/gate control schematic (sheet 5 of 5)

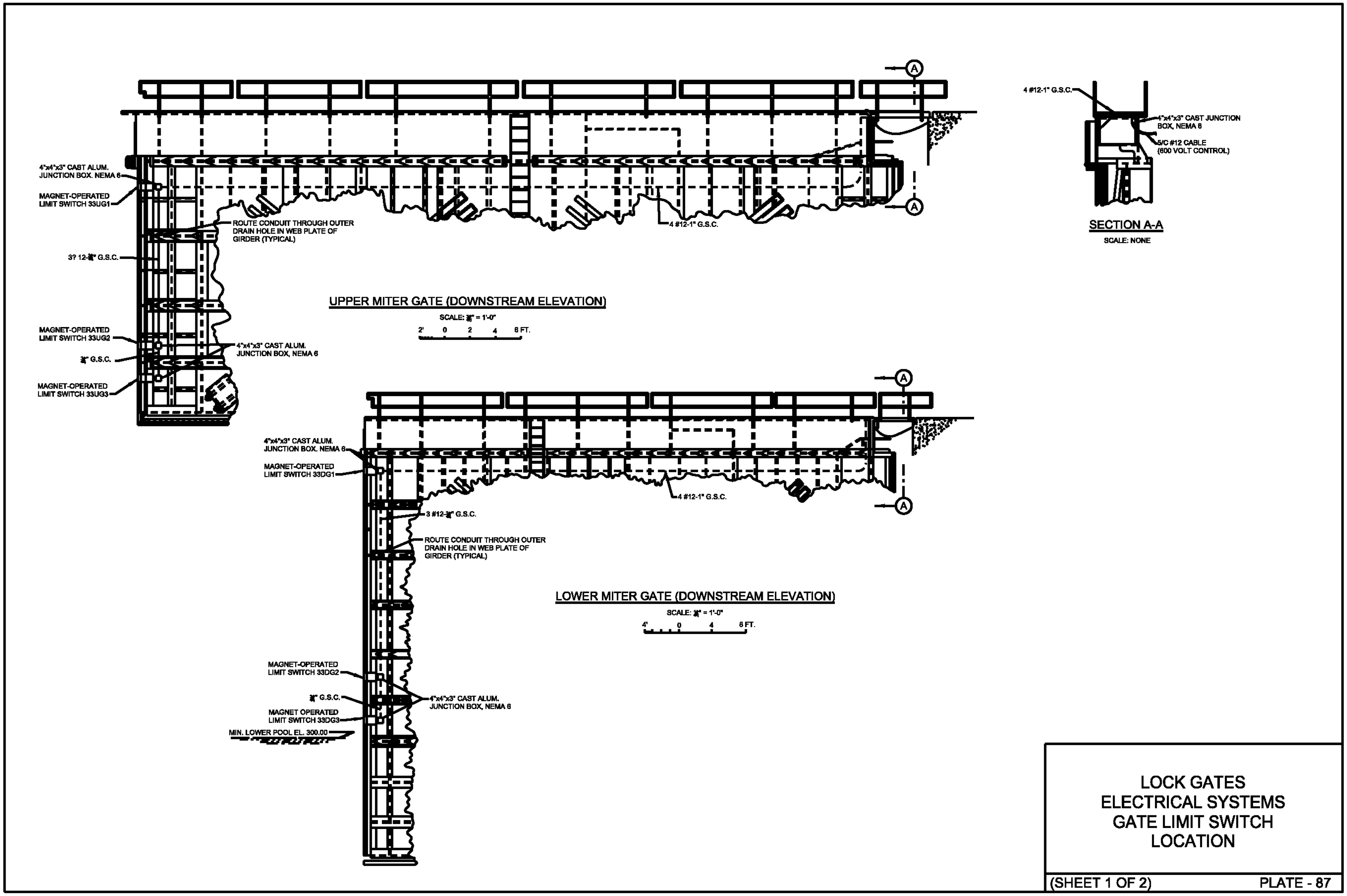


Figure B–87. Plate 87: Lock gates electrical systems, gate limit switch location (sheet 1 of 2)

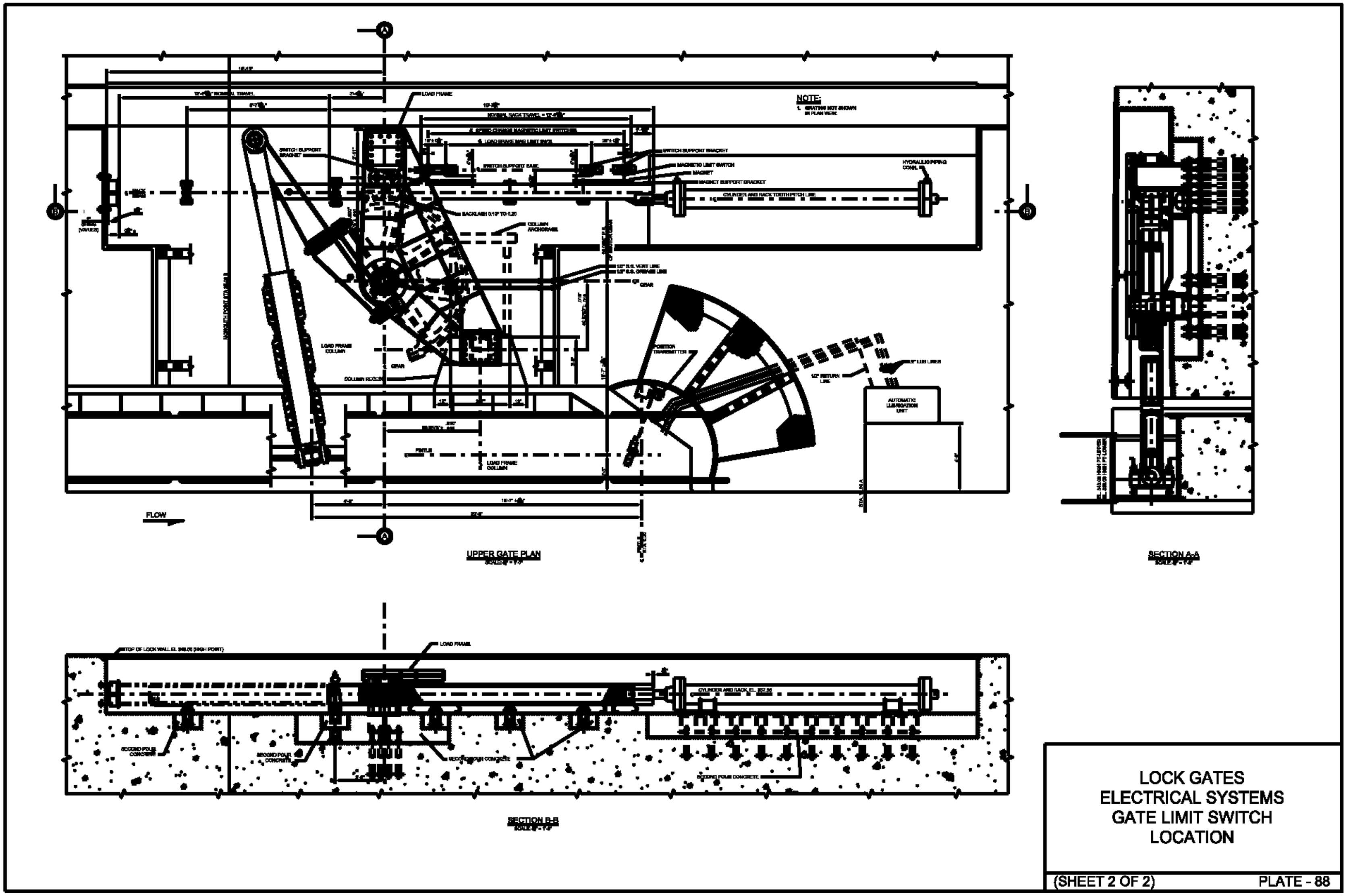


Figure B–88. Plate 88: Lock gates electrical systems, gate limit switch location (sheet 2 of 2)

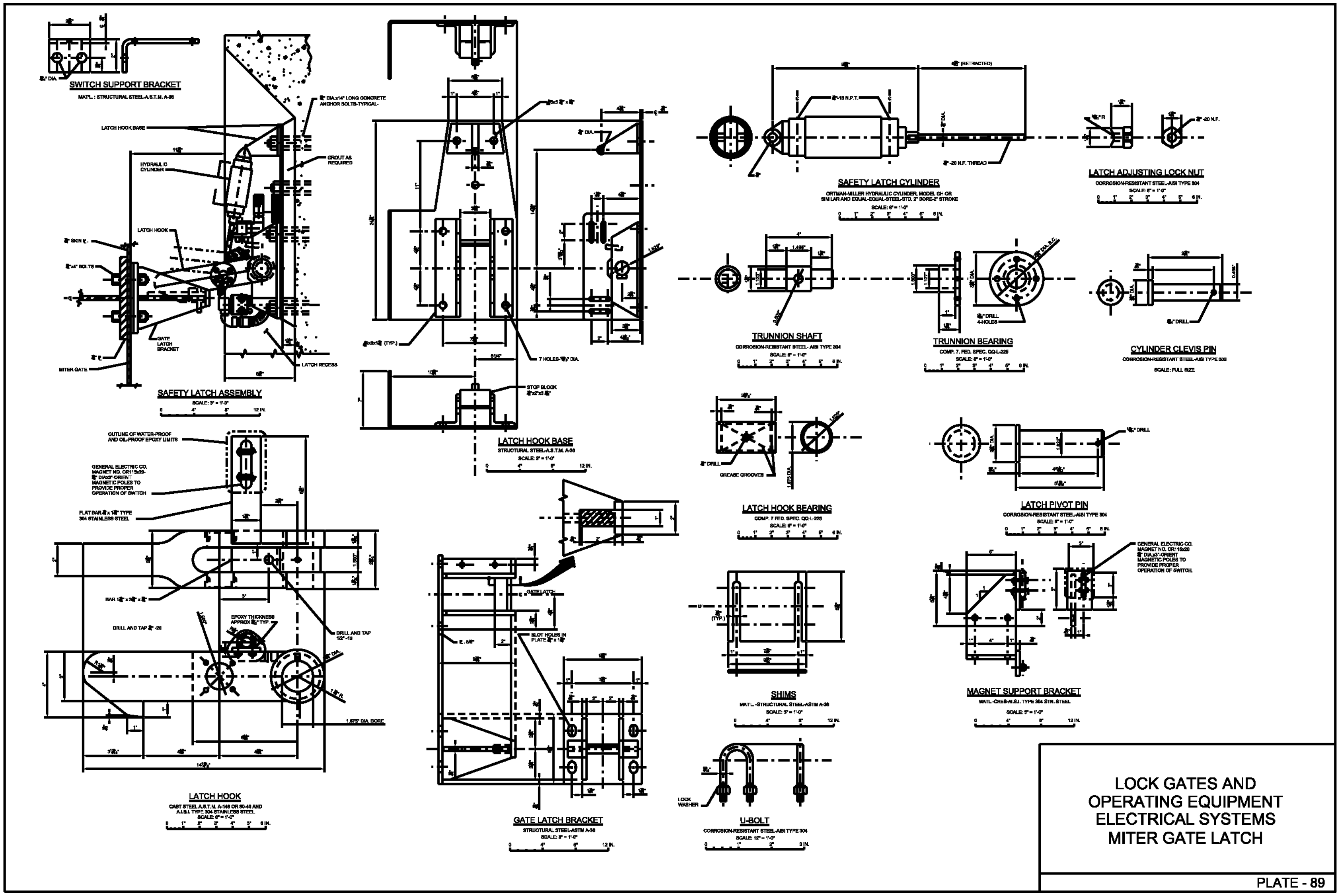
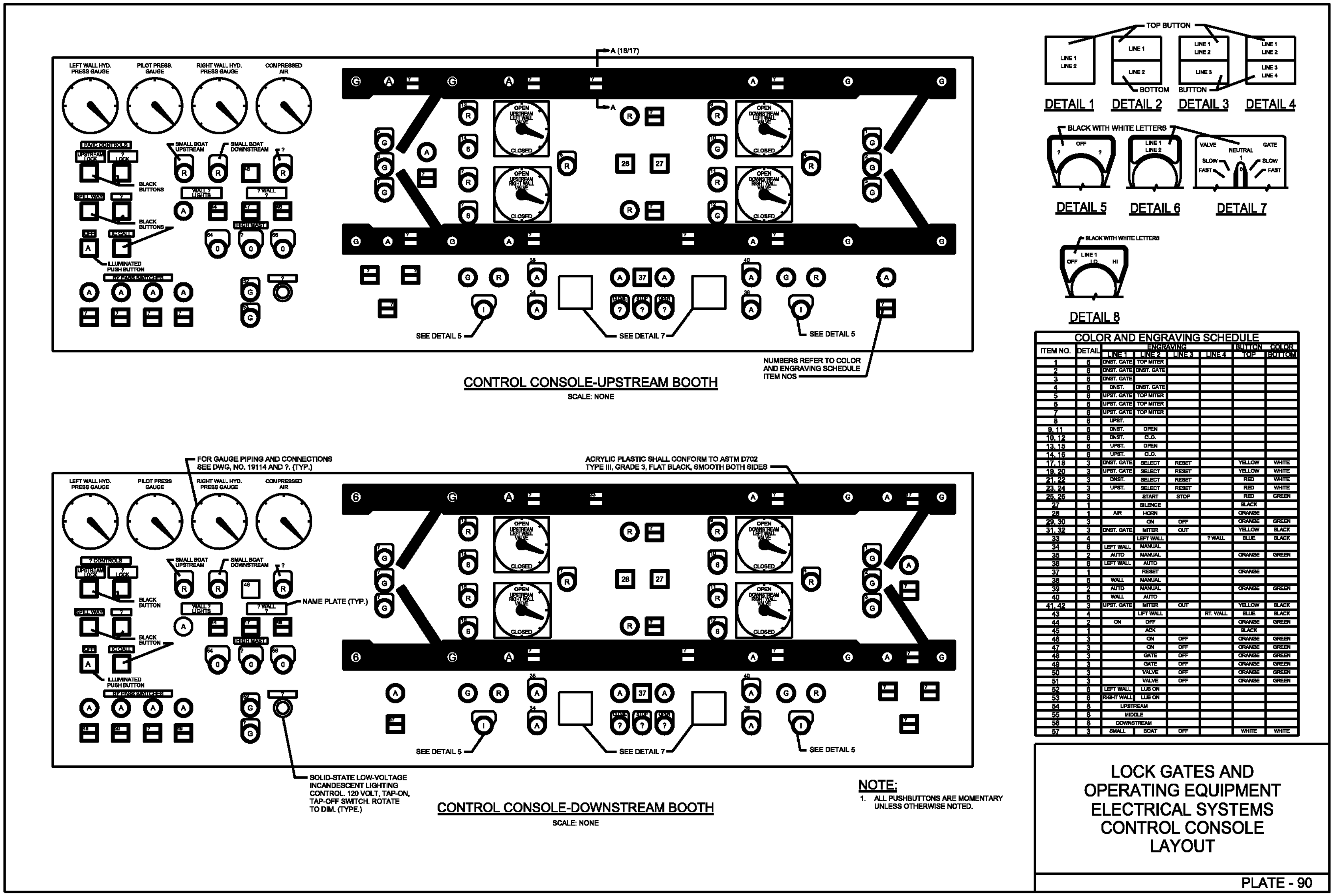


Figure B–89. Plate 89: Lock gates and operating equipment, electrical systems, miter gate latch



COLOR AND ENGRAVING SCHEDULE

ITEM NO.	DETAIL	ENGRAVING LINE 1	ENGRAVING LINE 2	ENGRAVING LINE 3	ENGRAVING LINE 4	BUTTON COLOR TOP	BUTTON COLOR BOTTOM
1	6	DNST. GATE	TOP MITER				
2	6	DNST. GATE	DNST. GATE				
3	6	DNST. GATE					
4	6	DNST.	DNST. GATE				
5	6	UPST. GATE	TOP MITER				
6	6	UPST. GATE	TOP MITER				
7	6	UPST. GATE	TOP MITER				
8	6	UPST.					
9, 11	6	DNST.	OPEN				
10, 12	6	DNST.	CLO.				
13, 15	6	UPST.	OPEN				
14, 16	6	UPST.	CLO.				
17, 18	3	DNST. GATE	SELECT	RESET		YELLOW	WHITE
19, 20	3	UPST. GATE	SELECT	RESET		YELLOW	WHITE
21, 22	3	DNST.	SELECT	RESET		RED	WHITE
23, 24	3	UPST.	SELECT	RESET		RED	WHITE
25, 26	3		START	STOP		RED	GREEN
27	1		SILENCE			BLACK	
28	1	AIR	HORN			ORANGE	
29, 30	3		ON	OFF		ORANGE	GREEN
31, 32	3	DNST. GATE	MITER	OUT		YELLOW	BLACK
33	4		LEFT WALL		? WALL	BLUE	BLACK
34	6	LEFT WALL	MANUAL				
35	2	AUTO	MANUAL			ORANGE	GREEN
36	6	LEFT WALL	AUTO				
37	1		RESET			ORANGE	
38	6	WALL	MANUAL				
39	2	AUTO	MANUAL			ORANGE	GREEN
40	6	WALL	AUTO				
41, 42	3	UPST. GATE	MITER	OUT		YELLOW	BLACK
43	4		LIFT WALL		RT. WALL	BLUE	BLACK
44	2	ON	OFF			ORANGE	GREEN
45	1		ACK			BLACK	
46	3		ON	OFF		ORANGE	GREEN
47	3		ON	OFF		ORANGE	GREEN
48	3		GATE	OFF		ORANGE	GREEN
49	3		GATE	OFF		ORANGE	GREEN
50	3		VALVE	OFF		ORANGE	GREEN
51	3		VALVE	OFF		ORANGE	GREEN
52	6	LEFT WALL	LUB ON				
53	6	RIGHT WALL	LUB ON				
54	8	UPSTREAM					
55	8	MIDDLE					
56	8	DOWNSTREAM					
57	3	SMALL	BOAT	OFF		WHITE	WHITE

LOCK GATES AND OPERATING EQUIPMENT ELECTRICAL SYSTEMS CONTROL CONSOLE LAYOUT

PLATE - 90

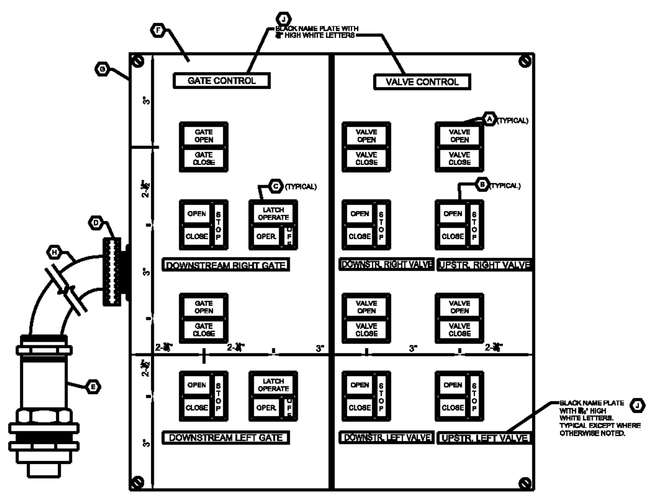
Figure B–90. Plate 90: Lock gates and operating equipment, electrical systems, control console layout

MATERIAL LIST

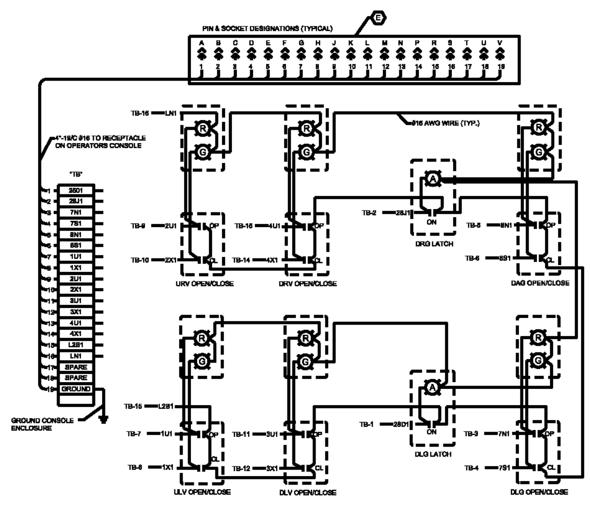
ITEM	DESCRIPTION	MANUFACTURER	CATALOG NO.	NO. REQ'D
A	DUAL INDICATING LIGHT UNIT TRANSFORMER TYPE RED LENS TO READ "VALVE OPEN" OR "GATE OPEN" AND GREEN LENS TO READ "VALVE CLOSE" OR "GATE CLOSE" AS SHOWN	CUTTER HAMMER	E3DCA INDICATOR E3DKGIO RED LENS E3DKG20 GREEN LENS	6 6 6
B	TWO-BUTTON OPERATOR WITH BLACK RELEASE BAR MAINTAINED CONTACT RED BUTTON MARKED "OPEN" AND GREEN BUTTON MARKED "CLOSE". 2 N.O. CONTACTS. OPEN AND CLOSED BUTTONS ARE MECHANICALLY INTERLOCKED. STOP RELEASES DEPRESSED BUTTON		E3QAG OPERATOR KC200 RED BUTTON KC300 GREEN BUTTON E3DKLA1 CONTACT BLOCKS E3DKTG FULL SHROUD	6 6 6 12 6
C	SINGLE-BUTTON OPERATOR WITH "OFF" RELEASE BAR AND TRANSFORMER TYPE INDICATING LIGHT. AMBER LENS TO READ "LIGHT OPERATE" YELLOW BUTTON "OPER" RED BUTTON "OFF"	CUTTER HAMMER	E300G OPERATOR E3DKG30 AMBER LENS E3DKC400 YELLOW BUTTON E3DKLAI CONTACT BLOCK (1 N.O.) E3DNTG FULL SHROUD	2 2 2 2 2
D	WATERTIGHT CABLE CONNECTION		CGB 296	1
E	CABLE PLUG WITH MATCHING SQUARE-FLANGED RECEPTACLE WITH WIRE-SEALED GROMMETS AND DUST CAP 19-WIRE, 19-POLE	ITT CANNON ELECTRIC	CV3456W22-14PN PLUG CV3450W22-14SN RECEPT	1 1
F	TERMINAL BLOCK IS 20 TERMINALS WITH MARKER STRIP IMPRINTED WITH 1/8" LETTERS AS SHOWN ON CONSOLE WIRING DIAGRAM MOUNT INSIDE CONSOLE INSULATED TERMINALS ON WIRES.	TRO CINCH CONNECTORS AMP	345-11-20-001, BLOCK 364-11-20-010, MARKER 320619 WIRE TERMINALS	1 1 34

MATERIAL LIST

ITEM	DESCRIPTION	MANUFACTURER	CATALOG NO.	NO. REQ'D
G	[illegible]"Hx13"Wx4-[illegible]"D ENCLOSURE W/BLANK HINGED COVER NEOPRENE GASKETED 14 GAUGE ALUMINUM 6061-T6 ALL SEAMS CONTINUOUSLY WELDED, RUBBER GROMMENTS ON METAL SURFACE. GROMMENTS TO BE SECURED TO ENCLOSURE WITH SCREWSAND NUTS.			1
H	19/C = 16 CABLE WITHxL POLYETHELYNE INSULATION OVER INDIVIDUAL CONDUCTORS WITH OVERALL NEOPRENE JACKET	GENERAL ELECTRIC	S1-58109	10 FT
J	ENGRAVED NAMEPLATE BAKELITE OR AN EQUIVALENT PLASTIC WITH [illegible]" INCH MINIMUM THICKNESS FASTENED TO CONSOLE WITH TWO CORROSION-RESISTANT ROUNDHEAD SCREWS.			8



DOWNSTREAM PORTABLE BACKUP CONSOLE



PORTABLE BACKUP CONSOLE
WIRING DIAGRAM

LOCK GATES AND
OPERATING EQUIPMENT
ELECTRICAL SYSTEMS
BACKUP CONTROL
CONSOLE

PLATE - 91

Figure B–91. Plate 91: Lock gates and operating equipment, electrical systems, backup control console

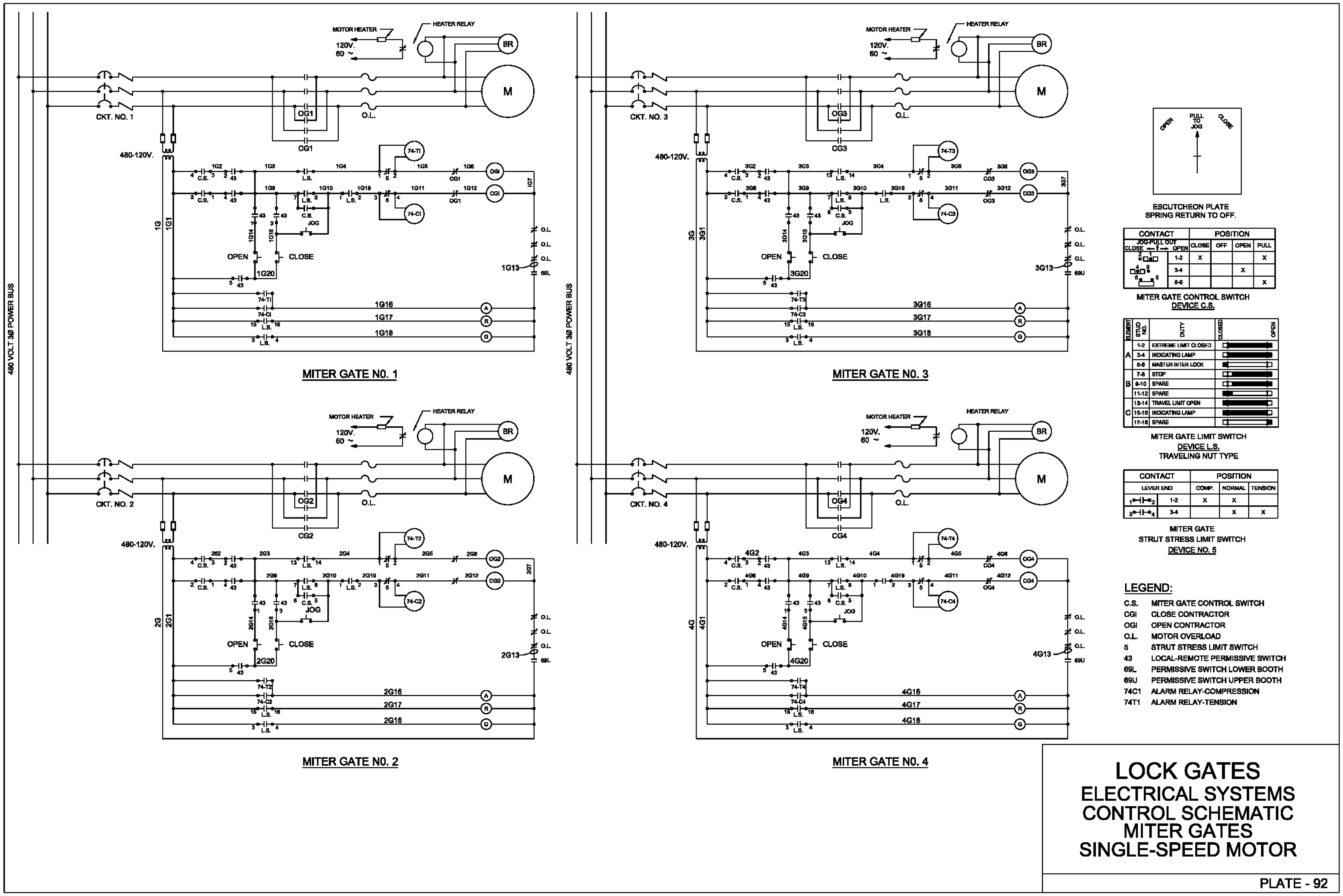


Figure B–92. Plate 92: Lock gates, electrical system control schematic, miter gates, single speed motor

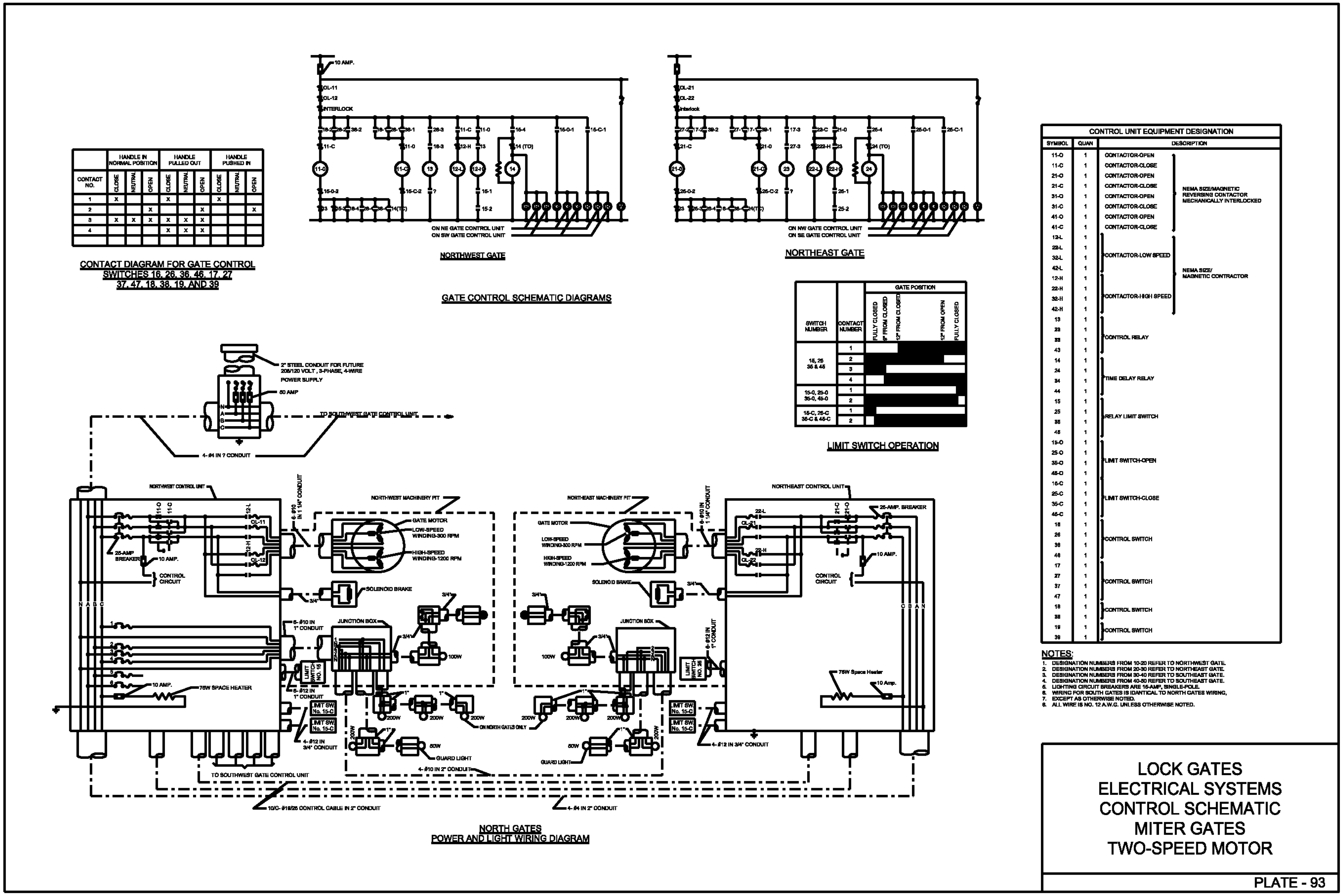


Figure B–93. Plate 93: Lock gates, electrical systems control schematic, miter gates, two-speed motor

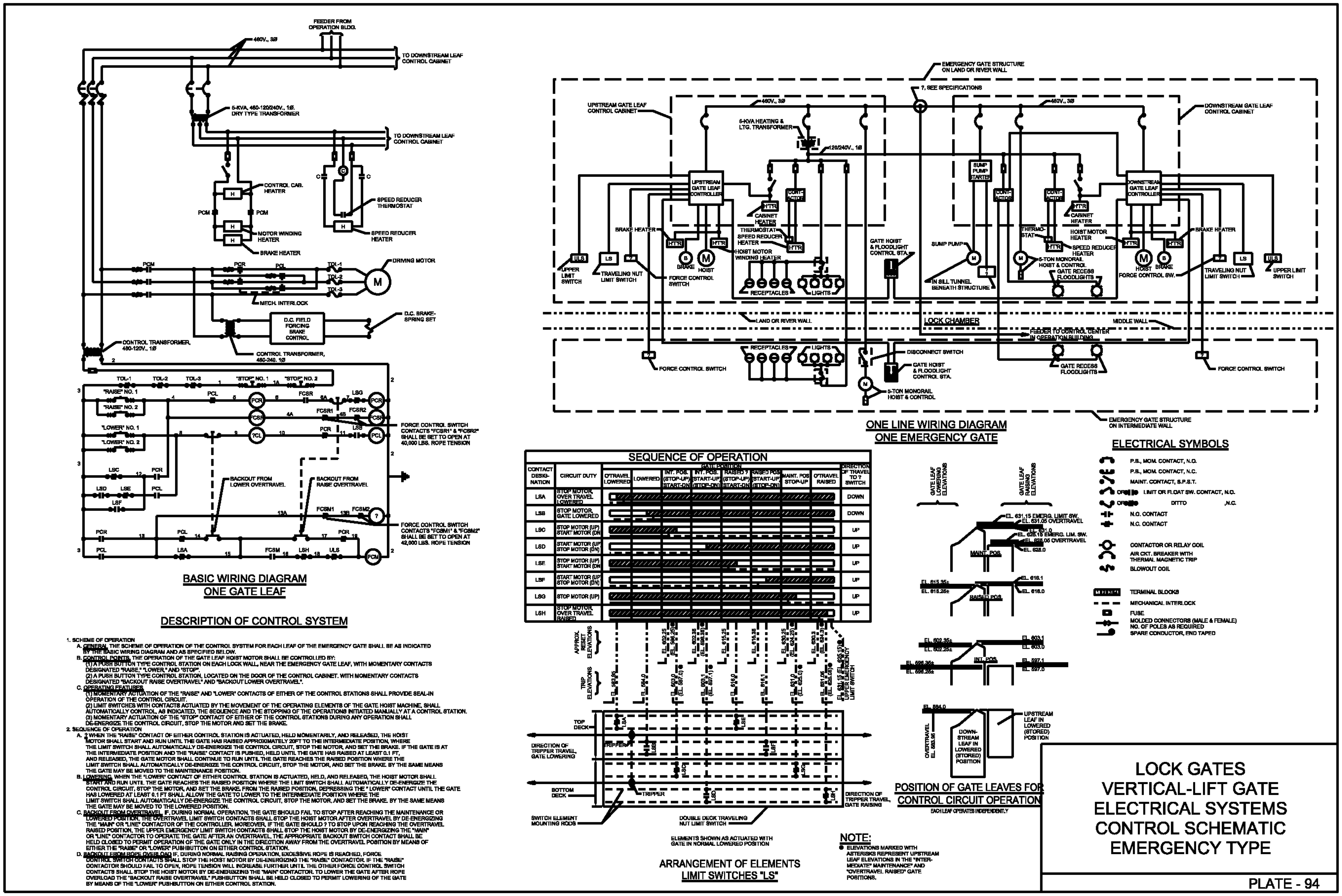


Figure B–94. Plate 94: Lock gates, vertical-lift gate, electrical systems control schematic, emergency type

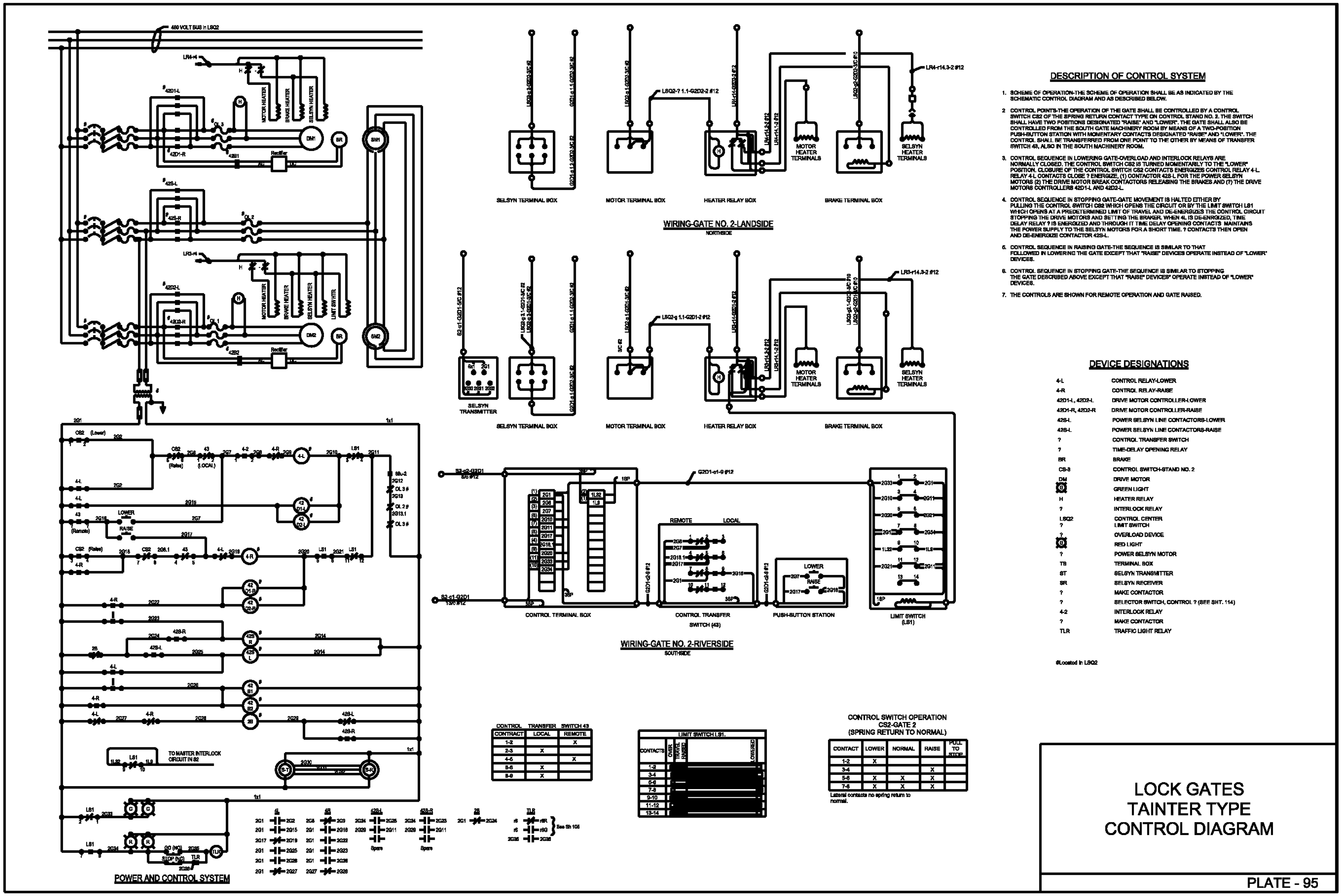


Figure B–95. Plate 95: Lock gates, tainter type, control diagram

B–14. Reference drawings to support Appendix C tainter gate calculations

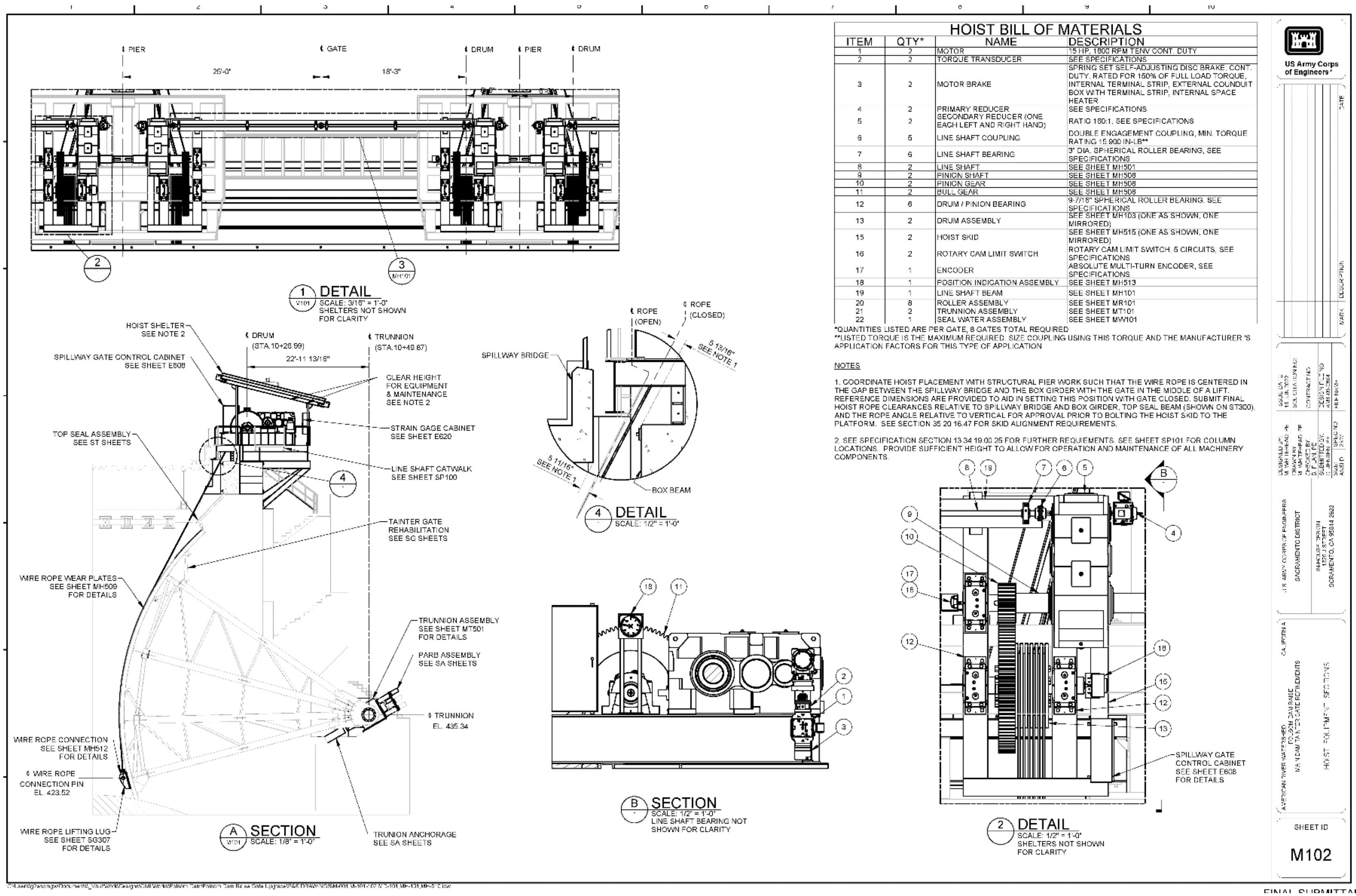


Figure B–96. Plate M 102: Hoist equipment sections

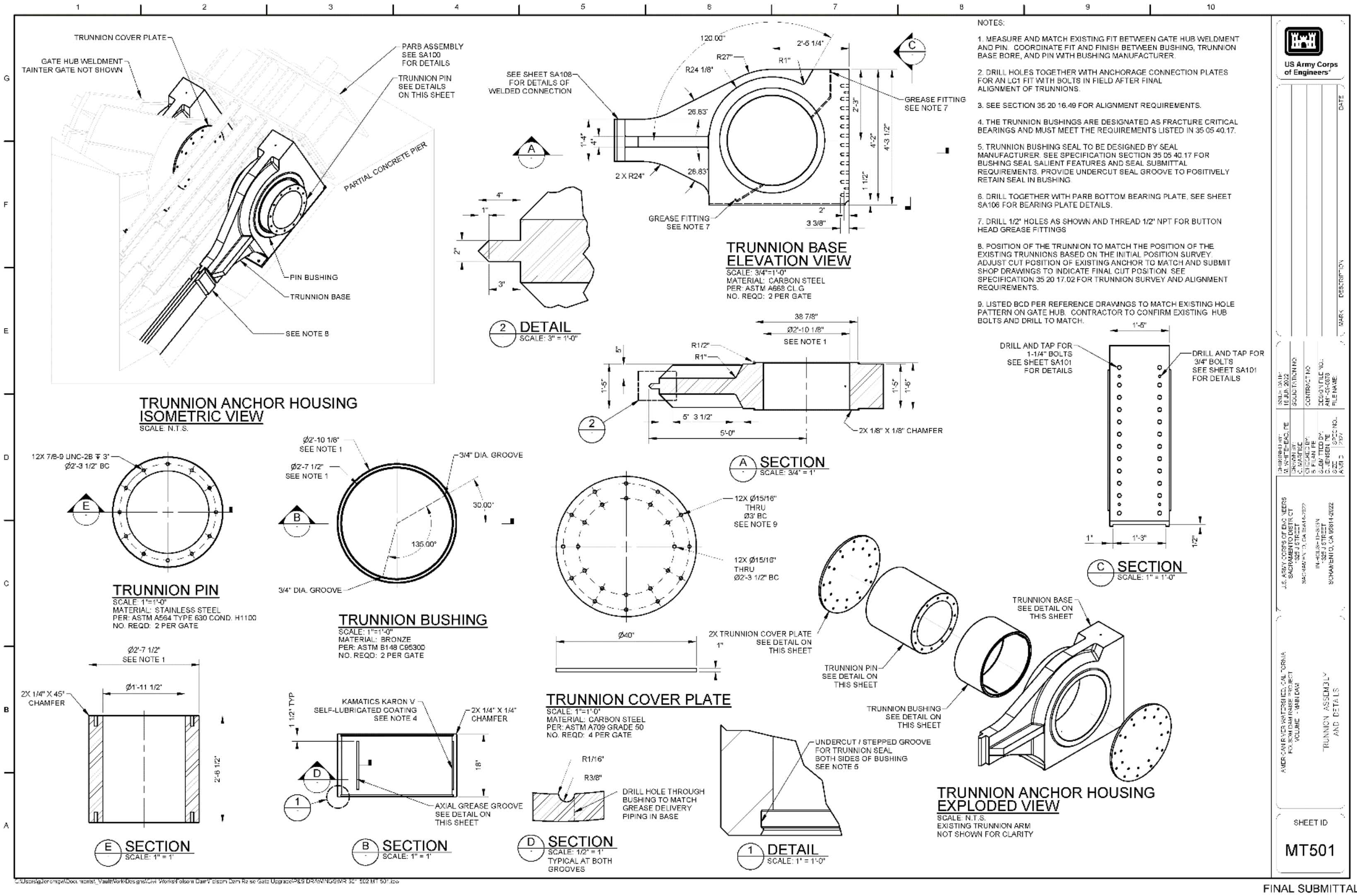


Figure B–97. Plate MT 501: Trunnion assembly and details

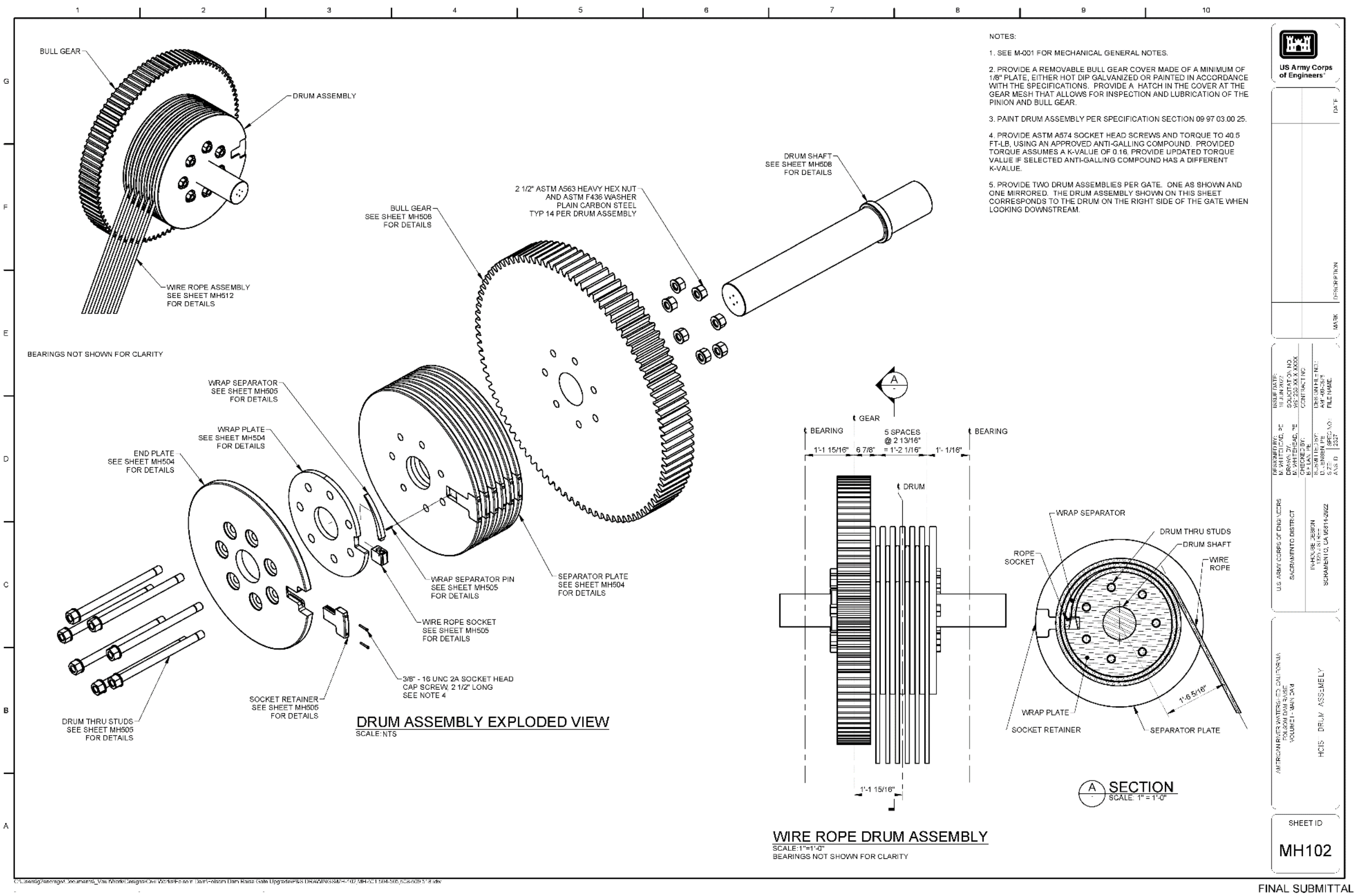


Figure B–98. Plate MH 102: Wire rope drum assembly

Appendix C
Calculations

C–1. Overview

a. This appendix provides information regarding the calculations for several different types of machinery and is provided separately from the EM 1110-2-2610 document. This information is relevant for calculating hoist loading, sector gate machinery loads, miter gate machinery loads, vertical lift gate loads, and tow haulage unit loading. This information should be referenced anytime these calculations are done for either new machinery or rehabilitated machinery. For additional information, the designer should reach out to the USACE Mechanical Engineering Community of Practice Lead (Civil Works) at HQ in Washington DC at the following link: https://www.usace.army.mil/Contact/.

b. The calculations provided include hoist machinery calculations for a tainter gate described and summarized below from Folsom Dam. This includes sizing of all machinery drive components including motor and gearbox and open gears and wire rope sizes. Other example tainter gate hoist calculations are also provided as well as sector gate and miter gate machinery calculations. Sector gate calculations include both direct head and reverse head conditions. Miter gate calculations are based on the Waterways Experiment Station 2-651 (USACE 1964) modeling report. The miter gate calculations also include the direct connect Claiborne model. Appendix C concludes with vertical lift gate machinery calculations and tow haulage unit sizing calculations.

C–2. List of calculation sheets included in the official file

a. Tainter Gate calculations (Folsom Dam).

(1) Part 1: Load Case A equipment loads.

(2) Part 2: Load Case B equipment loads.

(3) Part 3: Load Case C equipment loads.

(4) Part 4: Line shaft analysis.

(5) Part 5: Line shaft bridge analysis.

(6) Part 6: Open gearing analysis, pinion.

(7) Part 7: Open gearing analysis, bull gear.

(8) Part 8: Hoist drum shaft and drum through stud analysis.

(9) Part 9: Pinion shaft analysis.

(10) Part 10: Wire rope and gate connection component analysis.

(11) Part 11: Trunnion bearing system analysis.

(12) Part 13: Drum end plate analysis.

(13) Part 14: Roller contact stress.

(14) Appendix A: Folsom Dam spillway gate geometry.

(15) Appendix B: Structural load.

(16) Appendix C: Hydrostatic force calculation.

(17) Appendix D: Side seal friction calculation.

(18) Appendix E: Inertial load.

b. Sector gate calculations.

c. Miter gate calculations.

d. Vertical lift gate calculations.

e. Tow haulage unit calculations.

Appendix D
Self-Lubricated Material Failures at Peoria and LaGrange (Memorandum of Record, Extracted Text)

D–1. Overview

The “Damaged Self-Lubricated Pintles – LaGrange and Peoria Locks” Memorandum of Record (MOR), dated 18 August 2020, provides information regarding the miter gate pintle failures at these sites. Detailed photos are provided that show the damage. Observations and likely causes of failures are discussed. For additional information and for the original report, the designer should reach out to the USACE Mechanical Engineering Community of Practice Lead (Civil Works) at HQ in Washington DC at the following link: https://www.usace.army.mil/Contact/.

D–2. Extracted text (as published)

Background

Self-lubricated pintles were used on the upstream miter gates that were installed at LaGrange and Peoria Locks on the Illinois Waterway (IWW). The pintles were installed as part of the miter gate replacements at Peoria (October 2017) and LaGrange (March 2018). The new upstream miter gates weigh approximately 60% more than the original gates because of updated design criteria, which now includes barge impact, and the standardization of gate components. Self-lubricated pintles were procured as a contract modification after it was discovered that the short upstream gates (17.5-ft tall) would have an operating bearing pressure of approximately 6,000 psi, which exceeds the 4,500 psi maximum allowable bearing stress of the aluminum bronze bushing and the 2,500 psi maximum bearing stress for greased pintles recommended in EM 1110-2-2610, *Mechanical and Electrical Design for Lock and Dam Operating Equipment*. These relatively low recommended stresses are to prevent galling (material loss or gouging because of adhesion between the sliding surfaces) during operation.

The high bearing pressure can be addressed by increasing the material strength of the bushing and ball for a greased application, increasing the pintle ball size, using a self-lubricated bushing that can operate at higher bearing pressures, or decreasing bearing stresses by using buoyancy chambers on the gate. Buoyancy chambers have a poor maintenance and reliability record since they often fill with water due to localized deterioration. Increasing the material strength of a greased application would not have addressed the galling susceptibility. Increasing the pintle ball size would have resulted in drastic geometrical modifications and non-standard sizes. As such, using a higher strength self-lubricated bushing was the preferred alternative.

Appendix E
Regulating Outlet Report

E–1. Overview

a. This appendix provides information regarding the standardized Regulating Outlet (RO) Report prepared by the Portland District and completed in May 2023. The full report is provided separately from the EM 1110-2-2610 document; however, this information is relevant for all RO new designs and rehabilitations. For additional information, the designer should reach out to the USACE Mechanical Engineering Community of Practice Lead (Civil Works) at HQ in Washington DC at the following link: https://www.usace.army.mil/Contact/.

b. USACE operates Reservoir ROs that are critical for water management and flood damage reduction. ROs are used throughout USACE districts and are an integral part of dam safety. Due to their age, condition, and criticality, many ROs are currently scheduled for rehabilitation. This standardization effort serves as an opportunity to optimize the RO systems and standardize the new design across all USACE districts.

E–2. Purpose

The purpose of this report is to define RO nomenclature, outline the criteria and constraints, and determine the scope of rehabilitation. This report provides design alternatives and recommends a standard design for future RO rehabilitations. Future RO rehabilitations are expected to use this report as a baseline and tailor design features to site-specific needs. This approach is expected to streamline future design processes, incorporate lessons learned, and reduce the cost to operate and maintain these systems.