ENGINEER MANUAL

EM 1110-3-141
April 1984

ENGINEERING AND DESIGN

# Airfield Flexible Pavement

# Mobilization Construction

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, D.C. 20314

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Engineering and Design
AIRFIELD FLEXIBLE PAVEMENT
Mobilization Construction

1. Purpose. This manual provides guidance for designing airfield flexible pavement for U.S. Army mobilization facilities.

2. Applicability. This manual is applicable to all field operating activities having mobilization construction responsibilities.

3. Discussion. Criteria and standards presented herein apply to construction considered crucial to a mobilization effort. These requirements may be altered when necessary to satisfy special conditions on the basis of good engineering practice consistent with the nature of the construction. Design and construction of mobilization facilities must be completed within 180 days from the date notice to proceed is given with the projected life expectancy of five years. Hence, rapid construction of a facility should be reflected in its design. Time-consuming methods and procedures, normally preferred over quicker methods for better quality, should be de-emphasized. Lesser grade materials should be substituted for higher grade materials when the lesser grade materials would provide satisfactory service and when use of higher grade materials would extend construction time. Work items not immediately necessary for the adequate functioning of the facility should be deferred until such time as they can be completed without delaying the mobilization effort.

FOR THE COMMANDER:

PAUL F. KAVANAUGH
Colonel, Corps of Engineers
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DEPARTMENT OF THE ARMY
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# CHAPTER 1

# INTRODUCTION

1-1. Purpose and scope. This manual prescribes the standards to be used for airfield flexible pavement design for mobilization construction at Army installations.

1-2. Traffic classes. Airfield pavement areas have been categorized according to the weight of the using aircraft and the distribution of the traffic. Criteria for airfield pavement classes are presented in table 1-1.

1-3. Definition. Flexible pavements are so designated due to their flexibility under load and their ability to withstand small degrees of settlement without serious detriment. The design of a flexible pavement structure is based on the requirement to limit the deflections under load and to reduce the stresses transmitted to the natural subsoil. The principal components of the pavement include a bituminous concrete surface, a high-quality base course or stabilized material, and a subbase course. Figure 1-1 defines the components and the terminology used in flexible pavements. Examples of flexible pavements utilizing stabilized layers are shown in figures 1-2 and 1-3.

1-4. Use of flexible pavements. The use of flexible pavements on airfields must be limited to those areas not subjected to detrimental effects of jet fuel spillage and jet blast. Asphalt surfaced pavements have little resistance to jet fuel spillage and jet blast, and their use is limited in areas where these effects are severe. Flexible pavements are generally satisfactory for runway interiors, taxiways, shoulders, and overruns. Special types of flexible pavement (that is, tar rubber) or rigid pavement should be specified in critical operational areas.

Table 1-1. Pavement Loading Classifications*

| Class | Planned Aircraft Traffic | Design Basis |
|---|---|---|
| I | Rotary- and fixed-wing aircraft with maximum gross weights equal to or less than 20,000 pounds. | Class I pavement will accommodate all Army fixed-wing and rotary wing aircraft except the CH-47B/C, CH 54A/B and the proposed Heavy Lift Helicopter. This pavement design will be used for all airfield facilities other than where Class II, III, or IV pavement design is required. The design is based on 25,000 passes of the most critical aircraft in this class. |
| II | Rotary-wing aircraft with maximum gross weights between 20,001 and 50,000 pounds. | Class II pavement design will be used for facilities designated to accommodate the CH-47B/C and CH-54A/B aircraft. The design is based on 25,000 passes of the most critical aircraft in this class. (Note: Accommodation of Heavy Lift Helicopters dependent on further aircraft development). |
| III | Fixed-wing aircraft with maximum gross weights between 20,001 and 175,000 pounds and having one of the indicated gear configurations. | Class III pavement design is suitable for a large number of fixed-wing aircraft currently in the Air Force inventory. The design is based on 5,000 passes of the most critical aircraft in this class. Design criteria relates only to aircraft having one of the following gear configurations:<br><br>Single wheel, tricycle, 100 psi tire pressure.<br><br>Twin wheel, tricycle, 28-inch c. to c. spacing, 226 square inches contact area each tire.<br><br>Single tandem, tricycle, 60-inch c. to c. spacing, 400 square inches contact area each tire. |
| IV | Multiple wheel fixed-wing and rotary-wing aircraft other than those considered for Class III pavement. | Class IV pavement will be of special design based on gear configuration and gear loads of the most critical aircraft planned to use the facility. Class IV pavement design will also be used for facilities normally being designed as Class III pavements when over 5,000 passes of the most critical aircraft in that category are anticipated during the expected life of the pavement. Designs for special gear configurations shall be based on design curves provided in Air Force Manuals. Curves for Air Force Light, Medium, Heavy load and short field are included for reference. See table 7-1. |

* Type B traffic areas include all runways, primary taxiways, warmup aprons, and traffic lanes across parking aprons. Type C traffic areas include shoulders, overruns, secondary (ladder) taxiways, parking aprons except for traffic lanes, and other paved areas used by aircraft not included in Type B traffic areas. Type A and D traffic areas will not be considered for Class I, II, and III pavement loadings under mobilization design criteria.

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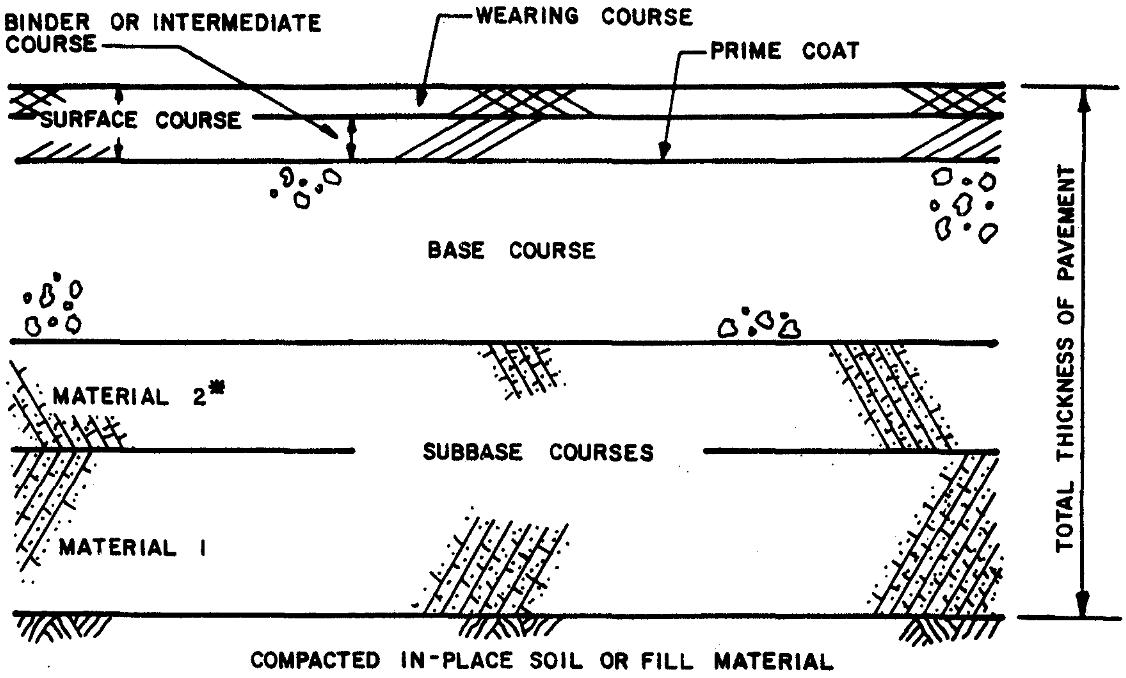


* MATERIAL 2 IS OF A HIGHER QUALITY THAN MATERIAL 1.

| | |
|---|---|
| **PAVEMENT** | Combination of subbase, base, and surface constructed on subgrade. |
| **SURFACE COURSE** | A hot mixed bituminous concrete designed as a structural member with weather and abrasion resisting properties. May consist of wearing and intermediate courses. |
| **PRIME COAT** | Application of a low viscosity liquid bitumen to the surface of the base course. The prime penetrates into the base and helps bind it to the overlying bituminous course. |
| **SEAL COAT** | A thin bituminous surface treatment containing aggregate used to waterproof and improve the texture of the surface course. |
| **COMPACTED SUBGRADE** | Upper part of the subgrade which is compacted to a density greater than the soil below. |
| **TACK COAT** | A light application of liquid or emulsified bitumen on an existing paved surface to provide a bond with the superimposed bituminous course. |
| **SUBGRADE** | Natural in-place soil, or fill material. |

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FIGURE 1-1. TYPICAL FLEXIBLE PAVEMENT AND TERMINOLOGY

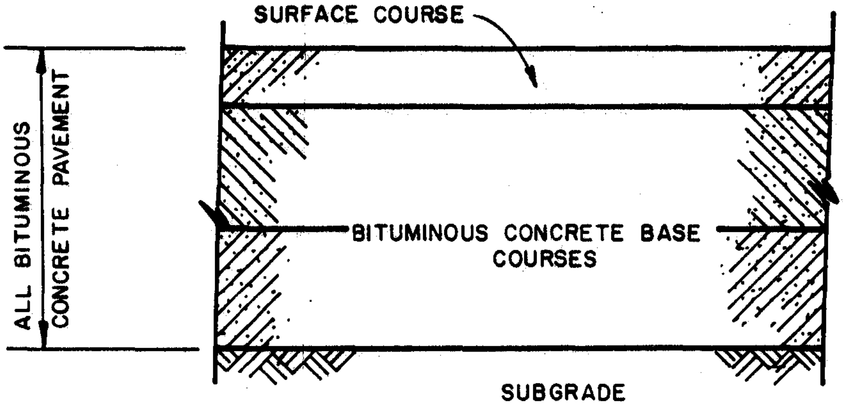


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FIGURE 1-2. TYPICAL ALL BITUMINOUS CONCRETE PAVEMENT

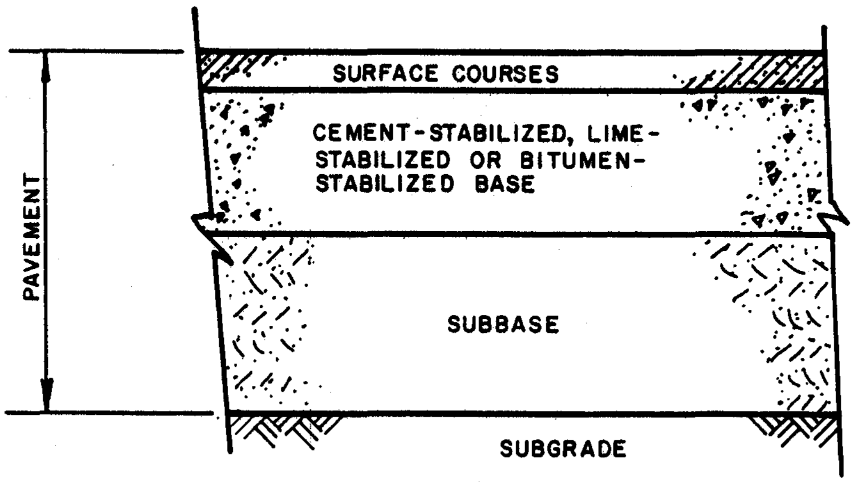


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FIGURE 1-3. TYPICAL STABILIZED BASE SECTION

# CHAPTER 2

# PRELIMINARY DESIGN DATA

2-1. Investigation. Before commencing with the design, complete investigations of the climatic conditions, topographical conditions, subgrade conditions, borrow areas, disposal areas, and sources of subbase, base, paving aggregates, and other paving materials of construction should be made.

a. Previous investigations. Previous subsurface investigations, pavement evaluation reports, construction records, and condition surveys from division, district, station files, and local paving agencies should be utilized to the maximum advantage possible.

b. Publications. Publications and other information from governmental agencies and professional societies as well as state agencies that may define surface and subsurface conditions and drainage patterns should be obtained. (See table 2-1).

Table 2-1. Sources of Information for Preliminary Subsurface Investigations

| Available Material | Source |
|---|---|
| Geologic maps; topographic maps; maps of surface material; aerial photographs | U.S. Geological Survey (USGS). See "USGS Index to Publications," Superintendent of Documents, Washington, DC 20402 |
| Soil maps; reports; aerial photographs | U.S. Department of Agriculture (USDA). See "Bulletin 22-R Transportation Research Board" for listings |
| Aerial photographs; topographic features of coastal areas | National Oceanic and Atmospheric Administration (formerly U.S. C&GS), Rockville, MD 20852 |
| Bulletins; papers on geological subjects | Geological Society of America (GSA) P.O. Box 1719, Boulder, CO 80302. Consult index to GSA |

c. Field reconnaissance. A field reconnaissance with the available topographical, geographical, and soil maps; aerial photographs; meteorological data; previous investigations; condition surveys; and pavement evaluation reports should be made. This step should precede an exploratory boring program.

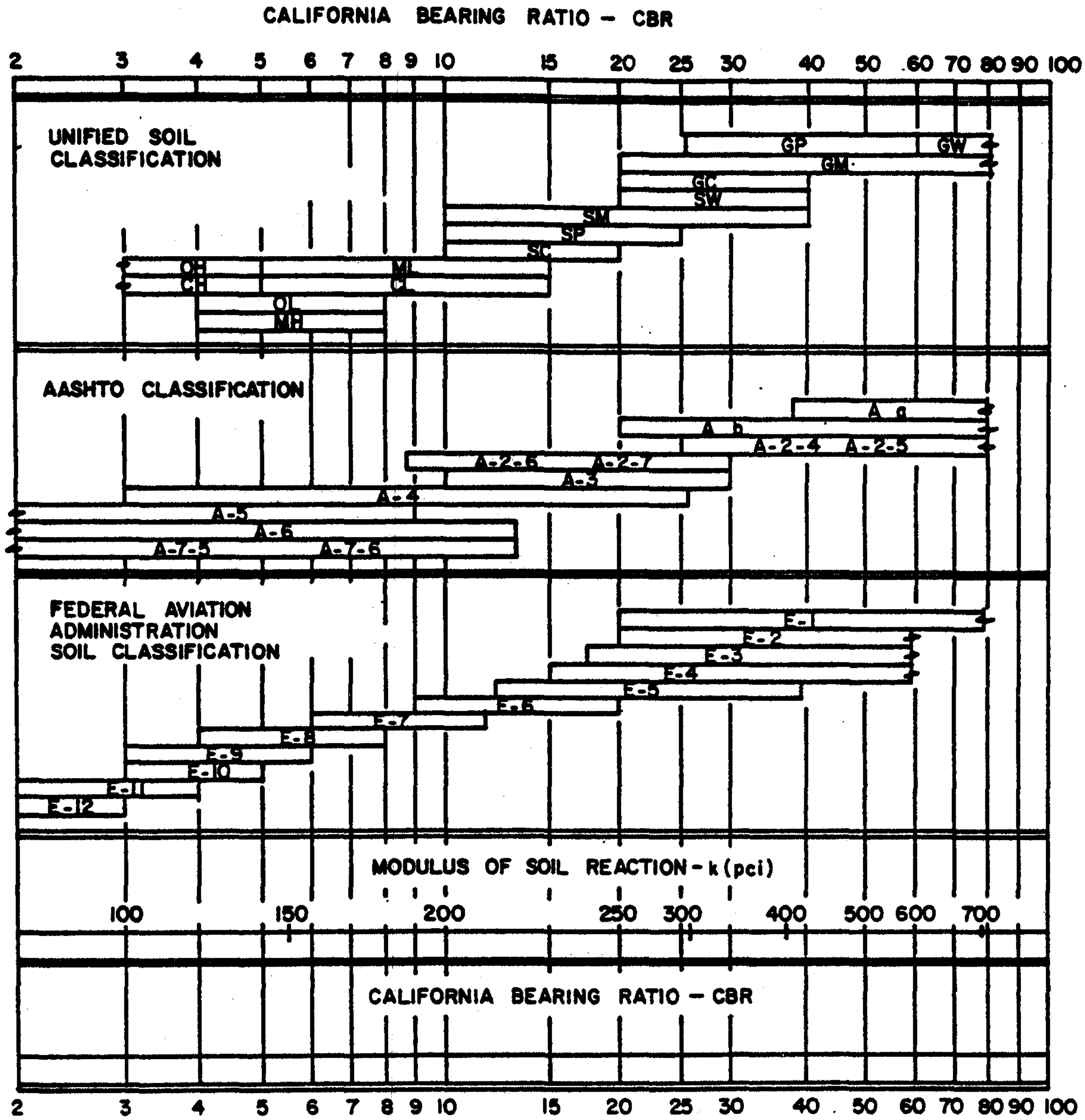
2-2. Exploratory borings. Exploratory borings according to the spacings and depths given in table 2-2 should be conducted. These are minimum values and should be supplemented with additional or deeper borings to cover unusual features. See figure 2-1 and table 2-3 for typical soil profiles and soil characteristics. Use figure 2-1 for approximate relationships between soil classifications and soil strength values when actual test results or existing information is not available.

Table 2-2. Minimum Requirements for Spacing and Depth of Exploratory Borings

| Item | Spacing Requirements |
|---|---|
| Runways and taxiways less than 200 feet wide | 200 to 300 feet on center longitudinally, on alternating sides of the centerline |
| Runways 200 feet wide or greater | two borings every 200 to 300 feet longitudinally, one boring 50 feet on each side of the centerline |
| Parking aprons and pads | one boring per 10,000-square foot area |
| **Item** | **Depth Requirements** |
| Cut areas | to a minimum of 10 feet below finished grade |
| Shallow fill (areas where not more than 6 feet of fill will be placed) | to a minimum of 10 feet below existing ground surface |
| High fill areas | to 50 feet below existing ground surface or to rock |

2-3. Soil classification and tests.

a. Soil classification. All soils will be classified in accordance with the Unified Soil Classification System. There have been instances where the use in construction specifications of such terms as "loam," "gumbo mud," and "muck" have resulted in misunderstandings. These terms are not specific and are subject to different interpretations throughout the United States. Such terms will not be used unless properly identified. Sufficient investigations will be performed at a particular site so that all soils to be used or removed during construction can be described in accordance with the Unified Soil




**PCA Soil Primer (EB007.068), With Permission of the Portland Cement Association, Skokie, IL.**

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FIGURE 2-1. APPROXIMATE INTERRELATIONSHIPS OF SOIL CLASSIFICATION AND BEARING VALUES

## TABLE 2-3. Soil Characteristics Pertinent To Roads and Airfields

| Major Divisions (1) | (2) | Symbol Letter (3) | Symbol Hatching (4) | Symbol Color (5) | Soil Type (6) | Performance Value as Subgrade When Not Subject to Frost Action (7) | Performance Value as Subbase When Not Subject to Frost Action (8) | Performance Value as Base When Not Subject to Frost Action (9) | Potential Frost Action (10) | Compressibility and Expansion (11) | Drainage Characteristics (12) | Compaction Equipment (13) | Unit Dry Weight lb per cu ft (14) | Typical Design Values: CBR (15) | Typical Design Values: Subgrade Modulus k lb per cu in. (16) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COARSE-GRAINED SOILS | GRAVEL AND GRAVELLY SOILS | GW | | Red | Well-graded gravels or gravel-sand mixtures, little or no fines | Excellent | Excellent | Good | None to very slight | Almost none | Excellent | Crawler-type tractor, rubber-tired roller, steel-wheeled roller | 125-140 | 40-80 | 300-500 |
| | | GP | | Red | Poorly graded gravels or gravel-sand mixtures, little or no fines | Good to excellent | Good | Fair to good | None to very slight | Almost none | Excellent | Crawler-type tractor, rubber-tired roller, steel-wheeled roller | 110-140 | 30-60 | 300-500 |
| | | GM d | | Yellow | Silty gravels, gravel-sand-silt mixtures | Good to excellent | Good | Fair to good | Slight to medium | Very slight | Fair to poor | Rubber-tired roller, sheepsfoot roller; close control of moisture | [illegible] | 40-60 | 300-500 |
| | | GM u | | Yellow | | Good | Fair | Poor to not suitable | Slight to medium | Slight | Poor to practically impervious | Rubber-tired roller, sheepsfoot roller | 115-135 | 20-30 | 200-500 |
| | | GC | | Yellow | Clayey gravels, gravel-sand-clay mixtures | Good | Fair | Poor to not suitable | Slight to medium | Slight | Poor to practically impervious | Rubber-tired roller, sheepsfoot roller | 130-145 | 20-40 | 200-500 |
| | SAND AND SANDY SOILS | SW | | Red | Well-graded sands or gravelly sands, little or no fines | Good | Fair to good | Poor | None to very slight | Almost none | Excellent | Crawler-type tractor, rubber-tired roller | 110-130 | 20-40 | 200-400 |
| | | SP | | Red | Poorly graded sands or gravelly sands, little or no fines | Fair to good | Fair | Poor to not suitable | None to very slight | Almost none | Excellent | Crawler-type tractor, rubber-tired roller | 105-135 | 10-40 | 150-400 |
| | | SM d | | Yellow | Silty sands, sand-silt mixtures | Fair to good | Fair to good | Poor | Slight to high | Very slight | Fair to poor | Rubber-tired roller, sheepsfoot roller; close control of moisture | 120-135 | 15-40 | 150-400 |
| | | SM u | | Yellow | | Fair | Poor to fair | Not suitable | Slight to high | Slight to medium | Poor to practically impervious | Rubber-tired roller, sheepsfoot roller | 100-130 | 10-20 | 100-300 |
| | | SC | | Yellow | Clayey sands, sand-clay mixtures | Poor to fair | Poor | Not suitable | Slight to high | Slight to medium | Poor to practically impervious | Rubber-tired roller, sheepsfoot roller | 100-135 | 5-20 | 100-300 |
| FINE-GRAINED SOILS | SILTS AND CLAYS LL IS LESS THAN 50 | ML | | Green | Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity | Poor to fair | Not suitable | Not suitable | Medium to very high | Slight to medium | Fair to poor | Rubber-tired roller, sheepsfoot roller; close control of moisture | 90-130 | 15 or less | 100-200 |
| | | CL | | Green | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays | Poor to fair | Not suitable | Not suitable | Medium to high | Medium | Practically impervious | Rubber-tired roller, sheepsfoot roller | 90-130 | 15 or less | 50-150 |
| | | OL | | Green | Organic silts and organic silt-clays of low plasticity | Poor | Not suitable | Not suitable | Medium to high | Medium to high | Poor | Rubber-tired roller, sheepsfoot roller | 90-105 | 5 or less | 50-100 |
| | SILTS AND CLAYS LL IS GREATER THAN 50 | MH | | Blue | Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts | Poor | Not suitable | Not suitable | Medium to very high | High | Fair to poor | Sheepsfoot roller, rubber-tired roller | 80-105 | 10 or less | 50-100 |
| | | CH | | Blue | Inorganic clays of high plasticity, fat clays | Poor to fair | Not suitable | Not suitable | Medium | High | Practically impervious | Sheepsfoot roller, rubber-tired roller | 90-115 | 15 or less | 50-150 |
| | | OH | | Blue | Organic clays of medium to high plasticity, organic silts | Poor to very poor | Not suitable | Not suitable | Medium | High | Practically impervious | Sheepsfoot roller, rubber-tired roller | 80-110 | 5 or less | 25-100 |
| HIGHLY ORGANIC SOILS | | Pt | | Orange | Peat and other highly organic soils | Not suitable | Not suitable | Not suitable | Slight | Very high | Fair to poor | Compaction not practical | - | - | - |

Note:

1. Column 3, division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is on basis of Atterberg limits; suffix d (e.g., GMd) will be used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u will be used otherwise.
2. In column 13, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment are listed because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of two types may be necessary.
   a. Processed base materials and other angular materials. Steel-wheeled and rubber-tired rollers are recommended for hard, angular materials with limited fines or screenings. Rubber-tired equipment is recommended for softer materials subject to degradation.
   b. Finishing. Rubber-tired equipment is recommended for rolling during final shaping operations for most soils and processed materials.
   c. Equipment size. The following sizes of equipment are necessary to assure the high densities required for airfield construction:
      Crawler-type tractor -- total weight in excess of 30,000 lb.
      Rubber-tired equipment -- wheel load in excess of 15,000 lb, wheel loads as high as 40,000 lb may be necessary to obtain the required densities for some materials (based on contact pressure of approximately 65 to 150 psi).
      Sheepsfoot roller -- unit pressure (on 6- to 12-sq-in. foot) to be in excess of 250 psi and unit pressures as high as 650 psi may be necessary to obtain the required densities for some materials. The area of the feet should be at least 5 percent of the total peripheral area of the drum, using the diameter measured to the faces of the feet.
3. Column 14, unit dry weights are for compacted soil at optimum moisture content for MIL-STD-621, method D 100, CE 55 compaction effort.
4. In column 15, the maximum value that can be used in design of airfields is, in some cases, limited by gradation and plasticity requirements.

(Table V, MIL-STD-619B of 12 June 1968)

Classification System plus any additional description considered necessary. If Atterberg limits, as indicated by the classification tests, are a required part of the description, the test procedures and limits will be referenced in the construction specifications.

b. Soil compaction.

(1) Test Method 100. The soil compaction test described in Test Method 100 of MIL-STD-621 or AASHTO T 99 will be used to determine the compaction characteristics of soils except as noted below. The degree of compaction required is expressed as a percentage of the maximum density obtained by the test procedure presented in MIL-STD-621 Test Method 100, Compaction Effort Designation CE 55. This is usually abbreviated as CE-55 maximum density.

(2) Other control tests. Certain types of soil may require the use of a laboratory compaction control test other than Test Method 100. This method should not be used if the soil contains particles that are easily broken under the blow of the tamper unless the field method of compaction will produce a similar degradation. Also, the unit weight of certain types of sands and gravels obtained in this method is sometimes lower than the unit weight that can be obtained by field methods; hence, this method may not be applicable. Density tests in these cases are usually made under some variation of the test method, such as vibration or tamping (alone or in combination) with some type hammer or effort other than that used in the test in order to obtain a higher laboratory density. Also, in some cases, it is necessary to use actual field compaction test sections.

c. Soil resistance.

(1) CBR test. The California Bearing Ratio (CBR) MIL-STD-621, Test Method 101 or AASHTO T 193 test will be used to evaluate the ability of soils to resist shear deformation. The CBR test is conducted by forcing a 2-inch-diameter piston into the soil. The load required to force the piston into the soil 0.1 inch (sometimes 0.2 inch) is expressed as a percentage of the standard value for crushed stone. The test is valid only when a large part of the deformation under penetration is shear deformation. The test can be performed on samples compacted in test molds, on undisturbed samples, or on material in place. The test must be made on material that represents the prototype condition that will be most critical from a design standpoint. For this reason, samples are generally subjected to a 4-day soaking period. Details of the test procedure are given in MIL-STD-621, Test Method 101. Test Method 101 is suitable for either field or laboratory application.

(2) Supplemental requirements. Laboratory CBR tests on gravelly materials often show CBR values higher than those obtained in the prototype, primarily because of the confining effect of the

6-inch-diameter mold. Therefore the CBR test has been supplemented by gradation and Atterberg limit requirements for gravelly materials.

d. Approximate relationships. Use figure 2-1 for approximate relationships between soil classifications and soil strength values when actual test results or existing information are not available.

2-4. Fill and subbase borrow areas. During reconnaissance, the site will be explored for potential borrow sources. See table 2-3 for comparative values of soils for use as subgrade and subbase; use field approximations of classifications as a guide to desirable sources. During preliminary exploration, samples of borrow materials will be taken to a depth of 2 to 4 feet below the anticipated depth of borrow on 50-foot centers. Surveys of local suppliers to determine the quality and quantity of commercially available fill materials will be made.

2-5. Availability of base and surfacing aggregate. Since these are generally crushed and processed materials, a survey should be made of the commercial suppliers in the general area. Available materials should be sampled, classified, and tested. In remote areas where commercial production is limited or nonexistent, investigate and test for quarry site location near the construction site.

2-6. Availability of other construction materials. Availability and quality of bituminous materials can be sought from the suppliers of these materials. The knowledge of the availability and type of portland cement, lime, fly ash, and other materials will also aid in the evaluation and applicability of structural layers. This information will be helpful in developing designs and alerting designers to unusual local conditions and shortages.

# CHAPTER 3

## SUBGRADE EVALUATION AND PREPARATION

3-1. General. The primary factors affecting subgrade suitability are listed in table 3-1.

3-2. Establishment of grade line. The subgrade line should be established to obtain the optimum natural support for the pavement consistent with economic utilization of available materials.

a. Rock. Rock excavation is to be avoided for economic reasons. Where excavation of rock is unavoidable, undercut to provide for full depth of base course under surface courses.

b. Ground water. The subgrade line will be above the flood plain and a minimum of 2 feet above wet season ground water level. Where not practicable, provide for permanent lowering of water table by drainage. (See EM 1110-3-136).

c. Balancing cut and fill. Balancing cut and fill should be considered but may not be a controlling mobilization factor in the design and construction of airfield pavements. Optimizing subgrade support and drainage should take precedence over balancing cut and fill.

3-3. Subgrade evaluation test by CBR. The basic CBR test is performed on compacted samples of the subgrade soil after a 4-day soaking. Samples are prepared at varying moisture contents and with three differing compactive efforts. The complete procedure is illustrated in figure 3-1 and the test methods are described fully in MIL-STD-621, Method 101. CBR tests can also be performed on the subgrade soil in place or on undisturbed samples of the subgrade soil. However, for design the latter test is used only in special cases. See table 3-2 for additional guidance on the use of CBR tests.

3-4. Subgrade density and compaction. For the CBR method of design, the in-place densities of the subgrade soils for the design aircraft must be at least equal to the values specified in table 3-3. If natural densities are less than the required values, the subgrade may be treated by one of the following procedures, as applicable:

- Compact from the surface (cohesionless soils except silts).

- Remove, process to desired water content, replace in lifts, and compact. Minimum compaction for replaced soils is 95 percent for cohesionless and 90 percent for cohesive soils. For a definition of cohesive and cohesionless soils see MIL-STD-621, Method 101.

Table 3-1. Primary Factors Affecting Subgrade Evaluation and Suitability

| Factor | Remarks |
|---|---|
| Characteristics of subgrade soils | Determine as shown in chapter 2. |
| Relative value as subgrade | See table 2-3. |
| Depth to rock | Determine during exploration of subgrade, if close to surface. |
| Depth to ground water | Determine seasonal fluctuations and effects of drainage. |
| In-place density of subgrade | From undisturbed samples or in-place tests. |
| Strength of subgrade: | |
| Natural condition<br>After compaction<br>Ultimate values | Determine during exploration and testing. Consider ultimate water contents after construction and their effect on strength characteristics. Follow procedure in MIL-STD-621 Method 101. |
| Settlement under fill loading | Determine effect of fill loading from consolidation tests. May require surcharge to consolidate a clay subgrade. Where local settlement data exists it should be used. |
| Frost susceptibility | See EM 1110-3-138 to determine during testing and exploration. |
| Weak or compressive layers in subsoil | Consider compaction, removal and replacement with granular material, or design pavement on basis of in-place strength and density. |
| Drainage | See EM 1110-3-136. |
| Variability of generalized soil profile | May cause differential surface movements. |

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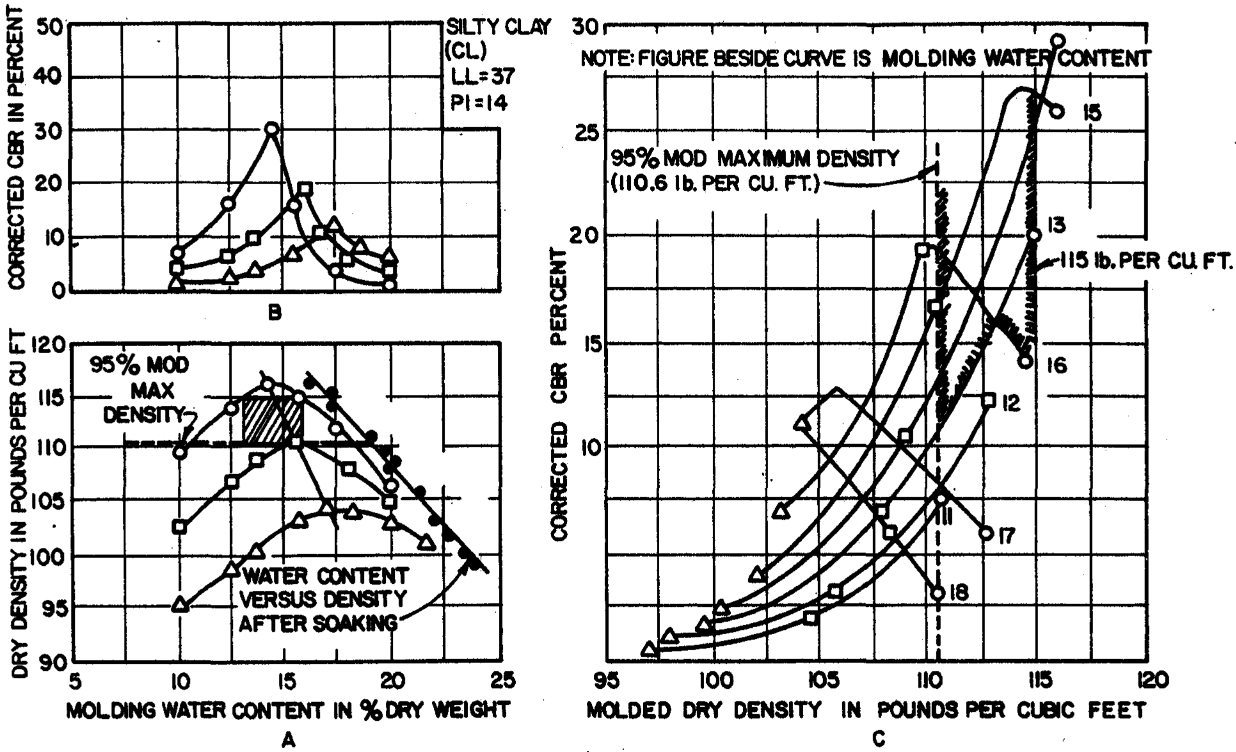


Legend

o= 55 blows/layer compactive effort

□= 26 blows/layer compactive effort

Δ= 12 blows/layer compactive effort

G= Specific gravity of soil

1. Step A. Determine moisture/density relationship (MIL-STD-621 Method 100) at 12.26 and 55 blows/layer. Plot density to which soil can be compacted in the field - for clay of example use 95 percent of maximum density. Plot desired moisture content range - for clay of example use ± 1-1/2 percent of optimum moisture content for approximately 13 and 16 percent. Shaded area represents compactive effort greater than 95 percent and within ± 1-1/2 percent of optimum moisture content.

2. Step B. Plot laboratory CBR (MIL-STD-621 Method 101) for 12.26 and 55 blows/layer.

3. Step C. Plot CBR versus clay density at constant moisture content. Plot attainable limits of compaction from graph A, 110.6 and 115 pcf for example, hatched area represents attainable CBR limits for desired compaction (110.6 to 115 pcf) and moisture content (13 to 16 percent). CBR ranges from 11 (95 percent compaction and 13 percent moisture content) to 26 (15 percent moisture content and maximum compactions). For design purposes use a CBR at low end of range - in example use CBR of 12 with moisture content specified between 13 and 16 percent.

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FIGURE 3-1. PROCEDURE FOR DETERMINING CBR OF SUBGRADE SOILS

Table 3-2. Choice of CBR Tests for Pavement Design

| | |
|---|---|
| Goal: | To design the pavement on the basis of the predominant subgrade moisture content anticipated in the life of the pavement. |
| Basic Test: | In the absence of reliable field information this moisture content is considered to be represented by 4 days soaking of the compacted subgrade soil in the CBR molds. |
| Exceptions: | (1) Where rainfall is light and the ground water table is low, substantial reductions can be made in the pavement thickness developed from soaked CBR tests (see section 7).<br><br>(2) The in-place CBR test may be used for subgrade soils where little increase in moisture is anticipated, such as:<br><br>(a) Coarse grained cohesionless soils.<br><br>(b) Soils which are at least 80 percent saturated in the natural site.<br><br>(c) Soils under existing adjacent pavements which can be used as indicators for the planned construction. Subgrade soils under pavements at least 3 years old are considered to have reached equilibrium moisture conditions. (Caution: Use care in making assumptions regarding similarity of soil types, drainage, and topography).<br><br>(3) Where subgrade compaction is not feasible or desirable as with saturated fine sands or silts, hard clays, and expansive soils, special approaches are necessary (see table 3-5). |

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Table 3-3. Subgrade Compaction Requirements
Depth Below Pavement Surface to Top of Subgrade (feet)

| | Army Class I Pavement | | Army Class II Pavement | | Army Class III Pavement | |
|---|---|---|---|---|---|---|
| | 15 Kip Gross Wt | Less Than 15 Kips | 30 Kip Gross Wt | Less Than 30 Kips | 100 Kip Gross Wt | Less Than 100 Kips |
| Cohesionless Subgrade | | | | | | |
| 100% | | | | | | |
| B | 1.0 | 1.0 | 1.5 | 1.0 | 2.0 | 1.5 |
| C | 1.0 | 0.5 | 1.0 | 0.5 | 1.5 | 1.5 |
| 95% | | | | | | |
| B | 1.5 | 1.5 | 2.0 | 1.5 | 4.0 | 2.5 |
| C | 1.5 | 1.0 | 1.5 | 1.5 | 3.0 | 2.5 |
| 90% | | | | | | |
| B | 2.5 | 2.0 | 3.0 | 2.0 | 6.5 | 4.0 |
| C | 2.0 | 1.5 | 2.5 | 1.5 | 4.5 | 3.5 |
| 85% | | | | | | |
| B | 3.0 | 2.5 | 4.0 | 3.0 | 7.5 | 5.5 |
| C | 2.5 | 2.0 | 3.5 | 2.5 | 6.5 | 5.0 |
| Cohesive Subgrade | | | | | | |
| 100% | | | | | | |
| B | 0.5 | 0.5 | 1.0 | 0.5 | 1.0 | 0.5 |
| C | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| 95% | | | | | | |
| B | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 1.5 |
| C | 1.0 | 0.5 | 1.0 | 0.5 | 2.0 | 1.5 |
| 90% | | | | | | |
| B | 1.5 | 1.0 | 1.5 | 1.5 | 3.0 | 2.0 |
| C | 1.5 | 1.0 | 1.5 | 1.0 | 2.5 | 2.0 |
| 85% | | | | | | |
| B | 1.5 | 1.5 | 2.0 | 1.5 | 4.0 | 3.0 |
| C | 1.5 | 1.0 | 1.5 | 1.5 | 3.5 | 2.5 |

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- Replace with suitable borrow material.

- Raise the grade so that natural densities meet required values.

- Stabilize: See EM 1110-3-137.

Thickness of compacted lifts can vary with type of equipment used, classification of soil, number of passes, and compaction requirements. Guidelines for varying thicknesses of lifts for 95 to 100 percent compaction are shown in table 3-4.

a. Additional requirements. In addition to the above requirements:

(1) Compact subgrade to a minimum of 95 percent for a depth of 6 inches below subbase.

(2) Place fill in subgrades at a minimum of 95 percent compaction for cohesionless soils and 90 percent for cohesive soils.

b. Special cases. Although compaction increases the strength of most soils, some soils lose strength when scarified and recompacted and some soils shrink or expand excessively under moisture changes. When these soils are encountered, special treatment is required. (See table 3-5 for recommended procedures.)

3-5. Subgrade stabilization. Subgrade material may be stabilized (a) to improve the soil quality by reducing plasticity and controlling expansion, (b) to provide a "working platform," and (c) to upgrade the material for use as subbase. Soil stabilization for quality improvement is discussed in EM 1110-3-137.

3-6. Fill quality. In general, coarse grain material is preferred to fine grain material. Fill material should be restricted as follows:

- Do not use expansive soils.

- Do not use peat or organic clays and silts.

Table 3-4. Compaction Equipment and Methods

| Equipment type | Applicability | Compacted lift thickness, in. | Passes or coverages | Dimensions and weight of equipment | Possible variations in equipment |
|---|---|---|---|---|---|
| | | Requirements for Compaction of 95 to 100 Percent Modified AASHTO Maximum Density | | | |
| Sheepsfoot rollers | For fine-grained soils or dirty coarse-grained soils with more than 20 percent passing the No. 200 sieve. Not suitable for clean coarse-grained soils. | 6 | 4 to 6 passes for fine-grained soil; 6 to 8 passes for coarse-grained soil | Soil type / Foot contact area, $in^2$ / Foot contact pressures, psi:<br>Fine-grained soil PI > 30 / 5 to 12 / 250 to 500<br>Fine-grained soil PI < 30 / 7 to 14 / 200 to 400<br>Coarse-grained soil / 10 to 14 / 150 to 250<br>Efficient compaction of soils wet of optimum requires less contact pressures than the same soils at lower moisture contents | For airfield work, drum of 60-in dia., loaded to 1.5 to 3 tons per lineal foot of drum generally is utilized. For smaller projects 40-in dia. drum, loaded to 0.75 to 1.75 tons per lineal foot of drum is used. Foot contact pressure should be regulated so as to avoid shearing soil on the third or fourth pass. |
| Rubber tire rollers | For clean, coarse-grained soils with 4 to 8 percent passing the No. 200 sieve. | 10 | 3 to 5 coverages | Tire inflation pressures of 60 to 80 psi for clean granular material or base course and subgrade compaction. Wheel load 18,000 to 25,000 lb. | Wide variety of rubber tire compaction equipment is available. For cohesive soils, light-wheel loads, such as provided by wobble-wheel equipment, may be substituted for heavy-wheel load if lift thickness is decreased. For cohesionless soils, large-size tires are desirable to avoid shear and rutting. |
| | For fine-grained soils or well-graded, dirty coarse-grained soils with more than 8 percent passing the No. 200 sieve. | 6 to 8 | 4 to 6 coverages | Tire inflation pressures in excess of 65 psi for fine-grained soils of high plasticity. For uniform clean sands or silty fine sands, use large size tires with pressure of 40 to 50 psi. | |
| Smooth wheel rollers | Appropriate for subgrade or base course compaction of well-graded sand-gravel mixtures. | 8 to 12 | 4 coverages | Tandem type rollers for base course or subgrade compaction, 10 to 15 ton weight, 300 to 500 lb per lineal inch of width of rear roller. | 3-wheel rollers obtainable in wide range of sizes. 2-wheel tandem rollers are available in the range of 1 to 20 ton weight. 3-axle tandem rollers are generally used in the range of 10 to 20 ton weight. Very heavy rollers are used for proof rolling of subgrade or base course. |
| | May be used for fine-grained soils other than in earth dams. Not suitable for clean well-graded sands or silty uniform sands. | 6 to 8 | 6 coverages | 3-wheel roller for compaction of fine-grained soil; weights from 5 to 6 tons for materials of low plasticity to 10 tons for materials of high plasticity. | |
| Vibrating baseplate compactors | For coarse-grained soils with less than about 12 percent passing No. 200 sieve. Best suited for materials with 4 to 8 percent passing No. 200, placed thoroughly wet. | 8 to 10 | 3 coverages | Single pads or plates should weigh no less than 200 lb. May be used in tandem where working space is available. For clean coarse-grained soil, vibration frequency should be no less than 1,600 cycles per minute. | Vibrating pads or plates are available, hand-propelled or self-propelled, single or in gangs, with width of coverage from 1-1/2 to 15 ft. Various types of vibrating-drum equipment should be considered for compaction in large areas. |
| Crawler tractor | Best suited for coarse-grained soils with less than 4 to 8 percent passing No. 200 sieve, placed thoroughly wet. | 10 to 12 | 3 to 4 coverages | No smaller than D8 tractor with blade, 34,500 lb weight, for high compaction. | Tractor weights up to 60,000 lb. |
| Power tamper or rammer | For difficult access, trench backfill. Suitable for all inorganic soils. | 4 to 6 in. for silt or clay, 6 in. for coarse-grained soils. | 2 coverages | 30-lb minimum weight. Considerable range is tolerable, depending on materials and conditions. | Weights up to 250 lb, foot diameter 4 to 10 in. |

Table 3-5. Special Cases of Subgrade Treatment

| Soil Type | Characteristics and Identification | Recommended Subgrade Procedures |
|---|---|---|
| Stiff, preconsolidated clays | These soils normally classified as CH or occasionally CL, may have greater strength in the undisturbed condition than when reworked and compacted to maximum density. Investigate comparative CBR's in both these conditions. Check expansive tendencies. | If undisturbed condition is stronger, do not attempt to compact. Minimize disturbance as much as possible. Use in-place CBR or soaked undisturbed samples for design. Check table 3-3 to assure compaction requirements are met. |
| Silts and very fine sands | These soils, normally classified as ML, become quick or spongy when compacted in presence of high water table or when saturated. Occasionally water may move up into subbase or base course during compaction. | Lower water table and dry out if feasible. Otherwise, do not attempt to compact. Remove and replace or blanket with sand or well graded granular material. Do not place open base or subbase directly on these soils. |
| Expansive soils | All clay soils have the potential for expansion under moisture changes. If test in CBR mold shows swell greater than 3 percent, special attention is necessary. Certain clays, especially in arid areas, are highly expansive and require deep subgrade treatment. These clays generally slake readily and have liquid limits above 40, plasticity index above 25, natural moisture close to the plastic limit, and activity ratio of 1.0 or greater. | For nominally expansive soils, determine optimium water content, compaction effort and overburden to control swell. Use corresponding CBR and density values for design. Particular attention should be directed to areas where soil profile is nonuniform. Field control of compaction moisture is critical. For highly expansive soils consider (a) replacement to depth of moisture equilibrium, (b) raising grade, (c) lime stabilization, (d) prewetting or other. |

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# CHAPTER 4

## SUBBASE COURSE

4-1. General. Suitable borrow material or other processed or stabilized material should be used between the subgrade and base to make up the pavement section. These layers are designated the subbase course.

4-2. Material source. Investigations and tests described in chapter 2 should be used to determine the location of suitable material for use as subbase. (See table 4-1 for test methods for subbase and base materials.) For mobilization conditions, material quality certification can be used to replace initial testing, especially in the case of local existing stockpiles, pits, or quarries.

4-3. Suitable materials. Subbase material can consist of the following:

- Naturally occurring coarse grained materials:

  Uncrushed gravel and sand
  Well-graded sands
  Disintegrated granite

- Special and processed material:

| | |
|---|---|
| Limerock | Quarry and nonhazardous mine waste |
| Coral | Slag |
| Caliche | Sand-shell mixtures |
| Crushed stone or gravel | |

- Blends of natural or processed materials. Subgrade materials used for blending should meet the requirements for liquid limit and plasticity index prior to mixing.

- Stabilized materials: See EM 1110-3-137.

a. Selection of design CBR for subbase. Determine the CBR value of the subbase from methods described in MIL-STD-621, Test Method 101. If the CBR exceeds the maximum permissible values, use the value shown in table 4-2.

Table 4-1. Test Methods for Subbase and Base

| Test | Test Standard ASTM | AASHTO | MIL-STD-621 Test Method |
|---|---|---|---|
| Sampling materials | D 75 | T 2 | |
| Unit weight of aggregate | C 29 | T 19 | |
| Soundness test | C 88 | T 104 | |
| Abrasion resistance by Los Angeles machine | C 131 | T 96 | |
| Sieve analysis | C 136 | T 27 | |
| Amount finer than No. 200 sieve | C 117 | | |
| Particle-sized analysis of soils | D 422 | T 88 | |
| Liquid limit | D 423[1] | T 89[1] | 103 |
| Plastic limit | D 424 | T 90 | 103 |
| In-place density and moisture content[2] | D 1556 | T 191 | |
| Moisture-density relations of soils | D 1557 | | 100 (CE 55) |
| Remolded CBR test | D 1883 | | 101 |
| In-place CBR test | | | 101 |
| Sand equivalent | D 2419 | T 176 | |
| Compressive strength-soil cement | D 1633 | | |
| Moisture density-soil cement[3] | D 558 | T 134 | |
| Wet-dry tests - soil cement | D 559 | T 135 | |
| Freeze-thaw tests - soil cement | D 560 | T 136 | |

[1]Use the 3 point "flow curve" method.

[2]See table 2-3 for alternative methods.

[3]Modified to require five layers, a 10-pound rammer and an 18-inch drop.

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Table 4-2. Maximum Permissible Values for Unbound Subbase

| Material | Maximum Requirements Design CBR | Maximum Values | | | | |
|---|---|---|---|---|---|---|
| | | Gradation | | | | |
| | | Size (in.) | Percent Passing No. 10 | Percent Passing No. 200 | Liquid Limit | Plasticity Index |
| Subbase | 50 | 3 | 50 | 15 | 25 | 5 |
| Subbase | 40 | 3 | 80 | 15 | 25 | 5 |
| Subbase | 30 | 3 | 100 | 15 | 25 | 5 |
| Subbase | 20 | 3 | - | 25[1] | 35[1] | 12[1] |

[1]Suggested limits.

b. Design example. An example of design CBR determination for a sample of gravelly sand follows:

| | |
|---|---|
| Soaked CBR | 41 |
| Maximum size, inches | 0.5 |
| Percent passing No. 10 sieve | 85 |
| Percent passing No. 200 sieve | 14 |
| Liquid limit | 12 |
| Plasticity index | 3 |

The design CBR for this material is 30 because 80 percent passing the No. 10 sieve is the maximum permitted for higher CBR values and this material has 85 percent passing.

c. Exceptions to gradation requirements. Cases may occur in which certain natural materials that do not meet gradation requirements may develop satisfactory CBR values in the prototype. Exceptions to the gradation requirements are permissible when supported by adequate in-place CBR tests on similar construction that has been in service for several years.

4-4. Additional requirements.

a. Subbase thickness. Determine required thickness of subbase as outlined in chapter 7. If less than 6 inches of subbase is required, consider increasing the thickness of base course.

b. Density requirement. Compact subbase to 100 percent of maximum density.

c. Frost susceptibility. In areas where frost penetration is a problem, consult criteria in EM 1110-3-138.

d. Expansive material. Do nct use material which has a swell of 3 percent or greater, as determined from the CBR mold, for subbase.

# CHAPTER 5

# BASE COURSE

5-1. General. The base course is subjected to high vertical stresses and must have high stability and be placed properly.

5-2. Suitable materials. Suitable materials include natural, processed, manufactured, and stabilized materials. See table 5-1 for listing and description of commonly used base materials. The information contained in this table is to provide an overview of the materials available for base. Use should be made of local material; full use should be made of local experience and requirements. It is recommended that quality controlled material reserves such as those maintained by state and local agencies be utilized where possible.

5-3. Design CBR of base course. Base course materials complying with the requirements of table 5-1 will be assigned CBR values as shown in the following tabulation.

| Type | Design CBR |
|---|---|
| Graded crushed aggregate (stone, gravel, slag) | 100 |
| Dry bound and water bound macadam | 100 |
| Limerock | 80 |
| Shell sand | 80 |
| Coral | 80 |
| Shell rock | 80 |
| Mechanically stabilized aggregate | 80 |

5-4. Minimum base course and surface thicknesses. The minimum allowable thicknesses for base and surface courses are listed in table 5-2. These thicknesses have been arbitrarily established so that the required subbase CBR will always be 50 or less.

5-5. Base course gradation and tests.

a. Testing. Under mobilization conditions, sophisticated testing equipment may be limited together with an increased workload on testing laboratories which will hamper expeditious construction. Therefore, an emphasis should be placed on quick results from field testing or

Table 5-1. Base Course Materials for Flexible Pavements

| Materials | Description-Source | Processing | Requirements-Comments |
|---|---|---|---|
| Crushed Stone and crushed gravel | Stone quarried from formations of granite, traprock and limestone. Gravel from deposits of river or glacial origin | The quarried rock and gravel are crushed and screened to produce a dense graded mix. See table 5-2 for gradation | Percentage of wear not to exceed 40. Liquid limit not to exceed 25. Plasticity index not to exceed 5. |
| Slag | Air-cooled, blast-furnace slag is by-product of steel manufacturing. Material is competitive in areas adjacent to steel mills. Slag is lighter in weight than stone, highly stable, hard, and rough textured. Slag also has ability to drain rapidly | Slag is air-cooled, crushed, and and graded to produce dense mix. Fines from other sources may be used for blending. See table 5-2 for gradation | Requirements for crushed stone apply. Slag weight to be not less than 65 pcf. |
| Macadam | Crushed stone, crushed slag, or crushed gravel | Crushed aggregate is screened and graded to produce coarse aggregate, choker aggregate, key aggregate, and screenings. See Type specifications for gradation | Procedure is to place alternate layers of the various size aggregate to form dry-bound, or wet-bound macadam base. |
| Shell Sand | The shells are dredged from dead reefs in the gulf coast waters of the United States. Shells consist of oyster and clam shells | Shells are washed, crushed, screened and blended with sand filler. Ratio of the blend shall be not less than 67 percent shell to 33 percent sand. Refer to local guide specificiations where available | Liquid limit not to exceed 25. Plasticity index not to exceed 5. Minimum CBR requirement is 60 at 100 percent compaction for layers following construction |
| Coral | Coral consists of hard, cemented deposits of skeletal origin. Coral is found in the reefs and inland deposits at atolls and islands in tropical regions. Caroline limestone, quarried from inland deposits and designated as quarry coral, is structurally soundest of the various coral materials available. Other types also useful for base material are reef coral and bank run coral. Cascajo or "gravelly coral" found as lagoon sediment at Guam, is also useful as base | Reef coral is removed by blasting and dredging and is stockpiled ashore, prior to crushing and grading. Quarry coral is obtained by blasting, and is crushed and graded to produce a dense mix. Use the following gradation:<br>Sieve Designation — Percent Passing<br>2 inch — 100<br>1-1/2 inch — 70-100<br>3/4 inch — 40-90<br>No. 4 — 25-60<br>No. 40 — 5-20<br>No. 200 — 0-10 | Percentage of wear not to exceed 50. Liquid limit not to exceed 25. Plasticity index not to exceed 5. Minimum CBR requirement is 60 at 100 percent compaction for layers following construction |
| Limerock | Limerock is a fossiliferous limestone of the oolitic type. Its main constituents are carbonates of calcium and magnesium. Commercial limerock deposits are located in Florida | Limerock is crushed, screened, and uniformly graded from 3-1/2 inches maximum to dust. Refer to local guide specifications where available | Minimum CBR requirement is 60 at 95 percent compaction. Liquid limit not to exceed 25. Plasticity index not to exceed 5. |
| Shell-Rock | Shell-rock or marine limestone are deposits or hard, cemented shells. Deposits are located in the coastal areas of North and South Carolina | Shell-rock is crushed, screened and graded to a dense mix. Refer to local guide specifications where available. | Percentage of wear not to exceed 50. Liquid limit not to exceed 25. Plasticity index not to exceed 5. Minimum CBR requirement is 60 at 100 percent compaction for layers following construction |
| Mechanically Stabilized Aggregate | Crushed and uncrushed coarse aggregate, fine aggregate, and binder | A blend of crushed and natural materials processed to provide a dense graded mix. See table 5-2 for gradation | Liquid limit not to exceed 25; plasticity index not to exceed 5. Percentage of wear not to exceed 50. |
| Stabilized Materials | See EM 1110-3-137 | See EM 1110-3-137 | See EM 1110-3-137 |

Table 5-2. Minimum Surface and Base Thickness Criteria

Class I Aircraft

Aircraft with gross weights less than 20,000 pounds

| | Minimum Thickness (in.) | | | | | |
|---|---|---|---|---|---|---|
| | 100-CBR Base | | | 80-CBR Base[1] | | |
| Traffic Area | Surface | Base | Total | Surface | Base | Total |
| B and C | 2 | 6 | 8 | 2 | 6 | 8 |

Class II Aircraft

Aircraft with gross weights between 20,001 and 50,000 pounds

| | Minimum Thickness (in.) | | | | | |
|---|---|---|---|---|---|---|
| | 100-CBR Base | | | 80-CBR Base[1] | | |
| Traffic Area | Surface | Base | Total | Surface | Base | Total |
| B and C | 2 | 6 | 8 | 3 | 6 | 9 |

Class III Aircraft

Aircraft with gross weights between 50,001 and 175,000 pounds

| | Minimum Thickness (in.) | | | | | |
|---|---|---|---|---|---|---|
| | 100-CBR Base | | | 80-CBR Base[1] | | |
| Traffic Area | Surface | Base | Total | Surface | Base | Total |
| B and C | 3 | 6 | 9 | 4 | 6 | 10 |

[1]Florida limerock and mechanically stabilized aggregate permitted.

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certification by the supplier that the materials meet the project specification whenever possible.

b. Gradation. See table 5-3 for gradation requirements for crushed stone, gravel, and slag. Consult guide specifications for gradation of materials not included in table 5-1.

Table 5-3. Gradation of Aggregates for Graded Crushed Aggregate Base Course

| Sieve Designation | Percentage by Weight Passing Square-Mesh Sieve - No. 1 | No. 2 | No. 3 |
|---|---|---|---|
| 2-inch | 100 | - | - |
| 1-1/2 inch | 70-100 | 100 | - |
| 1-inch | 45-80 | 60-100 | 100 |
| 1/2-inch | 30-60 | 30-65 | 40-70 |
| No. 4 | 20-50 | 20-50 | 20-50 |
| No. 10 | 15-40 | 15-40 | 15-40 |
| No. 40 | 5-25 | 5-25 | 5-25 |
| No. 200 | 0-10 | 0-10 | 0-10 |

5-6. Base course compaction. Compact the base course to a minimum of 100 percent maximum density.

5-7. Proof rolling. In addition to compacting the base course to the required density, proof-rolling on the surfaces of completed base courses is required. The proof roller is a heavy rubber-tired roller having four tires, each loaded to 30,000 pounds or more and inflated to at least 150 psi. A coverage is the application of one tire print over each point in the surface.

# CHAPTER 6

## BITUMINOUS MATERIALS COURSES

6-1. General. Bituminous surfaces provide a resilient, waterproof, load distributing medium that protects the base course against the detrimental effects of water and the abrasive action of traffic. The flexibility of bituminous pavement permits slight adjustments in the pavement structure, owing to consolidation, without detrimental effect. However, bituminous concrete is unsatisfactory for use where heat and blast effects from jet aircraft are severe. Also, asphaltic concrete is not resistant to fuel spillage and is satisfactory only where spillage is slight and very infrequent.

a. Bituminous mixes. The following part of this chapter provides an abbreviated guide to the design of hot mix bituminous surface and base courses. For a complete treatment on the criteria requirements, selection of materials, testing, design, and plant control of hot mixes, tar-rubber mixes, and surface treatments, refer to appendix A.

b. Definitions. See table 6-1 for terminology used in flexible pavement design.

6-2. Selection of materials.

a. Bituminous materials. Bituminous materials include asphalts, tars, and tar-rubber blends.

(1) Asphalts. Asphalt products are the normal choice for use in bituminous mixes for reasons of availability, serviceability, and economy.

(2) Tars. Tars are more susceptible to temperature changes than similar grades of asphalt; tars are also more toxic and difficult to handle. However, tars are more resistant to jet fuel spillage and are less likely than asphalts to strip from hydrophilic aggregates in the presence of water.

(3) Tar rubber blends. Mixtures of tar and synthetic rubber have increased resistance to fuel spillage and temperature changes. Consider use of tar-rubber blends for pavements where jet fuel spillage is infrequent.

b. Aggregates.

(1) Suitability of rock types. Alkaline rocks (limestone, dolomite) provide better adhesion with asphaltic films in the presence of water than acid or silicious rocks (granite, quartzite). Where acid rocks are used, addition of an antistripping agent or hydrated lime may be required.

Table 6-1. Specialized Terminology for Bituminous Pavement

| Item | Description |
|---|---|
| Coarse aggregate | Material larger than the No. 4 sieve |
| Fine aggregate | Material passing the No. 4 sieve and retained on No. 200 sieve |
| Mineral filler | Material finer than the No. 200 sieve |
| Wearing course | The top layer of bituminous concrete surface |
| Binder or intermediate course | The leveling or transition layer of bituminous concrete placed directly on a base course |
| Prime coat | A surface treatment of liquid bitumen applied to a nonbituminous base course before bituminous pavement is placed. Purpose is to penetrate and seal surface of base course |
| Tack coat | Bituminous emulsion or liquid bitumen placed on an existing concrete or bituminous pavement to provide good bond with the new bituminous course |
| Marshall stability value | The load in pounds causing failure in a compacted specimen of hot-mix bituminous concrete when tested in the Marshall apparatus |
| Flow | Total deformation in hundredths of of an inch at point of maximum load in the Marshall Stability Test |
| Percent air voids | That part of the compacted bitumen-aggregate mixture not occupied by aggregate or bitumen expressed in percent of total volume |
| Percent voids filled with bitumen | Percentage of voids in a compacted aggregate mass that are filled with bituminous cement |
| Penetration | The relative hardness or consistency of an asphalt cement. Measured by the depth a standard needle will penetrate vertically into a sample of asphalt under known conditions of temperature, loading, and time' |
| Viscosity | A measure of the ability of a bitumen to flow at a given temperature range. The stiffer the bitumen the higher the viscosity |
| Percent voids in the mineral aggregate (VMA) | The volume of void space in a compacted paving mix that includes the air voids and effective asphalt content, expressed as a percent of the volume of the sample |

(2) Crushed aggregate. The coarse and fine aggregates used for airfield pavement surface should be crushed materials, in order to assure high stability and performance. Bituminous base courses, however, may include natural materials in the fine fraction.

(3) Maximum size. In general, the maximum size of aggregate for the wearing course should not exceed 3/4 inch; in no case should the aggregate size exceed one-half the thickness of the compacted wearing course or two-thirds the thickness of any binder or intermediate course.

(4) Mineral filler. The type and quantity of mineral filler used affects the stability of the mix. For surface course mixes, mineral filler should be limestone dust, portland cement, or other inert similar materials. For bituminous bases natural filler is frequently adequate.

6-3. Design of bituminous concrete mix.

a. Criteria. Use the procedures and criteria described in appendix A and as condensed below for the design of hot mix bituminous concrete. Approved design mixes are available from Army, Federal, and state agencies which would meet the requirements outlined in this manual for mobilization construction. Existing acceptable design mixes should be utilized whenever possible. Where tests for aggregate and bituminous mix are required see table 6-2.

b. Asphalt cement grades. At present, in the United States, asphalt cement is specified by one of the following:

- Penetration grades

- AC viscosity grades

- AR viscosity grades

Correlation between penetration grades and viscosity grades for asphalts from different producers is not possible. Figure 6-1 gives the recommended grades for each area of the United States by penetration and viscosity designation. These recommendations should be tempered by local practice. Use the penetration grade designation in the areas when penetration grade asphalt is produced. The penetrations of AC and AR grades do not necessarily fall within the range of recommended values. In areas where viscosity grades are produced, determine the sources with acceptable penetration and approve those grades. See table 6-3 for specifications for asphalt, tars, and tar-rubber blends.

Table 6-2. Tests for Aggregate and Bitumen Mix

| Test | Test Standard[1] | Comments |
|---|---|---|
| Sampling aggregates | ASTM D 75 | |
| Mineral filler | ASTM D 242 | Specification for mineral filler |
| Resistance to abrasion-coarse aggregate | ASTM C 131 | Not more than 40 percent for surface courses. Not more than 50 percent for base courses. |
| Soundness-course aggregate | ASTM C 88 | After five cycles loss should not be more than: 12 percent sodium sulfate test or 18 percent magnesium sulfate test |
| Absorption and apparent specific gravity-course and fine aggregate | ASTM C 127<br>ASTM C 128 | Use apparent specific gravity for mix design when absorption is 2.5 percent or less |
| Marshall method for design of bituminous mixes | MIL-STD 620 Method 100<br>ASTM D 1559 | See text for requirements |
| Unit weight of aggregate | ASTM C 29 | Graded crushed slag as used in mix should have a compact weight of not less than 70 pcf |
| Immersion compression test-bitumen mix | MIL-STD 620 Method 104 | Require an index of 75 or better for acceptance[2] |

[1]Testing for Army airfields will be by MIL-STD where shown.

[2]Where index is less than 75, potential stripping is indicated. Add a recognized commercial anti-stripping agent or 1/2 to 1 percent hydrated lime and retest, or replace aggregate with new aggregate which will conform to requirements of immersion-compression test.

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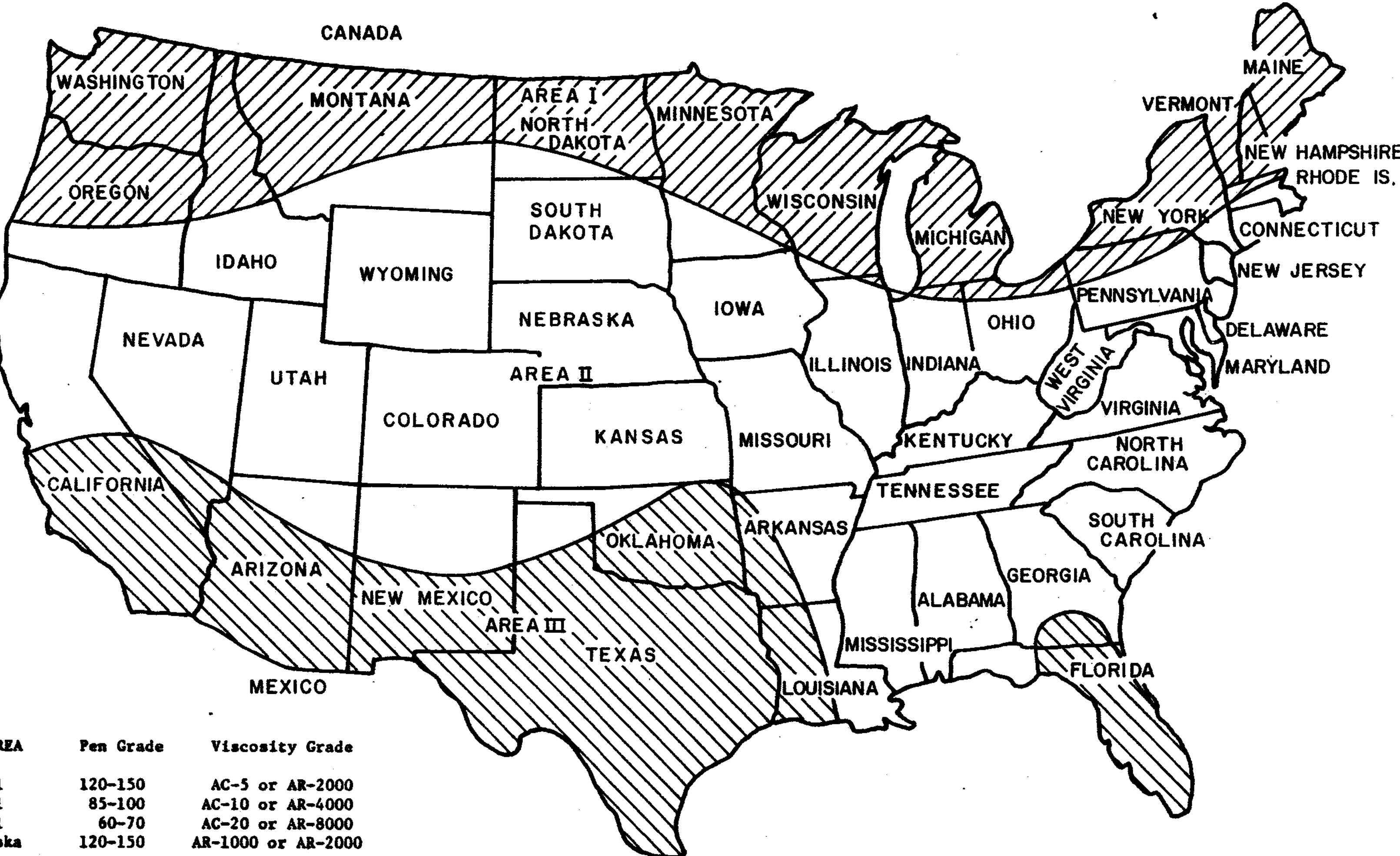


| AREA | Pen Grade | Viscosity Grade |
|---|---|---|
| 1 | 120-150 | AC-5 or AR-2000 |
| 11 | 85-100 | AC-10 or AR-4000 |
| 111 | 60-70 | AC-20 or AR-8000 |
| Alaska | 120-150 or 150-200 | AR-1000 or AR-2000 |
| Hawaii | 60-70 | AR-8000 |

NOTE: The penetration of viscosity graded asphalts do not necessarily fall within the ranges indicated. Where specific penetration requirements are desired, they should be so stipulated.

FIGURE 6-1. SELECTION GUIDE FOR ASPHALT CEMENT

Table 6-3. Specifications for Bituminous Materials

| Bitumen | Specification |
|---|---|
| Asphalt cement (penetration grades) | ASTM D 946 |
| Asphalt cement (AC and AR grades) | ASTM D 3381 |
| Asphalt, liquid (slow-curing) | ASTM D 2026 |
| Asphalt, liquid (medium-curing) | ASTM D 2027 |
| Asphalt, liquid (rapid-curing) | ASTM D 2028 |
| Asphalt, emulsified | ASTM D 977 |
| Asphalt, cationic emulsified | ASTM D 2397 |
| Tar | ASTM D 490 |
| Tar cement (base for rubberized tar) | ASTM D 2993 |
| Rubberized tar cement | ASTM D 2993 |

c. Selection of materials for mix design. Use materials (bitumen, aggregates, mineral filler) in the mix design that meet the requirements of the specifications and that will be used in the field for construction. Aggregate gradations are shown in table 6-4.

6-4. Testing for mix design.

a. General. Testing will indicate the properties that each blend selected will have after being subjected to appreciable traffic. A final selection of aggregate blend and filler will be based on these data with due consideration to the relative costs of the various mixes.

b. Test procedures. Design bituminous paving mixes by the Marshall method. Compaction requirements are summarized as follows:

| Types of Traffic | Design Compaction Requirements |
|---|---|
| Tire pressure 100 psi and over | 75 blows Marshall method |
| Tire pressure less than 100 psi | 50 blows Marshall method |

c. Optimum bitumen content and adequacy of mix. Plot data obtained in graphical form as shown in figure 6-2. See table 6-5 for point-on-curve and adequacy of mix criteria. The conventional Marshall method approach is as follows:

Table 6-4. Aggregate Gradations for Bituminous Concrete Pavements

Percent Passing by Weight

| Sieve Size | 1-1/2-in. Maximum[1] | | 1-in. Maximum | | 3/4-in. Maximum | | 1/2-in. Maximum | | 3/8-in. Maximum | | No. 4 Maxim | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low Pressure[2] | High Pressure[3] | Low Pressure | High Pressure | Low Pressure | High Pressure | Low Pressure | High Pressure | Low Pressure | High Pressure | Low Pressure | Pr |
| **Wearing Course** | | | | | | | | | | | | |
| 1-1/2 inch | 100 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | |
| 1 inch | 87±8 | -- | 100 | 100 | -- | -- | -- | -- | -- | -- | -- | |
| 3/4 inch | 79±9 | -- | 90±7 | 90±6 | 100 | 100 | -- | -- | -- | -- | -- | |
| 1/2 inch | 70±9 | -- | 81±9 | 81±7 | 89±9 | 89±7 | 100 | 100 | -- | -- | -- | |
| 3/8 inch | 63±9 | -- | 75±9 | 75±7 | 82±9 | 82±7 | 86±9 | 86±7 | 100 | -- | -- | -- |
| No. 4 | 51±9 | -- | 60±9 | 60±7 | 66±9 | 66±7 | 66±9 | 66±7 | 85±10 | -- | 100± | -- |
| No. 8 | 42±9 | -- | 47±9 | 47±7 | 53±9 | 53±7 | 53±9 | 53±7 | 72±10 | -- | 86±12 | -- |
| No. 16 | 34±9 | -- | 37±9 | 37±7 | 41±9 | 41±7 | 41±9 | 41±7 | 56±12 | -- | 72±16 | -- |
| No. 30 | 26±9 | -- | 27±9 | 27±7 | 31±9 | 31±7 | 31±9 | 31±7 | 42±10 | -- | 57±12 | -- |
| No. 50 | 19±8 | -- | 19±8 | 19±6 | 21±8 | 21±6 | 21±8 | 21±6 | 29±9 | -- | 43±17 | -- |
| No. 100 | 12±6 | -- | 12±6 | 13±5 | 13±6 | 13±5 | 13±6 | 13±5 | 18±7 | -- | 28±12 | |
| No. 200 | 4±3 | -- | 4±3 | 4.5±1.5 | 4±3 | 4.5±1.5 | 4±3 | 4.5±1.5 | 8±3 | -- | 9±5 | |
| **Binder or Intermediate Course** | | | | | | | | | | | | |
| 1-1/2 inch | 100 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1 inch | 84±9 | -- | 100 | 100 | -- | -- | -- | -- | -- | -- | -- | -- |
| 3/4 inch | 76±9 | -- | 83±9 | 90±6 | 100 | 100 | -- | -- | -- | -- | -- | -- |
| 1/2 inch | 66±9 | -- | 73±9 | 81±7 | 82±9 | 89±7 | 100 | 100 | -- | -- | -- | -- |
| 3/8 inch | 59±9 | -- | 64±9 | 75±7 | 72±9 | 82±7 | 83±9 | 86±7 | -- | -- | -- | -- |
| No. 4 | 45±9 | -- | 48±9 | 60±7 | 54±9 | 66±7 | 62±9 | 66±7 | -- | -- | -- | -- |
| No. 8 | 35±9 | -- | 37±9 | 47±7 | 41±9 | 53±7 | 47±9 | 53±7 | -- | -- | -- | -- |
| No. 16 | 27±9 | -- | 28±9 | 37±7 | 32±9 | 41±7 | 36±9 | 41±7 | -- | -- | -- | -- |
| No. 30 | 20±9 | -- | 21±9 | 27±7 | 24±9 | 31±7 | 28±9 | 31±7 | -- | -- | -- | |
| No. 50 | 14±7 | -- | 16±7 | 19±6 | 17±7 | 21±6 | 20±7 | 21±6 | -- | -- | -- | -- |
| No. 100 | 9±5 | -- | 11±5 | 13±5 | 12±5 | 13±5 | 14±5 | 13±5 | -- | -- | -- | |
| No. 200 | 5±2 | -- | 5±2 | 4.5±1.5 | 5±2 | 4.5±1.5 | 5±2 | 4.5±1.5 | -- | -- | -- | |

[1] 1-1/2 inch maximum surface course gradation will be used only for thick-lift pavements (3-inch or more).
[2] Use low-pressure gradation for pavements subjected to aircraft with tire pressures less than 100 psi.
[3] Use high-pressure gradation for pavements subjected to aircraft with tire pressures of 100 psi or greater.

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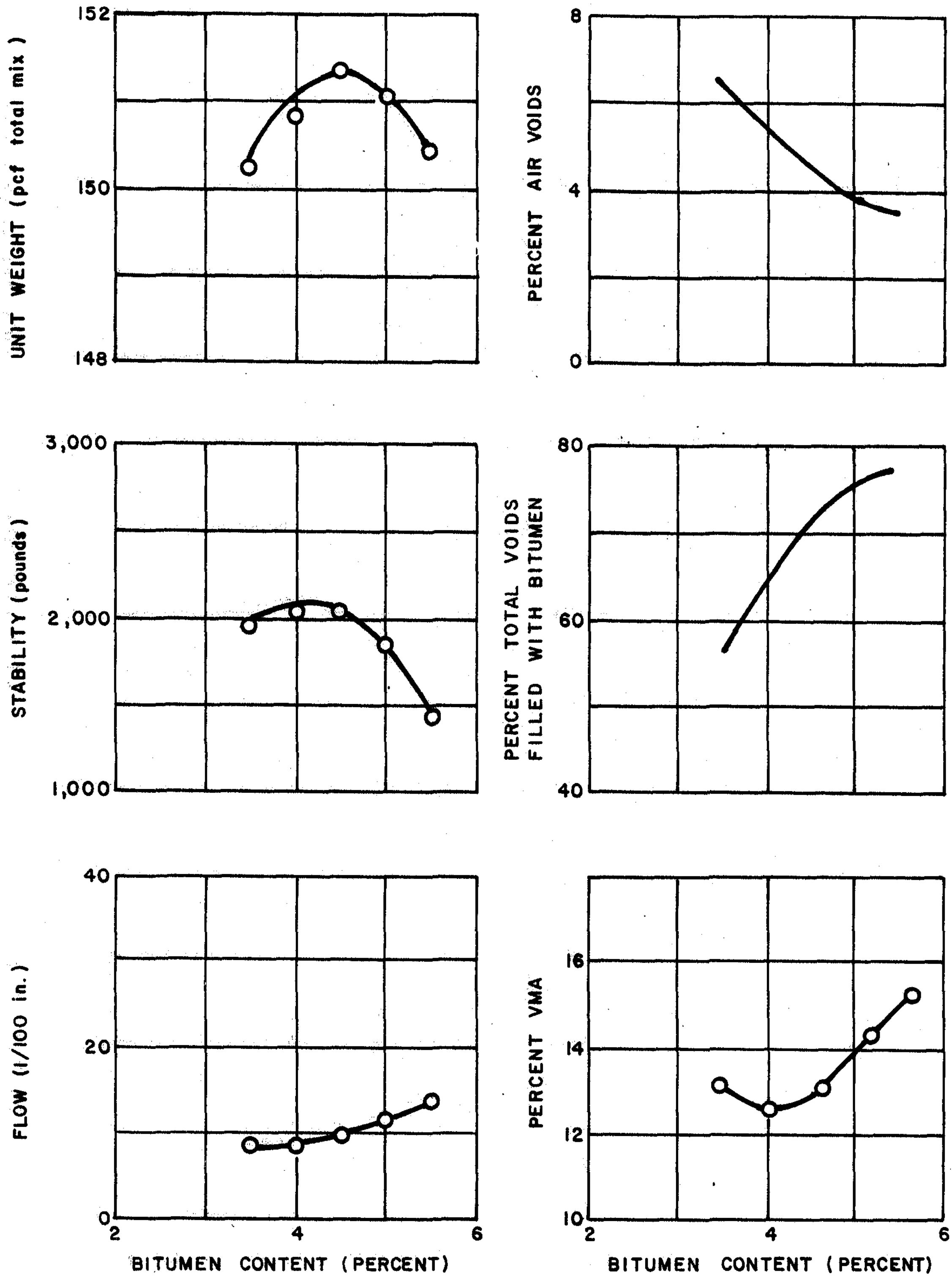


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FIGURE 6-2. ASPHALT PAVING MIX DESIGN, TYPICAL MIX

(1) Determine the optimum bitumen content by averaging the following values:

Bitumen content at peak of stability curve

Bitumen content at peak of unit weight curve (for wearing course only)

Bitumen content at the appropriate point of air voids curve

Bitumen content at the appropriate point on voids filled with bitumen curve

(2) Check for adequacy of mix for stability, flow, air voids, and voids filled with asphalt.

Table 6-5. Procedure for Determining Optimum Bitumen Content and Adequacy of Mix for Use With Aggregate Showing Water Absorption of 2-1/2 Percent or Less

| | Wearing Course | | Intermediate and Base Course | |
|---|---|---|---|---|
| Test Property | Point on Curve for Optimum Bitumen Content | Adequacy of Mix Criteria | Point on Curve for Optimum Bitumen Content | Adequacy of Mix Criteria |
| Marshall Stability 75 blows | peak of curve | 1,800 or higher | peak of curve | 1,800 or higher |
| Unit weight | peak of curve | not used | not used | not used |
| Flow | not used | 16 or less | not used | 16 or less |
| Percent air voids | 4 | 3-5 | 6 | 5-7 |
| Percent voids filled with bitumen | 75 | 70-80 | 60 | 50-70 |

d. Typical example. The determination of bitumen content and adequacy of mix is illustrated by the following example using the curves in figure 6-2 and criteria in table 6-5. The example is for a wearing course mix with 3/4-inch maximum aggregate.

(1) Determination of optimum bitumen content

| Point on Curve | Bitumen Content |
|---|---|
| Peak of stability curve | 4.3 percent |
| Peak of unit-weight curve | 4.5 percent |
| At 4 percent air voids curve | 4.8 percent |
| At 75 percent voids filled with asphalt curve | 4.9 percent |
| Average | 4.6 percent |

The optimum bitumen content of the mix in this example is 4.6 percent based on the weight of total mix.

(2) Check for adequacy of mix.

| Test Property | At Optimum or 4.6 Percent Bitumen | Criteria for Adequacy |
|---|---|---|
| Flow | 11 | Less than 16 |
| Stability | 2,050 | More than 1,800 |
| Percent air voids | 4.3 | 3 to 5 percent |
| Percent voids filled with bitumen | 72 | 70 to 80 percent |

The paving mix would be considered satisfactory for airfield traffic since it meets the criteria for adequacy.

6-5. Thickness of bituminous courses.

a. Intermediate and wearing course. Bituminous courses will be placed and compacted in such thicknesses to achieve density and smoothness requirements. The thickness of the wearing course should not exceed 2 inches compacted thickness and each intermediate course layer should not exceed 4 inches. The wearing course mix may be used for both courses.

b. Bituminous base course. The maximum lift of a bituminous base course should not exceed 6 inches.

6-6. Bituminous spray coats.

a. Prime coats. Prime coats should be applied to accomplish the following:

(1) To seal surface of base course in areas where rain may be expected prior to placement of the asphalt surface.

(2) To bind together "dusty" base surfaces.

(3) To bind together a base surface for protection against construction traffic.

(4) To bind overlying bituminous courses to the base.

Preferred materials for use as prime coats are the liquid asphalts MC-70, MC-250, RC-70, RC-250, and the tars RT-2 and RT-3. Application rates of the liquid asphalts and tars are between 0.15 and 0.4 gallon per square yard. Sufficient bitumen should be used to seal the voids but not more than can be readily absorbed. Asphalt emulsions have been used experimentally with varying success for prime coats. Emulsions do not penetrate as do liquid asphalts and may require a sand seal to prevent tracking. Emulsions used for priming are SS-1 and SS-1h diluted with 50 percent water and applied at approximately 0.1 gallon per square yard.

b. Tack coats. Tack coats are required on existing pavements to insure a bond with the new overlying bituminous concrete course. Tack coats may not be required between new layers of pavement where the upper layer is immediately constructed as the lower layer is completed. However, tack coats should be used on layers where construction is halted and placement of the overlaying layer is delayed. Tack coats should also be installed on surfaces which have become coated with fine sand or dust and on surfaces soiled from construction traffic. Soiled surfaces must be cleaned before application of a tack coat.

(1) Materials. Use emulsified asphalt SS-1, SS-1h, CSS-1, or CSS-1h diluted with equal parts of water. The following liquid asphalts or tars may also be used, RC-70, RT-6, and RT-7.

(2) Application. Apply tack coats with a pressure distributor at the rate of 0.05 to 0.15 gallon per square yard.

# CHAPTER 7

## FLEXIBLE PAVEMENT THICKNESS DESIGN

7-1. General. This section presents procedures for the thickness design of flexible pavements for runways, taxiways, and other airfield areas.

a. Flexible pavements. Flexible pavements include the following:

(1) Conventional flexible pavements consisting of a bituminous concrete surface on a high quality granular base and subbase course.

(2) Stabilized pavement consisting of bituminous concrete surface course over a section which may include a stabilized base, a stabilized subbase, or any combination of the aforementioned.

(3) All bituminous pavement consisting of asphalt concrete mixtures for all courses from top of surface to subgrade.

b. Basis for thickness design. The thickness design procedures included herein for conventional flexible pavement construction are based on CBR design methods developed for airfields. The design methods for pavements that include stabilized layers are based on modifications of the conventional procedures utilizing thickness equivalencies developed from highway and airfield test experience.

7-2. Flexible pavement design curves. Table 7-1 tabulates the flexible pavement design curves for use in this manual. The curves are identified by class or category, gear configuration, and a typical design aircraft where appropriate. The individual curves indicate the total required thickness of pavement for gross aircraft weight and aircraft passes. The Army defines a pass as one movement of the design aircraft past a given point on the pavement.

7-3. Design requirements. Flexible pavement designs must provide:

- Sufficient compaction of the subgrade and each pavement layer to prevent objectionable settlement under concentrated and repeated traffic. Compaction requirements are given in table 3-3.

- Adequate thickness of quality pavement components above the subgrade to prevent detrimental subgrade deformation, excessive deflection of the pavement surface, and excessive tensile strain in the bituminous pavement material under traffic.

- A stable, weather resistant, wear resistant, nonskid surface.

7-4. Thickness design. From the procedures included herein, the total thickness of the pavement, as well as the individual courses, may be

Table 7-1. Flexible Pavement Design Curves

| Identification | Service and Designation | Gear Configuration | Typical Aircraft |
|---|---|---|---|
| Figure 7-1 | Army Class I | single wheel tricycle | OV-1 |
| Figure 7-2 | Army Class II | dual wheel tricycle | CH-54 |
| Figure 7-3 | Army Class III | single tandem tricycle | C-130 |
| Figure 7-4 | Air Force-Light Load* | single wheel tricycle | ----- |
| Figure 7-5 (a) and (b) | Air Force-Medium Load* | dual tandem tricycle | ----- |
| Figure 7-6 (a) and (b) | Air Force-Heavy Load* | twin twin bicycle | ----- |
| Figure 7-7 | Air Force-Shoulder Pavement* | outrigger gear and vehicles | ----- |
| Figure 7-8 | Air Force-Shortfield Pavement* | single tandem tricycle | ----- |

*Air Force pavement design curves are provided for reference only.

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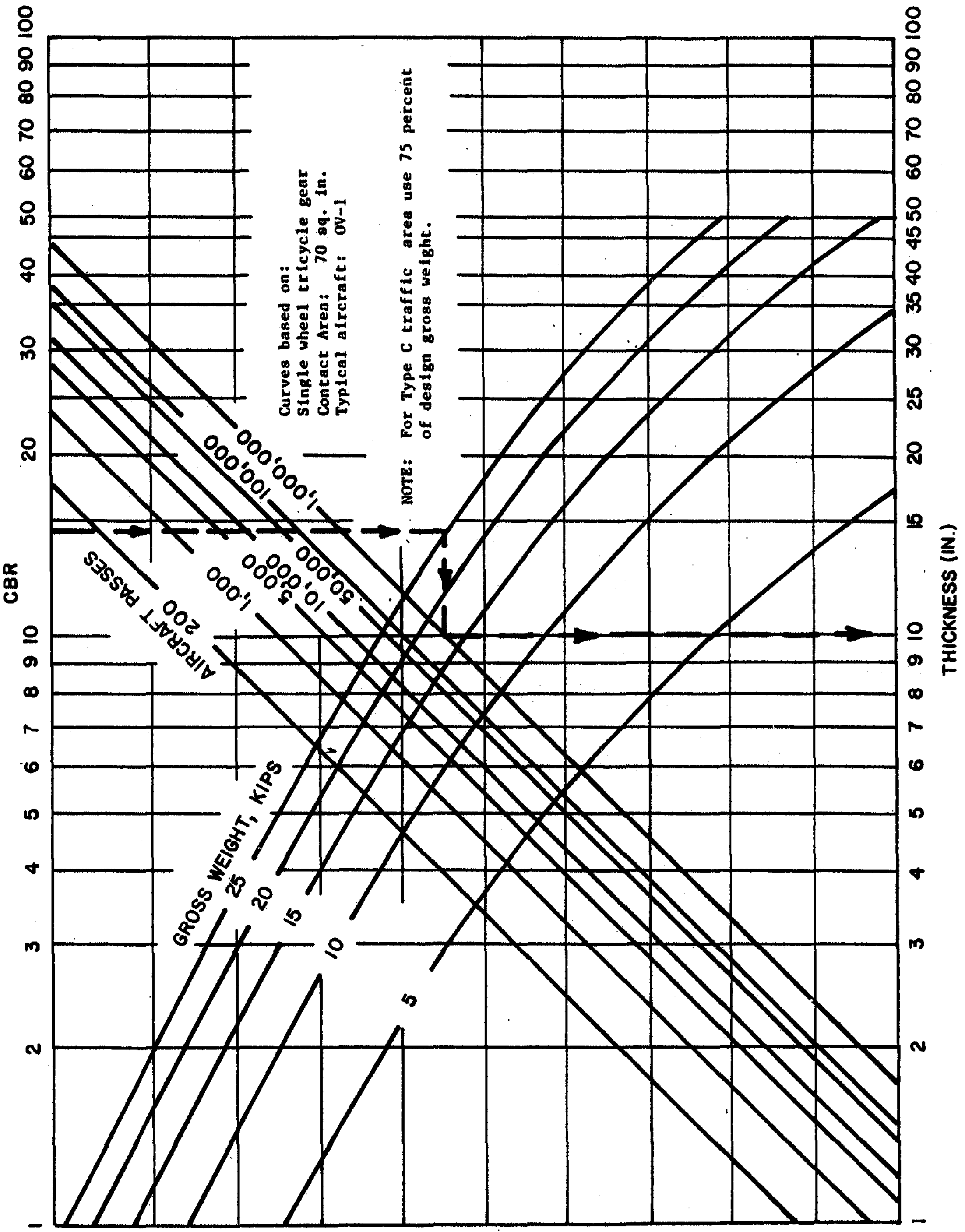


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FIGURE 7-1. FLEXIBLE PAVEMENT DESIGN CURVES, ARMY CLASS I AIRFIELD, TYPE B AND C TRAFFIC AREAS

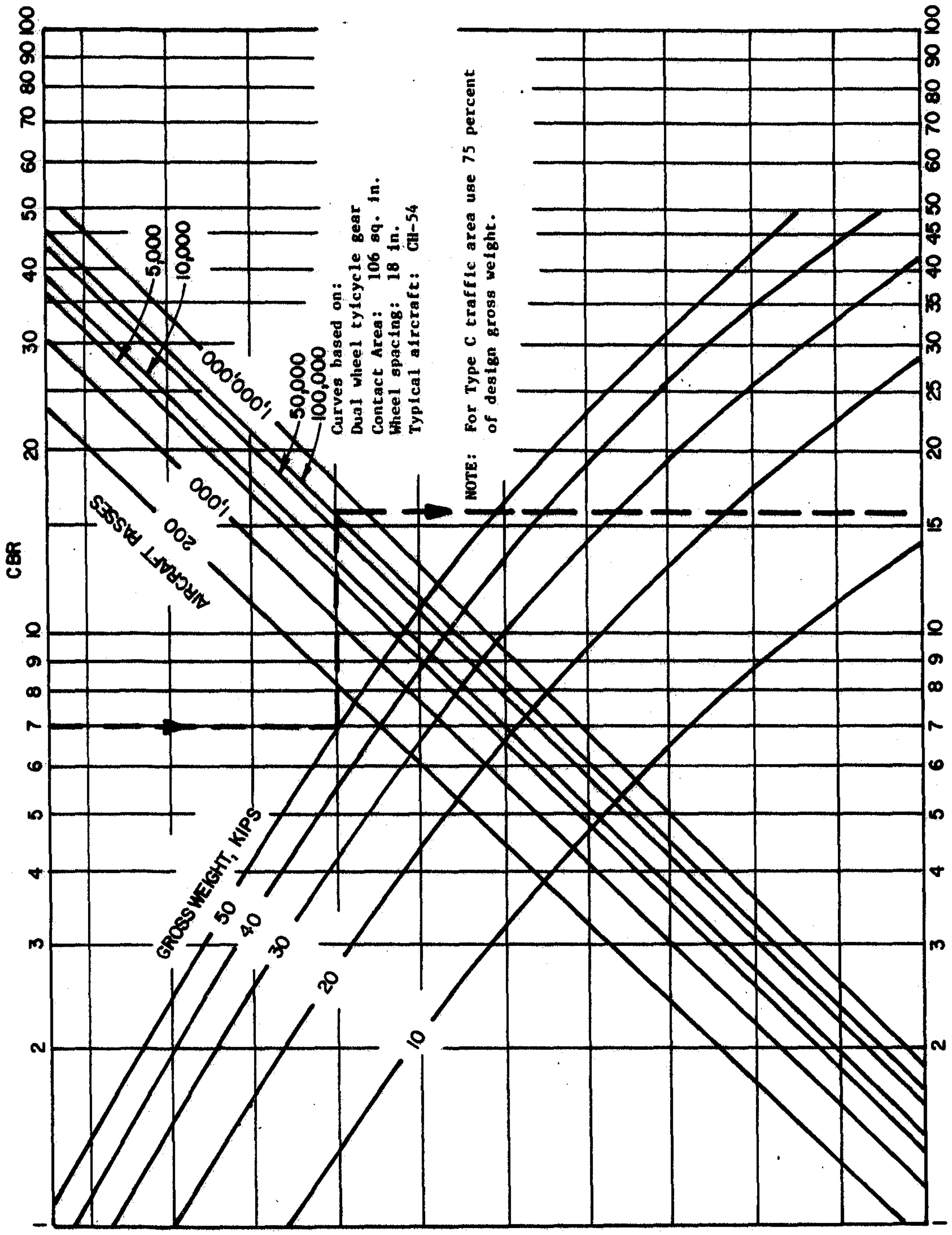


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FIGURE 7-2. FLEXIBLE PAVEMENT DESIGN CURVES, ARMY CLASS II AIRFIELD, TYPE B AND C TRAFFIC AREAS

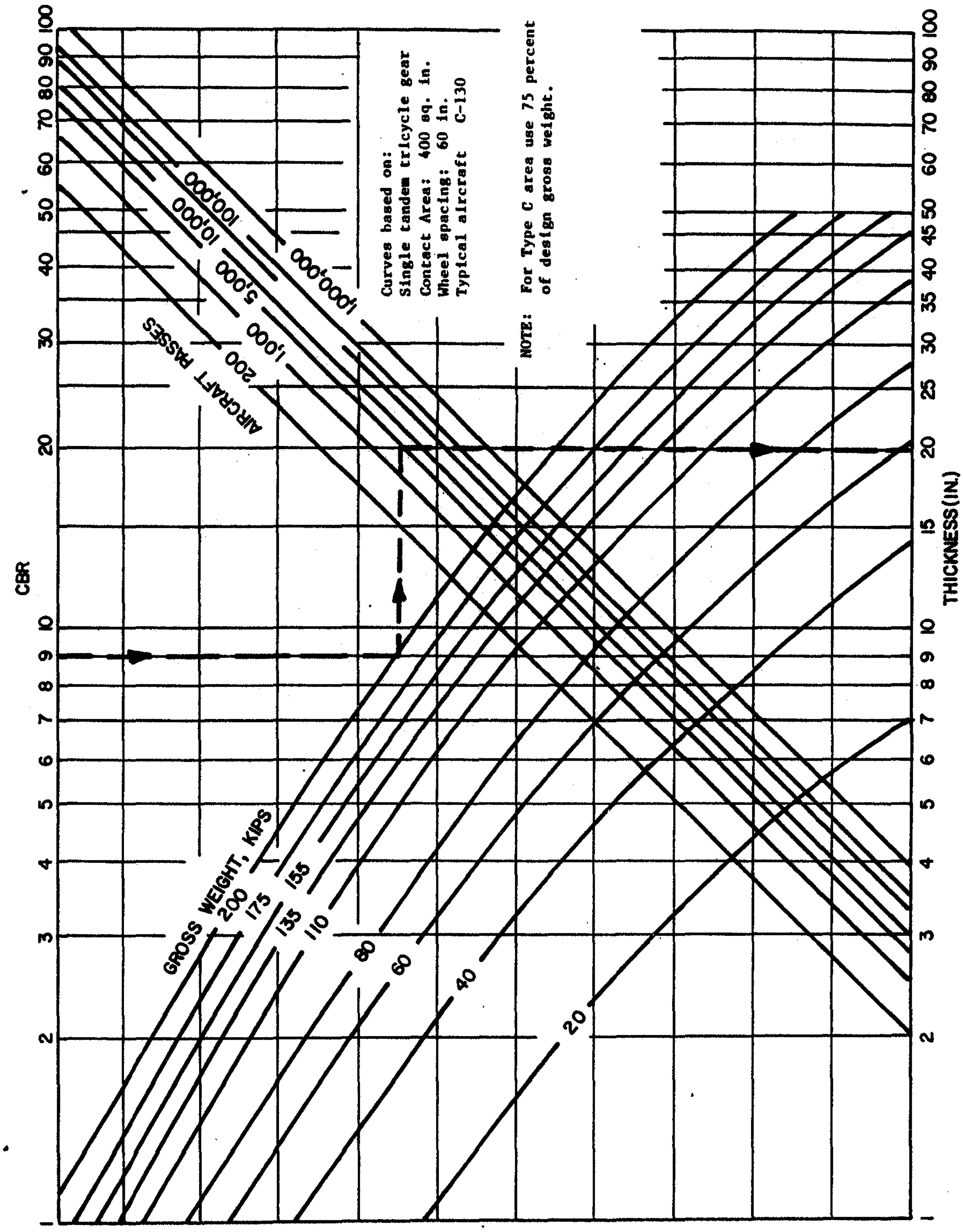


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FIGURE 7-3. FLEXIBLE PAVEMENT DESIGN CURVES,
ARMY CLASS III AIRFIELD, TYPE B AND C TRAFFIC AREAS

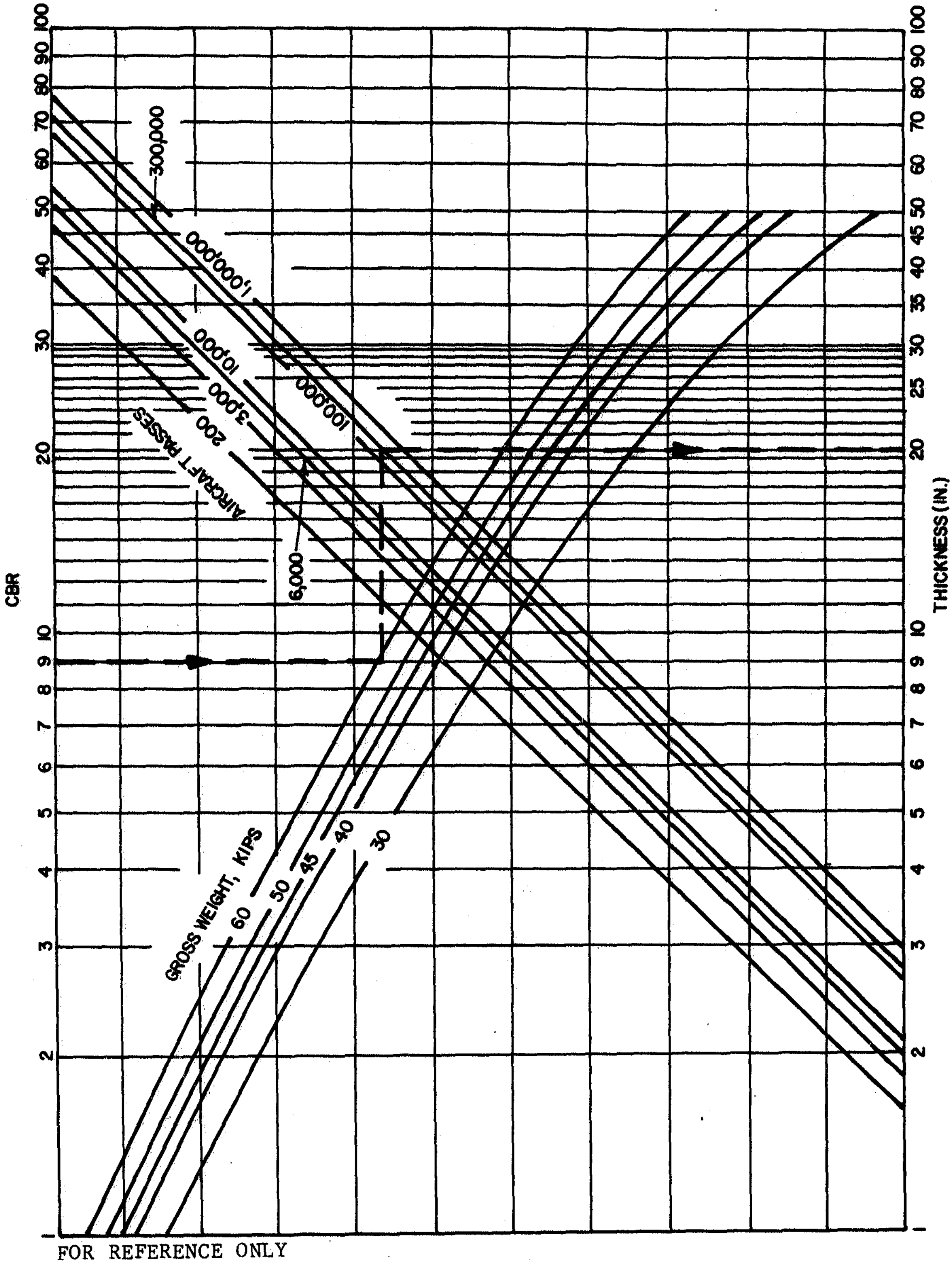


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FIGURE 7-4. FLEXIBLE PAVEMENT DESIGN CURVES, AIR FORCE LIGHT-LOAD PAVEMENT, TYPE B AND C TRAFFIC AREAS AND OVERRUNS

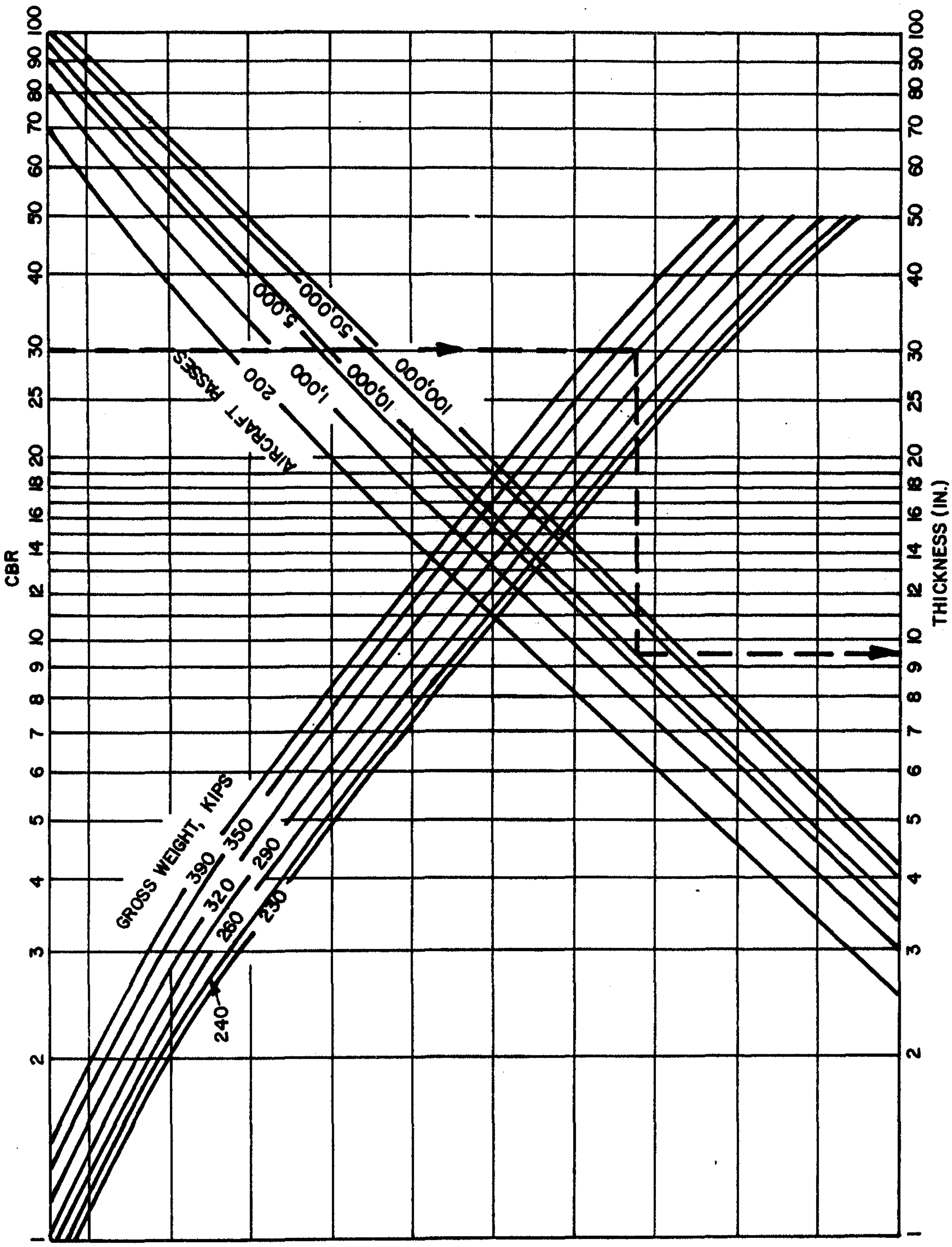


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FIGURE 7-5a. FLEXIBLE PAVEMENT DESIGN CURVES,
AIR FORCE MEDIUM-LOAD PAVEMENT, TYPE A TRAFFIC AREAS

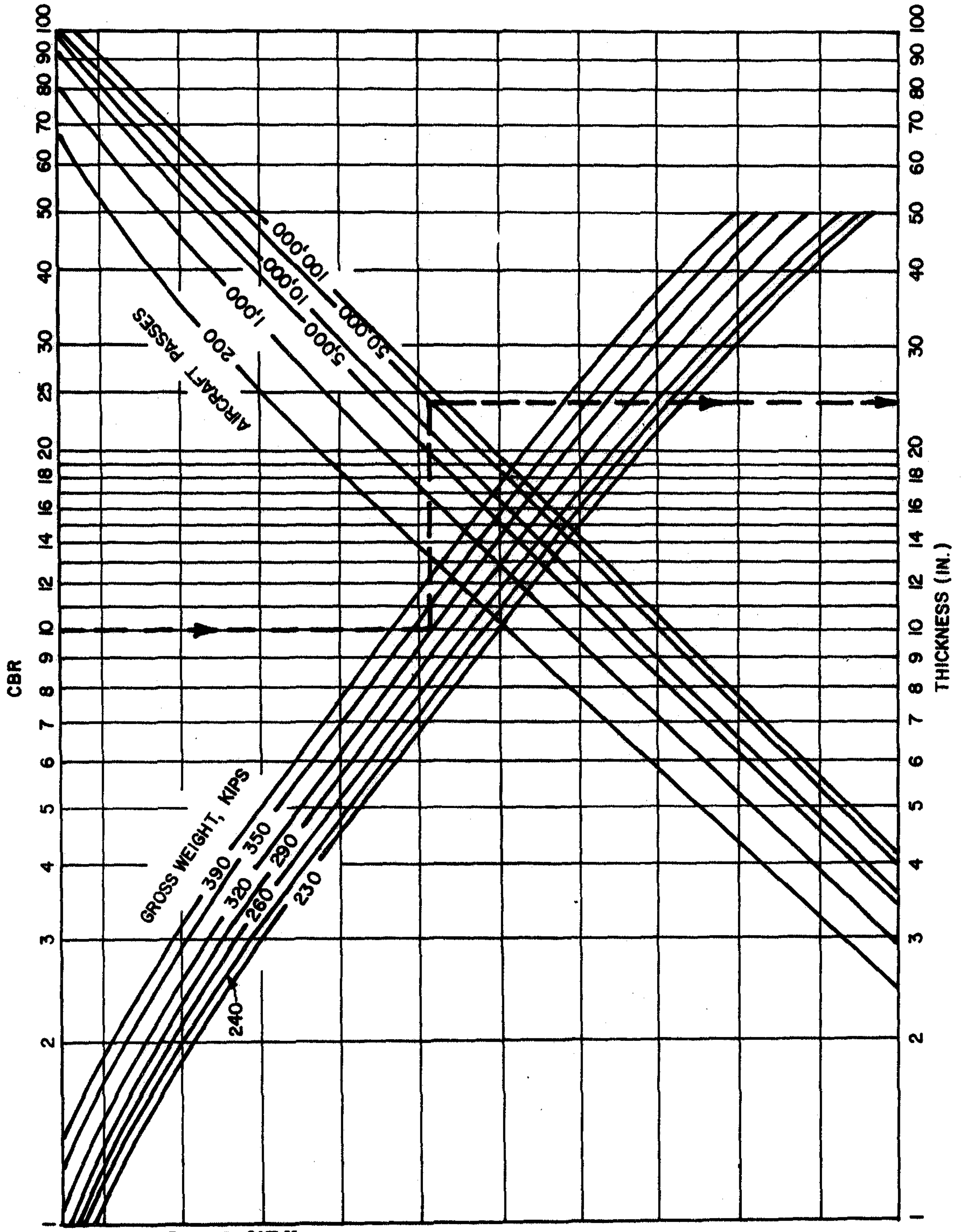


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FIGURE 7-5b. FLEXIBLE PAVEMENT DESIGN CURVES, AIR FORCE MEDIUM-LOAD PAVEMENT, TYPE B, C, AND D TRAFFIC AREAS AND OVERRUNS

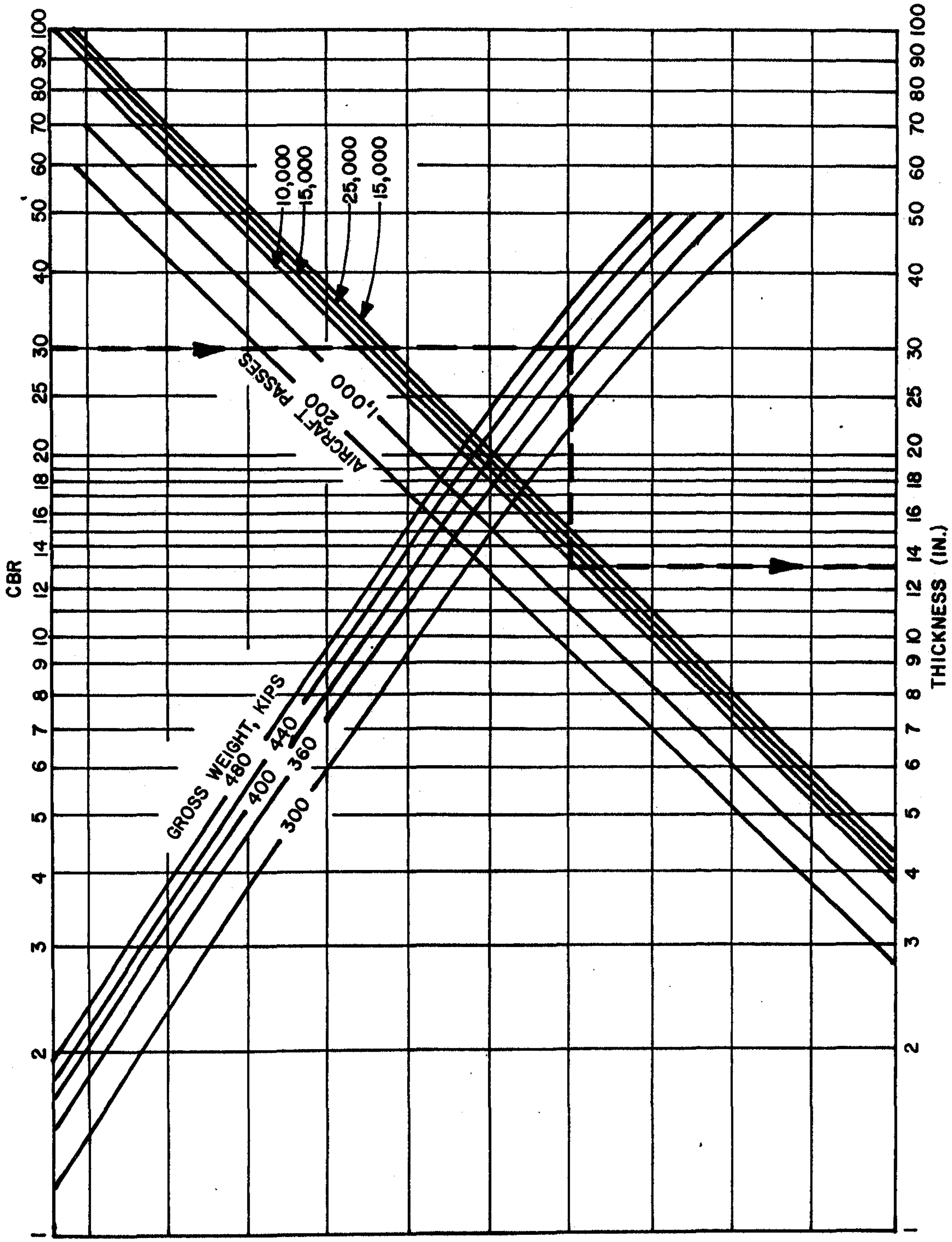


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FIGURE 7-6a. FLEXIBLE PAVEMENT DESIGN CURVES,
AIR FORCE HEAVY-LOAD PAVEMENT, TYPE A TRAFFIC AREA

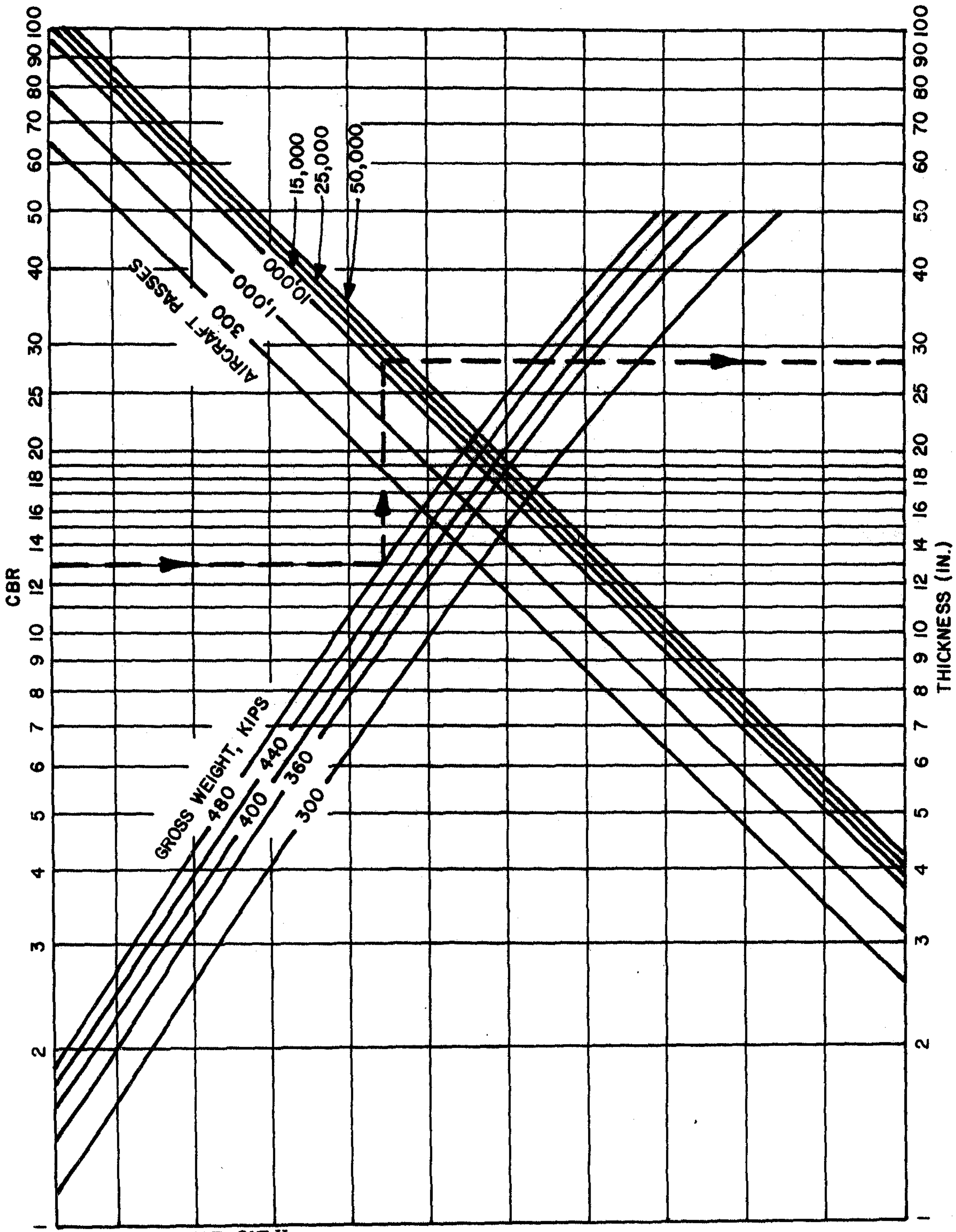


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FIGURE 7-6b. FLEXIBLE PAVEMENT DESIGN CURVES, AIR FORCE HEAVY-LOAD PAVEMENT, TYPES B, C, AND D TRAFFIC AREAS AND OVERRUNS.

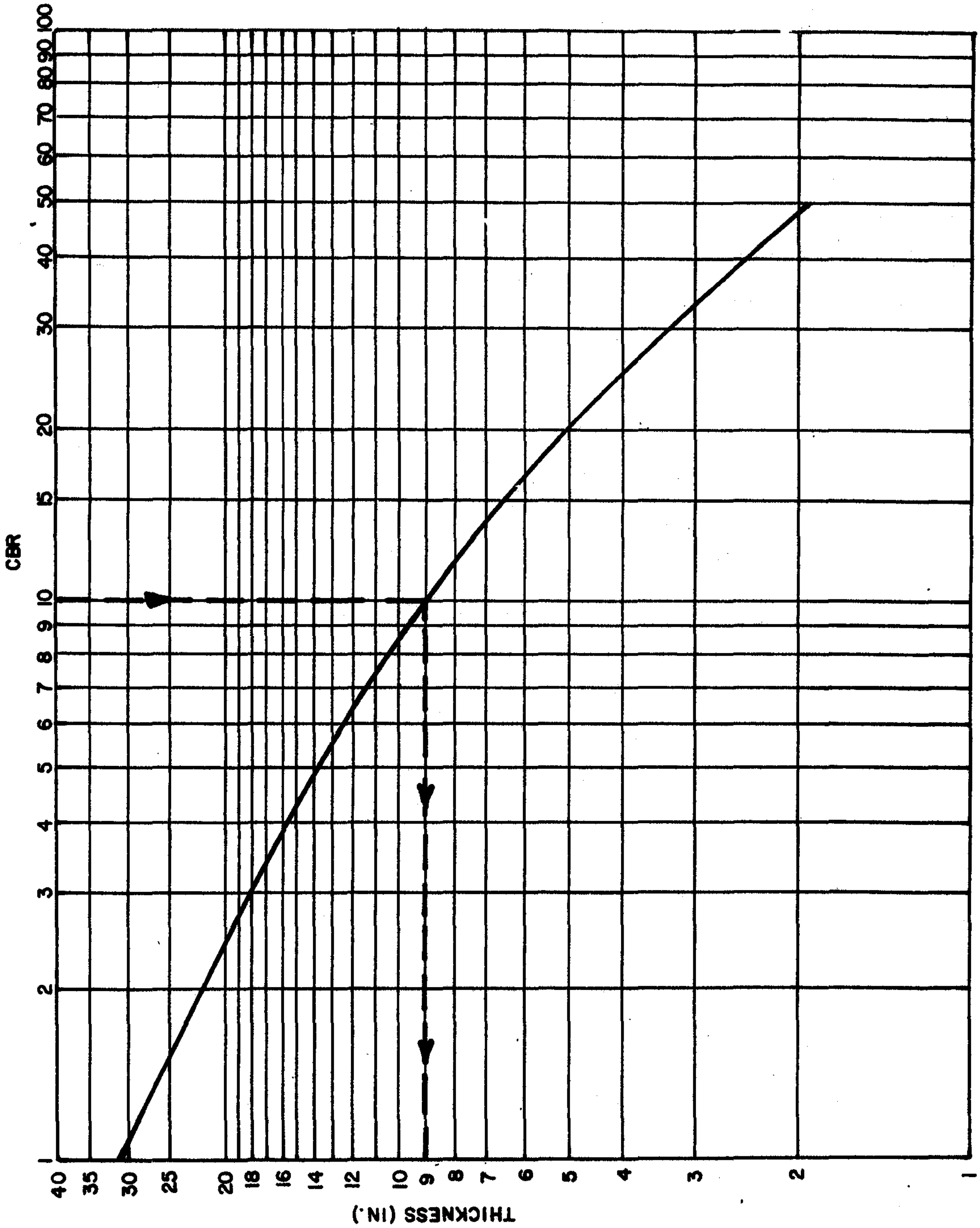


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FIGURE 7-7. FLEXIBLE PAVEMENT DESIGN CURVES
AIR FORCE SHOULDER PAVEMENT

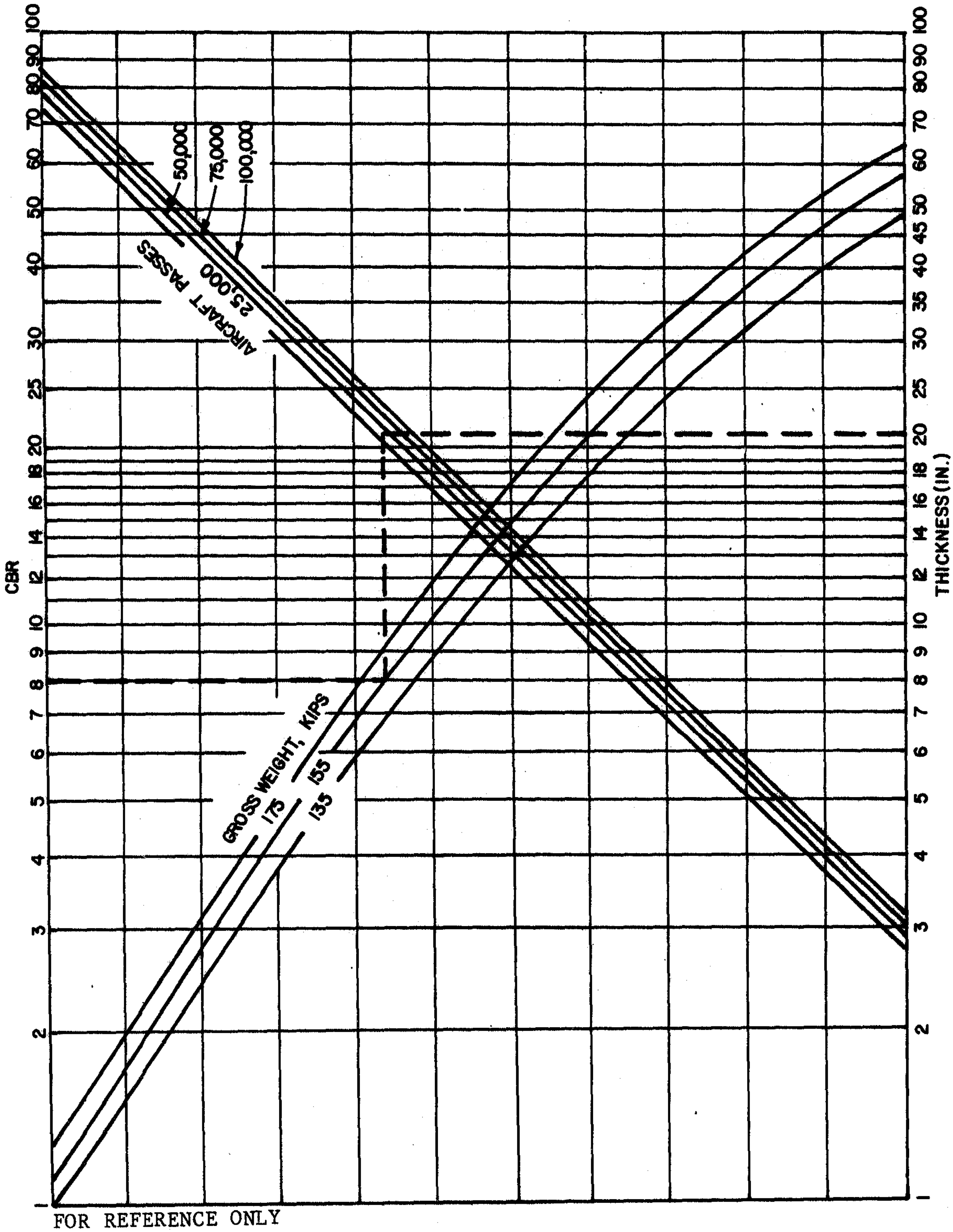


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FIGURE 7-8. FLEXIBLE PAVEMENT DESIGN CURVES, AIR FORCE SHORTFIELD PAVEMENT, TYPE A TRAFFIC AREAS AND OVERRUNS determined. These thicknesses together with the minimum thicknesses for surface and base courses provide the basis for pavement section design. Use table 5-2 for minimum thickness of base and surface course. See table 7-2 for an outline of the flexible pavement thickness design procedure. In addition, consider the following:

a. CBR values less than 3. Normally sites which include large areas of the natural subgrade with CBR values of less than 3 are not considered adequate for airfield construction. However, CBR values of less than 3 are acceptable for occasional isolated weak areas.

b. Frost areas. Pavement sections in frost areas must be designed and constructed with non-frost-susceptible materials of such depth to prevent destructive frost penetration into underlying susceptible materials. Design for frost areas should be in accordance with EM 1110-3-138.

c. Expansive subgrade. Determine if moisture condition of expansive subgrade is controlled and if adequate overburden is provided. (See table 3-5).

d. Limited subgrade compaction. Where subgrade compaction must be limited for special conditions (see tables 3-3 and 3-5), provide pavement thickness in conformance with reduced density and CBR of the prepared subgrade.

e. Rainfall and water table. In regions where the annual precipitation is less than 15 inches and the water table (including perched water table) will be at least 15 feet below the finished pavement surface, the danger of high moisture content in the subgrade is reduced. Where in-place tests on similar construction in these regions indicate that the water content of the subgrade will not increase above the optimum, the total pavement thickness, as determined by CBR tests on soaked samples, may be reduced by as much as 20 percent.

f. Pavement section comparison. Compare design pavement sections with field behavior of similar pavement sections on comparable soil conditions; assess the traffic on similar pavement sections with the design traffic loading.

7-5. Design examples. The examples are not to be used as design criteria. They are intended solely to illustrate how the criteria in this manual would be used in an assumed situation. Any attempt to arbitrarily apply these examples to actual design problems without a complete design analysis, following the procedures outlined in this manual, may result in faulty pavement design.

Table 7-2. CBR Flexible Pavement Design Procedure

| Item | Procedure |
|---|---|
| Total thickness | 1. Determine design CBR of subgrade (see chapter 3) |
| | 2. Enter top of flexible pavement design curve (figure 7-1 to figure 7-8) with design subgrade CBR and follow it downward to intersection with appropriate gross weight curve, then horizontally to appropriate aircraft passes curve, then down to required total pavement thickness above subgrade. |
| Thickness of surface and base course | 3. Determine design CBR of subbase material (see chapter 4). |
| | 4. Enter top of curve at design CBR of subbase, follow procedure in procedure 2 above to obtain required thickness of base and surface above subbase course. |
| | 5. Determine the required minimum thickness of base and surface from table 5-2. Increase combined thickness of base and surface to required minimum, if necessary. |
| Thickness of subbase course | 6. Subtract thickness of surface and base from the total thickness to obtain the required thickness of subbase. |
| | 7. If less than 6 inches, consider increasing thickness of base course. |
| Subgrade Compaction | 8. See table 3-3 for required compaction of subgrade. |

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a. Design example 1.

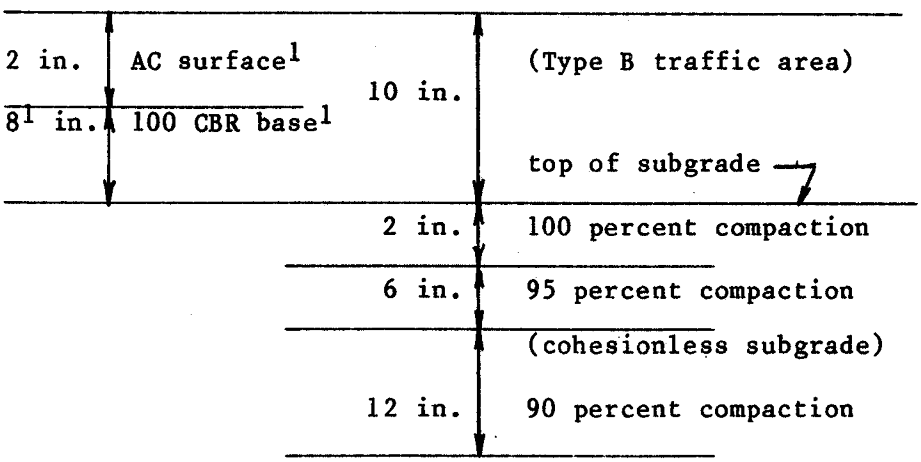
(1) Design an airfield, Type B traffic area for a single-wheel tricycle gear aircraft with a gross load of 25-kips for 1,000,000 pååsses. Subgrade is a poorly graded sand with a design CBR of 16; in-place density of the subgrade is 90 percent to a depth of 10 feet.

(2) From figure 7-1 the total pavement section required is 10 inches.

(3) From table 5-2 the minimum required surface and base thicknesses are 2 inches and 6 inches respectively, for a total of 8 inches.

(4) Use a 10-inch pavement section consisting of 2 inches of asphalt concrete surface and 8 inches of 100 CBR base on subgrade to provide the 10 inches required above the subgrade.

(5) Determine the compaction requirements from table 3-3. The design section is as follows:




[1]Base and subbase compacted to 100 percent.

Since the existing subgrade has an in-place density of 90 percent, the compaction of the 8 inch upper layer of the subgrade may be achieved by moistening and compacting in place.

b. Design example 2.

(1) Design a heavy load pavement to accommodate a 480-kip gross load twin twin gear assembly aircraft in a Type B traffic area for 15,000 passes. Design CBR of the lean clay subgrade is 13, the natural in-place density of the clay is 87 percent extending to 10 feet. The analysis that follows assumes that subgrade does not require special treatment and frost penetration is not a problem.

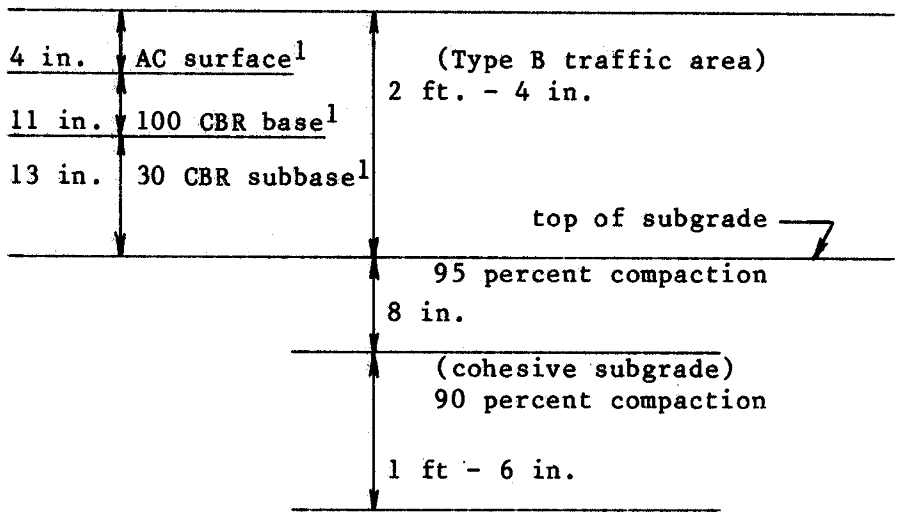
(2) Enter figure 7-6(b) at CBR = 13 down to 480-kip GROSS WEIGHT curve then right to the 15,000 AIRCRAFT PASSES curve thence down to the required thickness of pavement, 28 inches.

(3) The design CBR of the subbase material has been determined to be 30. Enter figure 7-6(b) at CBR 30 and find that the required thickness of base and surface is 15 inches for the design aircraft. From table 5-2, the required minimum thickness of the surface course is 4 inches and of the base, 9 inches. Use 4 inch asphalt concrete surface and 11 inches of 100 CBR base to provide the 15 inches required above the 30 CBR subbase.

(4) The required thickness of subbase is 13 inches (28 inches less 15 inches).

(5) From table 3-3 it is determined that for cohesive subgrade soils, 95 percent compaction is required to 3 feet below pavement surface and 90 percent compaction to a 4-1/2-foot depth.

(6) The design section is illustrated below:




[1]Base and subbase compacted to 100 percent.

7-6. Stabilized pavement sections. Stabilized layers may be incorporated in the pavement sections in order to make use of locally available materials which cannot otherwise meet the criteria for base course or subbase course. The strength and durability of the stabilized courses must be in accordance with requirements of chapters 4 and 5. (See requirements EM 1110-3-137).

a. Equivalency factors. The use of stabilized soil layers within a flexible pavement provides the opportunity to reduce the overall thickness of pavement structure required to support a given load. This is accomplished through the use of the equivalency factors presented in table 7-3. Factors are shown for replacement of base and subbase material and indicate that 1 inch of stabilized material is equivalent to the number of inches of unbound materials shown in the table. That is, 1 inch of cement-stabilized gravels or sands is equivalent to 1.15 inches of base-course material and 2.3 inches of subbase material. Any stabilized soil used to replace a base or subbase must meet the requirements described in EM 1110-3-137.

b. Design. The design of a pavement having stabilized soil layers is accomplished through the application of equivalency factors to the individual unbound soil layers of a pavement. A conventional flexible pavement is first designed, then the base and subbase are converted to an equivalent thickness of stabilized soil. This conversion is made by dividing the thickness of unbound material by the equivalency factor. For example, assume that a conventional pavement has been designed consisting of 4 inches of AC, 10 inches of base, and 15 inches of subbase for a total thickness above the subgrade of 29 inches. It is desired to replace the base and subbase with cement-stabilized GW material. The equivalency factor for the base-course layer is 1.15; therefore, the thickness of stabilized GW to replace 10 inches of base course is 10/1.15 or 8.7 inches. The equivalency factor for the subbase layer is 2.3, and the thickness of stabilized GW to replace the 15-inch subbase is 15/2.3 or 6.5 inches. The thickness of stabilized GW needed to replace the base and subbase would be 15.2 inches.

c. Use of equivalency factors. To design a pavement with an all-bituminous concrete section, the total thickness of a conventional pavement section and the thickness of the surface courses are first determined as outlined in table 7-2. Let us assume that the total thickness for a conventional pavement section is 28 inches and the required thickness for the surface courses is 4 inches. Minimum thickness requirement for the base course is 6 inches. The indicated thickness for an unbound subbase is 28 inches minus 4 inches of asphaltic concrete surface courses and 6 inches of all-bituminous concrete base or 18 inches. The equivalency factor for the subbase course layer is 2.3. The required thickness for the all-bituminous concrete bottom layer is 18 inches/2.3 or 7.8 inches (use 8 inches). The total thickness of the all-bituminous concrete section is 18 inches.

7-7. Special areas. Areas such as overrun areas, airfield and heliport shoulders, blast areas, and reduced load areas require special treatment as described below.

a. Overrun areas. Pave overrun areas for the full width of the runway exclusive of shoulders, and for a length of 200 feet on each end of Class I, II, and III runways. Surface the overrun areas with double bituminous surface treatment except for that portion (150 feet long x

Table 7-3. Equivalency Factors

| Material | Equivalency Factors Base | Equivalency Factors Subbase |
|---|---|---|
| Unbound Crushed Stone | 1.00 | 2.00 |
| Unbound Aggregate | _[1] | 1.00 |
| Asphalt-Stabilized | | |
| All-Bituminous Concrete | 1.15 | 2.30 |
| GW, GP, GM, GC | 1.00 | 2.00 |
| SW, SP, SM, SC | _[1] | 1.50 |
| Cement-Stabilized | | |
| GW, GP, SW, SP | 1.15[2] | 2.30 |
| GC, GM | 1.00[2] | 2.00 |
| ML, MH, CL, CH | _[1] | 1.70 |
| SC, SM | _[1] | 1.50 |
| Lime-Stabilized | | |
| ML, MH, CL, CH | _[1] | 1.00 |
| SC, SM, GC, GM | _[1] | 1.10 |
| Lime, Cement, Fly Ash Stabilized | | |
| ML, MH, CL, CH | _[1] | 1.30 |
| SC, SM, GC, GM | _[1] | 1.40 |

[1]Not used as base course.

[2]Cement is limited to 4 percent by weight or less.

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runway width) abutting the runway pavement end which will have wearing surface of 2 inches of dense graded asphaltic concrete for blast protection. Minimum base course CBR values are as follows:

| Design Loading | Minimum Base Course CBR |
|---|---|
| Class III | 80[1] |
| Class II | 801 |
| Class I | 50[2] |

[1]Any 80 CBR type base course listed in chapter 5.

[2]Must meet all requirements for 50 CBR subbase materials listed in chapter 4.

b. Paved shoulders. Shoulder areas will be paved to support the aircraft outrigger gear and for protection against jet blast. The wearing surface will be 2 inches of dense graded asphaltic concrete; design the pavement thickness in accordance with figure 7-7.

c. Shoulders. Design shoulders adjacent to hardstand and apron areas to sustain traffic of support vehicles. Design the pavement thickness of shoulder areas in accordance with figure 7-7. Use a double bituminous surface treatment on a minimum 6-inch base consisting of 40 CBR material or better.

d. Overrun areas and other shoulder areas. Compact surface of overrun areas and shoulder areas, except shoulders adjacent to aprons and hardstands, to 90 percent maximum density for a depth of 6 inches. Stabilize the shoulders for dust and erosion control against blast of motor blades. Provide vegetative cover, anchored mulch, coarse graded aggregate, liquid palliatives, or a double bituminous surface treatment. When a double bituminous surface treatment is specified, provide a 4-inch base of 40 CBR material or better.

# CHAPTER 8

## SPECIAL SURFACE TREATMENTS AND SPECIAL DETAILS

8-1. General. This section covers surface treatments for improvement of skid resistance, reduction of hydroplaning tendency, and resistance to fuel spillage.

8-2. Surface treatment for improved skid resistance. Improved skid resistance and the elimination of the tendency to hydroplane may be accomplished by proper drainage and proper aggregate selection or by application of a porous friction course or by grooving the pavement surface. These surface treatments are applicable to runways and high speed taxiways.

8-3. Porous friction surface course. Porous friction surface course consists of an open graded bituminous concrete containing a large proportion of one-sized coarse aggregate. The large void content permits water to drain through the layer laterally out to the shoulders. Porous friction courses are also described as "open graded mix," "plant mix seal," and "popcorn mix." In addition to improving skid resistance and preventing hydroplaning, porous friction courses provide the following additional advantages:

- Improved visibility of pavement marking.

- Reduced tire splash and spray.

Some disadvantages include:

- Susceptibility to fuel spills.

- Susceptibility to clogging by mud, blow sand, and rubber.

8-4. Prior preparation. Porous friction courses and grooving should only be applied to structurally adequate sections capable of supporting existing and future aircraft traffic. The pavement surface should be checked for proper surface drainage; transverse grades should be a minimum of 1 percent. Pavements which are understrength, have insufficient slope for drainage, contain depressed areas, or are cracked, should be strengthened and should have deficiencies corrected prior to applying a porous friction course or grooving.

8-5. Fuel resistant surfacings. Jet fuel-resistant bituminous surfacings may be used in new construction, where expedient, or as overlays. See appendix A for criteria on fuel resistant rubberized-tar mixes. Design fuel resistant flexible pavement as outlined in chapter 7 for conventional pavement, except that the surface will consist of a tar or asphalt binder topped with a minimum of 1-1/2 inches of rubberized tar wearing course. Joints in the wearing course are particularly critical and care must be taken in bonding the joints to prevent leakage which would result in deterioration of the asphalt below.

8-6. Fuel resistant seal coat. Structurally adequate asphaltic pavements in good condition subject to fuel spillage may be protected by a rubberized-tar slurry seal. Rubberized-tar slurry seal provides a fine grained, slippery surface which is resistant to fuel spillage. Because of the slippage surface imparted by this type seal, it is not to be used on runways and taxiways.

8-7. Juncture between rigid and flexible pavements. Experience has shown that objectionable roughness often develops at the juncture of a rigid and flexible pavement under aircraft traffic. This roughness generally takes the form of subsidence or shoving. For details on this juncture, see EM 1110-3-142.

# APPENDIX A

## HOT-MIX BITUMINOUS PAVEMENTS, DESIGN AND CONTROL

AI. General.

Al-1. Procedures and criteria. Procedures and criteria in this appendix apply to design and control of hot-mix bituminous pavements using penetration grades of asphalt cement, tar cement, or rubberized tar.

Al-2. Alternative approaches. It is anticipated that under mobilization conditions, bituminous pavement materials will be supplied by established local sources. In most cases these sources have been utilized by Federal or state agencies in the past and have approved design mixes available to meet the needs as outlined in this manual. Review of the available mix results along with the associated material test results and supplemented by field inspections and testing of present materials should supply sufficient information to proceed with design and construction.

Al-3. Design requirements. The following discussion is presented to provide the designer with design requirements as an aid to evaluating available materials and to provide information on methods of obtaining design data if not locally available.

A2. Design.

A2-1. Survey of materials. A survey of materials available in suitable quantities for use in construction of the pavement is the first step in the design of a paving mixture. Materials normally required for the paving mixture are coarse aggregate, fine aggregate, mineral filler, and bitumen.

A2-2. Sampling. Sufficient quantities of materials are to be obtained to provide for laboratory pavement design tests subsequently described.

a. Fine and coarse aggregate. Sampling of fine and coarse aggregate will be in accordance with ASTM D 75.

b. Mineral filler. Sampling of mineral filler will be in accordance with ASTM C 183.

c. Asphalt cement, tar cement, and rubberized tar. Sampling of all bituminous materials will be in accordance with ASTM D 140.

A2-3. Testing of pavement materials.

a. Tests on aggregates. Aggregates for use in bituminous pavements should be clean, hard, and durable. Aggregates that are angular in shape generally provide more stable pavements than do rounded ones. In most cases, aggregates will be supplied from established sources where laboratory testing has taken place. Existing laboratory tests should be utilized to the greatest extent possible in providing design data.

(1) Sieve analysis. A sieve analysis of the aggregates considered for use in a paving mix is of value in several respects. An experienced engineer can obtain general information from the grading curve as to the suitability of the aggregate for a paving mix, the quantity of bitumen required, and whether or not mineral filler should be added. Also, a sieve analysis is required if the aggregate is to be used in laboratory tests for paving mix design, as described later. Sieve analyses of fine and coarse aggregates are to be in accordance with ASTM C 136. Figure A-1 is a form suggested for use in recording and calculating data obtained from sieve analysis. Mechanical analysis data for typical coarse aggregate, fine aggregate, sand, and mineral filler used in a paving mixture are shown in figure A-1.

(2) Specific gravity. Specific gravity values for aggregates used in a paving mix are required in the computation of percent voids total mix and percent voids filled with bitumen in the compacted specimens. Criteria have been established to furnish limiting values for these factors. However, specific gravity values must be determined with care and in accordance with specified procedures in order that application of the criteria will be valid. Two different specific gravity determinations are provided, and the selection of the appropriate test procedures depends on the water absorption of each aggregate blend.

(a) ASTM apparent specific gravity. Apparent specific gravity of the fine and coarse aggregate need be used only with aggregate blends showing water absorption of less than 2.5 percent. The apparent specific gravity is to be determined in accordance with ASTM C 127 for coarse aggregate, ASTM C 128 for fine aggregate, and ASTM C 188 or D 854 (whichever is applicable) for mineral filler. Figure A-2 is a form suggested for use in recording data from these tests. Typical data have been supplied in this form as an illustration of its use. Properly weighted values, based on the amount of each type of material in a given blend, should be used in computations subsequently discussed.

(b) Bulk-impregnated specific gravity. For aggregate blends showing water absorption to be 2.5 percent or greater, the bulk-impregnated specific gravity is to be used. This specific gravity will be determined in accordance with the procedure outlined in Method 105, MIL-STD-620.

## SIEVE ANALYSIS

| JOB NO: | PROJECT: TYPICAL MIX | DATE: |
|---|---|---|

STOCKPILE SAMPLES DRY GRADATION

| SAMPLE NO. Crushed Coarse Aggregate | | | | SAMPLE NO. Crushed Fine Aggregate | | | |
|---|---|---|---|---|---|---|---|
| U.S. STAND. SIEVE NO. | WEIGHT RETAINED | % RETAINED | % PASS | U.S. STAND. SIEVE NO. | WEIGHT RETAINED | % RETAINED | % PASS |
| | | | | | | | |
| 3/4 | | | 100 | 3/4 | | | |
| 1/2 | 225.9 | 30.0 | 70.0 | 1/2 | | | 100 |
| 3/8 | 267.3 | 35.5 | 34.5 | 3/8 | 1.1 | 0.2 | 99.8 |
| NO. 4 | 237.2 | 31.5 | 3.0 | NO. 4 | 53.9 | 9.8 | 90.0 |
| NO. 8 | 22.6 | 3.0 | | NO. 8 | 104.6 | 19.0 | 71.0 |
| NO. 16 | | | | NO. 16 | 104.6 | 19.0 | 52.0 |
| NO. 30 | | | | NO. 30 | 96.3 | 17.5 | 34.5 |
| NO. 50 | | | | NO. 50 | 82.5 | 15.0 | 19.5 |
| NO. 100 | | | | NO. 100 | 60.5 | 11.0 | 8.5 |
| NO. 200 | | | | NO. 200 | 30.3 | 5.5 | 3.0 |
| -200 | | | | -200 | 16.5 | 3.0 | |
| TOTAL | 753.0 | | | TOTAL | 550.3 | | |
| WEIGHT ORIGINAL SAMPLE | | | | WEIGHT ORIGINAL SAMPLE | | | |

WASHED GRADATION

| SAMPLE NO. Natural Sand | | | | SAMPLE NO. Limestone Filler | | | |
|---|---|---|---|---|---|---|---|
| U.S. STAND. SIEVE NO. | WEIGHT RETAINED | % RETAINED | % PASS | U.S. STAND. SIEVE NO. | WEIGHT RETAINED | % RETAINED | % PASS |
| | | | | | | | |
| 3/4 | | | | 3/4 | | | |
| 1/2 | | | | 1/2 | | | |
| 3/8 | | | | 3/8 | | | |
| NO. 4 | | | | NO. 4 | | | |
| NO. 8 | | | | NO. 8 | | | |
| NO. 16 | | | | NO. 16 | | | |
| NO. 30 | | | 100 | NO. 30 | | | |
| NO. 50 | 9.4 | 4.5 | 95.5 | NO. 50 | | | 100 |
| NO. 100 | 54.6 | 26.0 | 69.5 | NO. 100 | 2.3 | 2.0 | 98.0 |
| NO. 200 | 124.9 | 59.5 | 10.0 | NO. 200 | 9.4 | 8.0 | 90.0 |
| -200 (T) | 21.0 | 10.0 | | -200 (T) | 105.3 | 90.0 | |
| TOTAL | 209.9 | | | TOTAL | 117.0 | | |

Natural Sand:

(A) WEIGHT ORIGINAL SAMPLE 209.2 GM
(B) WEIGHT AFTER WASHED 193.7 GM
(C) WASH LOSS (A - B) 15.5 GM
(S) -200 FROM SIEVING 5.5 GM
(T) TOTAL -200 C + S 21.0 GM
USE "T" TO CALCULATE PERCENTAGES

Limestone Filler:

(A) WEIGHT ORIGINAL SAMPLE 117.4 GM
(B) WEIGHT AFTER WASHED 18.9 GM
(C) WASH LOSS (A - B) 98.5 GM
(S) -200 FROM SIEVING 6.8 GM
(T) TOTAL -2000 C + S 105.3 GM
USE "T" TO CALCULATE PERCENTAGES

| TESTED BY: | COMPUTED BY: | CHECKED BY: |
|---|---|---|

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FIGURE A-1. SIEVE ANALYSIS

| SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS | | | | DATE |
|---|---|---|---|---|
| PROJECT | JOB TYPICAL MIX | | | |
| COARSE AGGREGATE | | | | |
| MATERIAL PASSING 3/4" SIEVE AND RETAINED ON 3/8" SIEVE | UNITS | | | |
| SAMPLE NUMBER Coarse aggregate | | | | |
| 1. WEIGHT OF OVEN - DRY AGGREGATE | GM. | 378.3 | | |
| 2. WEIGHT OF SATURATED AGGREGATE IN WATER | GM. | 241.0 | | |
| 3. DIFFERENCE (1.-2.) | GM. | 137.3 | | |
| APPARENT SPECIFIC GRAVITY, $G = \frac{(1.)}{(3.)}$ | 2.755 | | | |
| FINE AGGREGATE | | | | |
| MATERIAL PASSING NUMBER 3/8" SIEVE | UNITS | | | |
| SAMPLE NUMBER Natural sand | | | | |
| 4. WEIGHT OF OVEN - DRY MATERIAL | GM. | 478.8 | | |
| 5. WEIGHT OF FLASK FILLED WITH WATER AT 20°C | GM. | 678.6 | | |
| 6. SUM (4.+5.) | GM. | 1157.4 | | |
| 7. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C, | GM. | 977.4 | | |
| 8. DIFFERENCE (6.-7.) | GM. | 180.0 | | |
| APPARENT SPECIFIC GRAVITY, $G = \left(\frac{4.}{8.}\right)$ | 2.660 | | | |
| FILLER | UNITS | | | |
| SAMPLE NUMBER Limestone Filler | | | | |
| 9. WEIGHT OF OVEN - DRY MATERIAL | GM. | 466.5 | | |
| 10. WEIGHT OF FLASK FILLED WITH WATER AT 20°C, | GM. | 676.1 | | |
| 11. SUM (9.+10.) | GM. | 1142.6 | | |
| 12. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C, | GM. | 973.8 | | |
| 13. DIFFERENCE (11.-12.) | GM. | 168.8 | | |
| APPARENT SPECIFIC GRAVITY, $G = \left(\frac{9.}{13.}\right)$ | 2.764 | | | |
| BINDER | UNITS | | | |
| SAMPLE NUMBER 6873 | | | | |
| 14. WEIGHT OF PYCNOMETER FILLED WITH WATER | GM. | 61.9595 | | |
| 15. WEIGHT OF EMPTY PYCNOMETER | GM. | 37.9215 | | |
| 16. WEIGHT OF WATER (14.-15.) | GM. | 24.0380 | | |
| 17. WEIGHT OF PYCNOMETER + BINDER | GM. | 47.8617 | | |
| 18. WEIGHT OF BINDER (17.-15.) | GM. | 9.9402 | | |
| 19. WEIGHT OF PYCNOMETER + BINDER + WATER TO FILL PYCNOMETER | GM. | 62.1568 | | |
| 20. WEIGHT OF WATER TO FILL PYCNOMETER (19.-17.) | GM. | 47.8617 | | |
| 21. WEIGHT OF WATER DISPLACED BY BINDER | GM. | 9.7429 | | |
| APPARENT SPECIFIC GRAVITY, $G = \left(\frac{18.}{20.}\right)$ | 1.020 | | | |
| REMARKS | | | | |
| TECHNICIAN (Signature) | COMPUTED BY (Signature) | CHECKED BY (Signature) | | |

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FIGURE A-2. SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS

(3) Wear requirements for coarse aggregate. The determination of percentage of wear for coarse aggregates may not be necessary if the aggregate has been found satisfactory by previous tests. However, coarse aggregates obtained from new or doubtful deposits must be tested for conformance to specification requirements using ASTM C 131.

(4) Soundness test. The soundness test is used where damage from freezing is expected to be a problem. It is not necessary to conduct the soundness test on aggregate that has been found satisfactory by previous tests. However, aggregate obtained from new or doubtful deposits will be tested for conformance to specification requirements using ASTM C 88.

(5) Swell test. Experience has indicated that bituminous pavements produced from clean, sound stone, slag, or gravel aggregates and from mineral filler produced from limestone will show values in the swell test of less than 1.5 percent. However, aggregates considered to be of doubtful character will be tested for conformance to specification requirements for percentage of swell in accordance with AASHTO T 101.

(6) Immersion-compression test. This test should be conducted on all paving mixes considered for construction of pavements. (See Method 104, MIL-STD-620).

b. Tests on mineral filler. Some mineral fillers have been found to be more satisfactory in asphalt paving mixtures than others. For example, fine sands and clays are normally less suitable fillers than limestone filler or portland cement. Well-graded materials are more suitable than poorly graded materials. A limited amount of laboratory work has indicated that mineral fillers of reasonably uniform gradation and falling within the limits set forth in paragraph A2-3.f. hereinafter, are generally satisfactory. Satisfactory pavements may be designed using commercial fillers that conform to ASTM Standards. The specific gravity of the mineral filler is required in void computation. It will be determined in accordance with ASTM D 854, or alternatively, ASTM C 188, except that when the bulk-impregnated specific gravity is used, the mineral filler is to be included in the blended aggregate. (See Method 103, MIL-STD-620). Figure A-2 is a form suggested for tabulation and computation of these data; typical data have been entered in this form to illustrate its use.

c. Tests on bitumen. Test requirements for asphalt cement, tar for rubberized-tar blends, rubberized-tar blends, and tar are outlined in the mobilization specifications. Figure A-2 is a form suggested for use in determining specific gravity of bitumen; typical data are included in this form.

d. Selection of materials for mix design. The first step in the design of a paving mix is the tentative selection of materials. The bitumen used in the laboratory tests must be the same as that which will be used in field construction. The selection of aggregates and mineral filler for the paving mix is more involved than the selection of the bitumen. Aggregates and mineral fillers that do not meet the requirements of the specifications previously discussed should be eliminated from further consideration. The remaining aggregates and filler must then be examined from both technical and economical viewpoints. The final objective is to determine the most economical blend of aggregates and mineral filler that will produce a pavement meeting the engineering requirements set forth in this manual. In general, several blends should be selected for laboratory mix-design tests. The mix-design gradation (i.e., job-mix formula) plus or minus job-mix tolerances must fall within the gradation tolerances specified in the appropriate guide specification.

e. Combining aggregates. In the production of paving mixes, it is generally necessary to combine aggregates from two or more sources. Mathematical equations are available for making such combinations, but they are not presented herein because they are lengthy and normally it is easier to use trial-and-error procedures. Methods and procedures described herein will permit determination of the most suitable aggregate or blend available, and will prescribe the proper bitumen content for the particular aggregate blend determined to be the most suitable. Whenever a paving mix will not meet established criteria, as subsequently outlined, it is necessary either to improve the gradation of the aggregate being used or to use another aggregate. The choice as to improvement of gradation or the use of another aggregate is a matter of engineering judgment involving an analysis of the available aggregate supplies and various economic considerations.

f. Addition of mineral filler. The filler requirements of each aggregate blend must be estimated after the blends to be tested in the laboratory have been selected. Considerations should be given to the items discussed in paragraph A2-3.b. in selecting the mineral filler to be used. The quantity of mineral filler to be added depends on several factors, among which are the amount of filler naturally present in the aggregate, desired reduction in voids, the extent to which additional increments of filler will decrease the optimum bitumen content of the mixture, the extent to which it may be necessary to improve the stability of the mixture, and the cost of the filler. The addition of mineral filler reduces the quantity of bitumen required for the paving mixture. The addition of excessive amounts of filler is not economical, as a limit is reached at which no further reduction in optimum bitumen content occurs with an increase in filler. It also has been indicated that the addition of a satisfactory mineral filler within practical limits increases the stability of a paving mixture. Excessive amount of filler, however, may decrease the durability of the paving mixture. Therefore, while the addition of some mineral filler is normally beneficial to the paving mixture, the addition of large quantities of filler not only is uneconomical, but may also be detrimental to the paving mixture. Experience has indicated that filler contents should not exceed about 10 percent for bituminous concretes and about 20 percent for sand asphalts. Practical considerations usually will dictate quantities of about 5 percent filler for bituminous concrete and 10 percent for sand asphalts. When there has been no previous experience with a particular aggregate, it may be desirable to conduct laboratory tests at more than one filler content in order that the best mixture can be selected.

A2-4. Laboratory testing for mix design.

a. General procedure. Laboratory testing will indicate the properties that each blend selected would have after being subjected to appreciable traffic. A final selection of aggregate blend and filler will be based on these data with due consideration to relative costs of the various mixes. The procedures set forth in the following paragraphs are directly applicable to all mixes containing not more than 10 percent of aggregate retained on the 1-inch sieve. The procedure to follow when a mix contains more than 10 percent aggregate exceeding the 1-inch-maximum size is outlined in Method 103, MIL-STD-620.

b. Preparation of test specimens. The selection of materials for use in designing the paving mix was discussed in paragraph 6-2. For purposes of illustration, suppose that it has been determined that an aggregate gradation for a hot-mix design should be the median of the limiting gradation curves in figure A-3. This is the blend on which design data are required. The initial pavement mix design tests will usually be made in a central testing laboratory. The initial tests will be conducted on samples of stockpile materials submitted by the Contractor. Paragraph (1) below outlines the procedure for proportioning stockpile samples to produce a blend of materials to meet a specified gradation. The final mix will be based on bin samples taken from the bituminous plant; in this step, it will again be necessary to determine what proportions of the bin materials will be required to meet a specified gradation. The final mix design will usually be made in a field laboratory near the plant, or the bin samples may be sent to the central laboratory that conducted the initial design tests on the stockpile samples. Paragraph (2) below outlines the procedure for combining processed bin samples to meet a specified gradation.

(1) Proportioning of stockpile samples. As a preliminary step in mixture design and manufacture, it is necessary to determine the approximate proportions of the different available stockpiled materials required to produce the desired gradation of aggregate. This is necessary in order to determine whether a suitable blend can be produced and, if so, the approximate proportion of aggregates to be fed from the cold feed into the dryer. Sieve analyses are run on material from each of the stockpiles and these data entered in a form as

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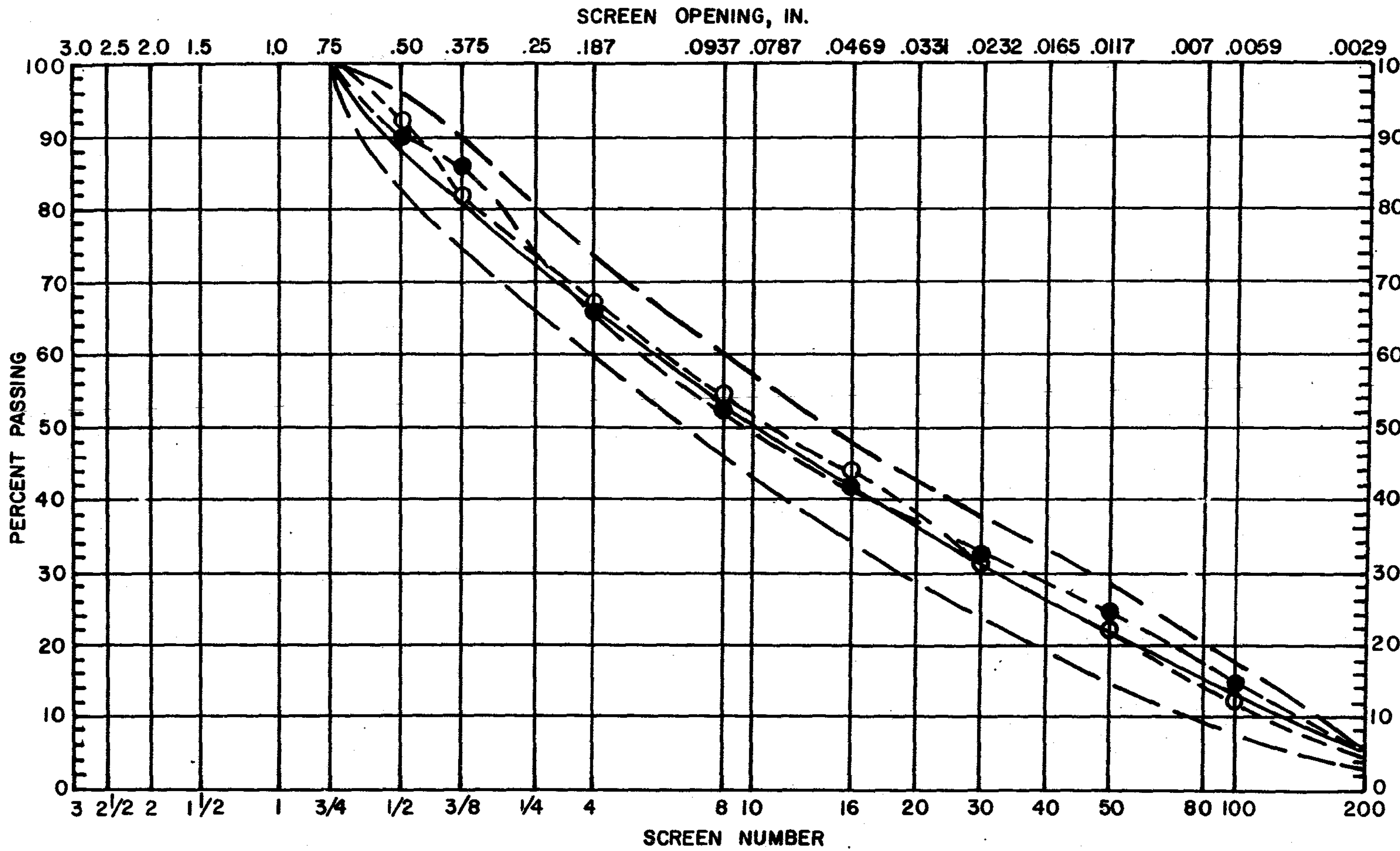


LEGEND

- Specification Gradation
- Specification Tolerances
- Blending Of Stockpile Samples
- Blending Of Bin Samples

FIGURE A-3. GRADATION DATA FOR HOT MIX DESIGN illustrated at the top of figure A-4. The data are shown graphically in figure A-5. These fractions must be combined to produce the desired blend. The percentage of each fraction required to produce this blend is entered in the form at the middle of figure A-4; these percentages are most easily determined by trial-and-error calculations.

(2) Proportioning of bin samples. Once it is demonstrated that a suitable blend can be prepared from the available materials, then samples of these materials can be processed for use in the laboratory design tests. Sieve analyses must be conducted for each batch of processed aggregate. The processed aggregates are comparable to those obtained in the hot bins of an asphalt plant. Results from these sieve analyses should be entered in a form as illustrated at the top of figure A-6. The data are shown graphically in figure A-7. A study of the data from the sieve analysis of the processed samples indicates that, of the material processed to pass the 3/4-inch sieve and be retained on 3/8-inch sieve, 76 percent was retained on the 3/8-inch sieve. The desired blend requires 18 percent to be retained on the 3/8-inch sieve; and since all of the 3/4- to 3/8-inch fraction in the desired blend will come from this 3/4- to 3/8-inch fraction, in the first trial, 18 percent of the 3/4- to 3/8-inch was used. The percentage data are entered in the second column (percent used) of the center portion (trial No. 1) of figure A-6 as illustrated. These percentage figures are then used to determine the proportional part of each aggregate size in each of the separated fractions. If the combined blends contained 18 percent of the 3/4- to 3/8-inch fraction, then 18.0, 9.0, 4.3, 1.3, and 0.2 percent of the total blend would pass the 3/4-, 1/2-, 3/8-inch, No. 4 sieves, respectively. The same reasoning is used for the 3/8-inch to No. 8 fraction. The data indicate 90 percent retained on the No. 8 sieve, and the desired blend calls for 29 percent of the 3/8-inch to No. 8 fraction to be retained on the No. 8. Nearly all of this fraction will come from the 3/8-inch to No. 8 fraction bin; therefore, 34 percent has been used as a trial. This procedure is then followed for the other fractions, the data being entered in figure A-6 as indicated, and the grading of the combined blend is determined by the addition of all percentages under each screen-size heading. The grading of this recombined blend is then checked against the desired grading (fig A-6). One or two trials are usually sufficient to produce a combination of the desired grading within the allowable tolerances.

c. Bitumen contents for specimens. The quantity of bitumen required for a particular aggregate is one of the most important factors in the design of a paving mixture; it can be determined by procedures described in the following paragraph. However, an estimate for the optimum amount of bitumen based on total weight of mix must be made in order to start the laboratory tests. Laboratory tests normally are conducted for a minimum of five bitumen contents: two above, two below, and one at the estimated optimum content. One percent incremental changes of bitumen may be used for preliminary work;

## BITUMINOUS MIX DESIGN
## (TRIAL METHOD)

| JOB NO.: | PROJECT TYPICAL MIX | DATE: |
|---|---|---|

### GRADATION OF MATERIAL

| SIEVE SIZE | PERCENT USED | SIEVE SIZE - PERCENT PASSING | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3/4 | 1/2 | 3/8 | 4 | 8 | 16 | 30 | 50 | 100 | 200 |
| Cr C A | 100 | | 100 | 70.0 | 34.5 | 3.0 | | | | | | |
| Cr F A | 100 | | 100 | 100 | 99.8 | 90.0 | 71.0 | 52.0 | 34.5 | 19.5 | 8.5 | 3.0 |
| Sand | 100 | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 95.5 | 69.5 | 10.0 |
| LSF | 100 | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98.0 | 90.0 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

### COMBINED GRADATION FOR BLEND - TRAIL NO. 1

| SIEVE SIZE | PERCENT USED | SIEVE SIZE - PERCENT PASSING | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3/4 | 1/2 | 3/8 | 4 | 8 | 16 | 30 | 50 | 100 | 200 |
| Cr C A | 27.0 | | 27.0 | 18.9 | 9.3 | 0.8 | | | | | | |
| Cr F A | 63.0 | | 63.0 | 63.0 | 62.9 | 56.7 | 44.7 | 32.8 | 21.7 | 12.3 | 5.4 | 1.9 |
| Sand | 8.0 | | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 7.7 | 5.6 | 0.8 |
| LSF | 2.0 | | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.8 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| BLEND | | | 100 | 91.9 | 82.2 | 67.5 | | 42.8 | 31.7 | 22.0 | 12.0 | 4.5 |
| DESIRED | | | 100 | 89.0 | 82.0 | 67.0 | | 41.0 | 31.0 | 22.0 | 13.0 | 4.5 |

### COMBINED GRADATION FOR BLEND - TRAIL NO. ____

| SIEVE SIZE | PERCENT USED | SIEVE SIZE - PERCENT PASSING | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3/4 | 1/2 | 3/8 | 4 | 8 | 16 | 30 | 50 | 100 | 200 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| BLEND | | | | | | | | | | | | |
| DESIRED | | | | | | | | | | | | |

| COMPUTED BY: | CHECKED BY: |
|---|---|

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FIGURE A-4. BLENDING OF STOCKPILE SAMPLES

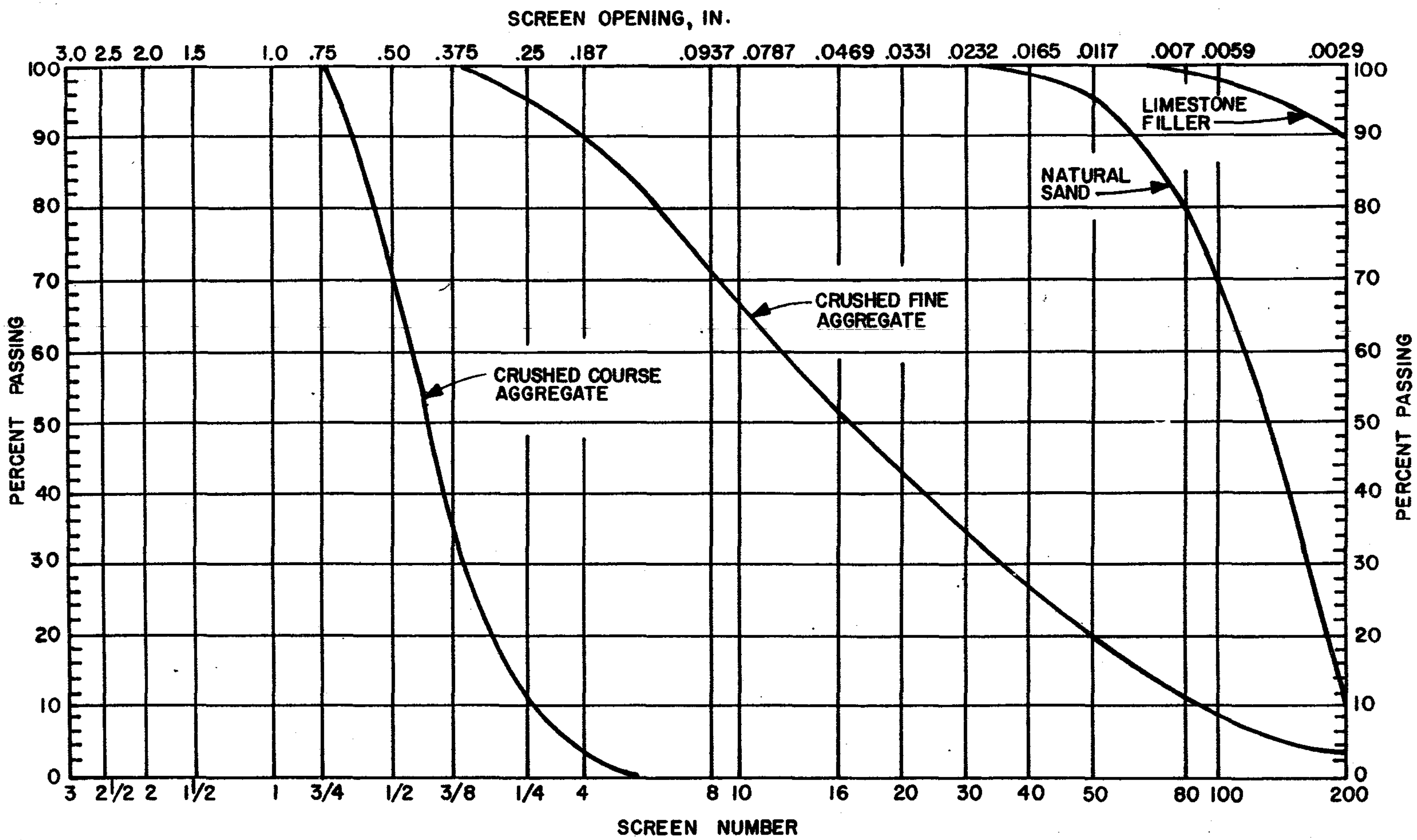


FIGURE A-5. GRADATION DATA FOR STOCKPILE AGGREGATES

## BITUMINOUS MIX DESIGN
## (TRIAL METHOD)

| JOB NO.: | PROJECT TYPICAL MIX | DATE: |
|---|---|---|

### GRADATION OF MATERIAL

| SIEVE SIZE | PERCENT USED | SIEVE SIZE - PERCENT PASSING | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3/4 | 1/2 | 3/8 | 4 | 8 | 16 | 30 | 50 | 100 | 200 |
| 3/4-3/8 | 100 | | 100 | 50.0 | 24.0 | 7.0 | 1.0 | | | | | |
| 3/8-8 | 100 | | 100 | 100 | 100 | 49.0 | 10.0 | 1.0 | | | | |
| -No. 8 | 100 | | 100 | 100 | 100 | 100 | 100 | 84.0 | 65.0 | 46.5 | 26.5 | 5.0 |
| LSF | 100 | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98.0 | 90.0 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

### COMBINED GRADATION FOR BLEND - TRAIL NO. 1

| SIEVE SIZE | PERCENT USED | SIEVE SIZE - PERCENT PASSING | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3/4 | 1/2 | 3/8 | 4 | 8 | 16 | 30 | 50 | 100 | 200 |
| 3/4-3/8 | 18.0 | | 18.0 | 9.0 | 4.3 | 1.3 | 0.2 | | | | | |
| 3/8-8 | 34.0 | | 34.0 | 34.0 | 34.0 | 16.6 | 3.4 | 0.3 | | | | |
| -No. 8 | 45.0 | | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 37.8 | 29.3 | 20.9 | 11.9 | 2.2 |
| LSF | 3.0 | | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.9 | 2.7 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| BLEND | | | 100 | 91.0 | 86.3 | 65.9 | 51.6 | 41.1 | 32.3 | 23.9 | 14.8 | 4.9 |
| DESIRED | | | 100 | 89.0 | 82.0 | 67.0 | 53.0 | 41.0 | 31.0 | 22.0 | 13.0 | 4.5 |

### COMBINED GRADATION FOR BLEND - TRAIL NO. ______

| SIEVE SIZE | PERCENT USED | SIEVE SIZE - PERCENT PASSING | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3/4 | 1/2 | 3/8 | 4 | 8 | 16 | 30 | 50 | 100 | 200 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
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| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| BLEND | | | | | | | | | | | | |
| DESIRED | | | | | | | | | | | | |

| COMPUTED BY: | CHECKED BY: |
|---|---|

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FIGURE A-6. BLENDING OF STOCKPILE SAMPLES

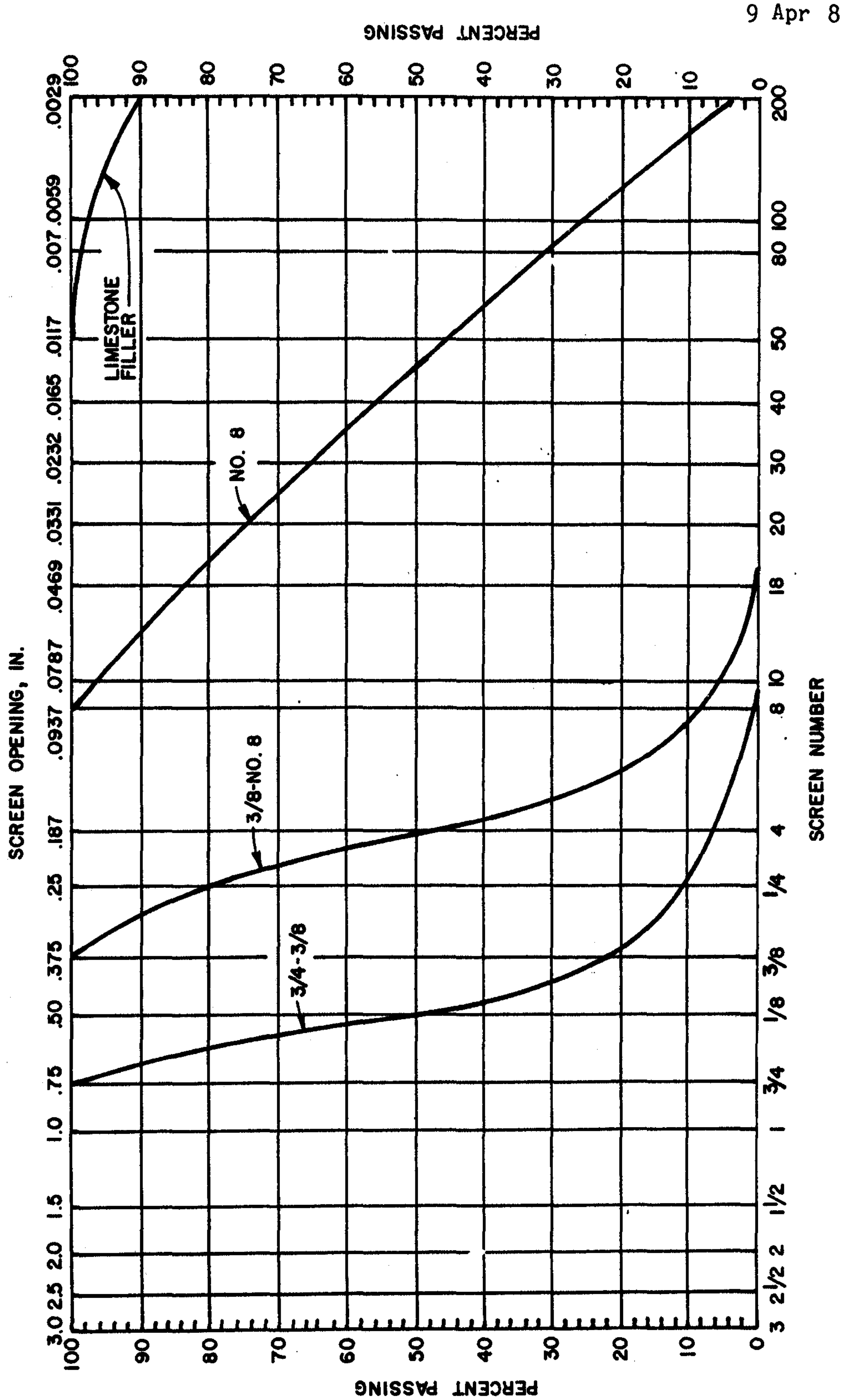


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FIGURE A-7. GRADATION DATA FOR BIN SAMPLES however, increments of 1/2 percent generally are used when the approximate optimum bitumen content is known, and for final design. Tar and rubberized tar generally require about the same volume of bitumen, but since tar is heavier than asphalt, the percentage by weight will be somewhat higher.

d. Selection of design method. The Corps of Engineers authorize two methods of design of bituminous paving mixtures in the laboratory, namely the Marshall procedure and the gyratory method. The procedures for conducting these mix-design tests are described in Methods 100 and 102, MIL-STD-620, respectively. Method 101 is complementary to both Methods 100 and 102. Laboratory design compaction requirements are summarized as follows:

| Type of Traffic | Design Compaction Requirements |
|---|---|
| Tire pressures less than 100 psi | 50 blows or equivalent gyratory compaction |
| Tire pressures 100-250 in non-channelized traffic area, solid tires and tracked vehicles | 75 blows or equivalent gyratory compaction |
| Tire pressures 250 psi and above plus any channelized traffic area | Gyratory compaction mandatory |

e. Tabulation of data. After the laboratory design method has been selected and test specimens prepared, data should be tabulated on forms similar to those shown in Methods 100 and 101 if the Marshall procedure is used. These forms would also be used if the gyratory procedure is used, as well as the forms shown in Method 102 normally used for the gyratory procedure. A form similar to that shown in figure A-8 will facilitate tabulation of specimen test propery data and is preferable to similar but less complete forms used in Methods 100 and 101 of MIL-STD-620. Plots of data from figure A-8 for stability, flow, unit weight, percent voids total mix, and percent voids filled with bitumen should be made, using a form similar to that shown in figure A-9. The average actual specific gravity is obtained for each set of test specimens, as shown in column G of figure A-8. Each average value is multiplied by 62.4 to obtain density in pounds per cubic foot, and these data are entered in column L. The density values thus obtained are plotted as shown on figure A-9, and the best smooth curve is then drawn. New density values are read from the curve for points that may be off the curve, as is the case for density at 4.0 percent bitumen. The new density for 4.0 percent bitumen content is entered in column L beneath the original figure. The new density is divided by 62.4 and

COMPUTATION OF PROPERTIES OF ASPHALT MIXTURES

| Job No.: | | | Project: Typical Mix | | | Description of Blend: | | | | | | Date: | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specimen No. | Asphalt Cement - % | Thickness In. | Weight-Grams | | Volume cc | Specific Gravity | | AC by Volume - % | Voids - Percent | | Unit Weight Total Mix lb/Cu Ft | Stability - Lb | | Flow Units of 1/100 In. |
| | | | In Air | In Water | | Actual | Theor. | | Total Mix | Filled | | Measured | Converted | |
| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
| | | | | | (D-E) | (D)/(F) | | BxG/(Sp. Gr. of AC) | G/(100-100H) | I/(I+J) | (Gx62.4) | | * | |
| A-3.5 1 | 3.5 | | 1228.3 | 716.3 | 512.0 | 2.399 | | | | | | 2020 | 2020 | 11 |
| 2 | | | 1219.5 | 712.2 | 507.3 | 2.404 | | | | | | 1862 | 1936 | 10 |
| 3 | | | 1205.5 | 705.3 | 500.2 | 2.410 | | | | | | 1821 | 1894 | 8 |
| 4 | | | 1206.2 | 708.4 | 497.8 | 2.423 | | | | | | 1892 | 1968 | 8 |
| Avg | | | | | | 2.409 | | | | | 150.3 | | 1955 | 9 |
| Curve | | | | | | 2.409 | 2.579 | 8.3 | 6.6 | 55.7 | 150.3 | | | |
| | | | | | | | | | | | | | | |
| A-4.0 1 | 4.0 | | 1276.9 | 747.3 | 529.6 | 2.411 | | | | | | 2110 | 2026 | 10 |
| 2 | | | 1252.6 | 733.3 | 519.3 | 2.412 | | | | | | 2025 | 2025 | 9 |
| 3 | | | 1243.5 | 730.7 | 512.8 | 2.425 | | | | | | 1995 | 1995 | 9 |
| 4 | | | 1230.4 | 722.8 | 507.6 | 2.424 | | | | | | 2020 | 2101 | 9 |
| Avg | | | | | | 2.418 | | | | | 150.9 | | 2037 | 9 |
| Curve | | | | | | 2.421 | 2.559 | 9.5 | 5.4 | 63.8 | 151.1 | | | |
| | | | | | | | | | | | | | | |
| A-4.5 1 | 4.5 | | 1254.4 | 738.2 | 516.2 | 2.430 | | | | | | 2050 | 2050 | 12 |
| 2 | | | 1238.3 | 726.8 | 511.5 | 2.421 | | | | | | 2095 | 2095 | 9 |
| 3 | | | 1239.0 | 724.9 | 514.1 | 2.410 | | | | | | 2110 | 2110 | 10 |
| 4 | | | 1273.5 | 752.0 | 521.5 | 2.442 | | | | | | 2045 | 2045 | 10 |
| Avg | | | | | | 2.426 | | | | | 151.4 | | 2075 | 10 |
| Curve | | | | | | 2.426 | 2.539 | 10.7 | 4.5 | 70.4 | 151.4 | | | |
| | | | | | | | | | | | | | | |
| A-5.0 1 | 5.0 | | 1237.9 | 727.0 | 510.9 | 2.423 | | | | | | 1875 | 1875 | 14 |
| 2 | | | 1300.0 | 763.7 | 536.3 | 2.424 | | | | | | 2130 | 1981 | 10 |
| 3 | | | 1273.6 | 746.9 | 526.7 | 2.418 | | | | | | 1900 | 1824 | 12 |
| 4 | | | 1247.9 | 731.8 | 516.1 | 2.418 | | | | | | 1855 | 1855 | 12 |
| Avg | | | | | | 2.421 | | | | | 151.1 | | 1884 | 12 |
| Curve | | | | | | 2.421 | 2.519 | 11.9 | 3.9 | 75.3 | 151.1 | | | |
| | | | | | | | | | | | | | | |
| A-5.5 1 | 5.5 | | 1237.3 | 724.1 | 513.2 | 2.411 | | | | | | 1450 | 1450 | 12 |
| 2 | | | 1264.0 | 740.6 | 523.4 | 2.415 | | | | | | 1530 | 1469 | 14 |
| 3 | | | 1286.4 | 752.4 | 534.0 | 2.409 | | | | | | 1615 | 1550 | 13 |
| 4 | | | 1253.5 | 733.8 | 519.7 | 2.412 | | | | | | 1505 | 1505 | 16 |
| Avg | | | | | | 2.412 | | | | | 150.5 | | 1494 | 14 |
| Curve | | | | | | 2.409 | 2.500 | 13.0 | 3.6 | 78.3 | 150.3 | | | |
| | | | | | | | | | | | | | | |
| *From conversion table | | | | | Computed by: | | | | | Checked by: | | | | |

FIGURE A-8. COMPUTATION OF PROPERTIES OF ASPHALT MIXTURES

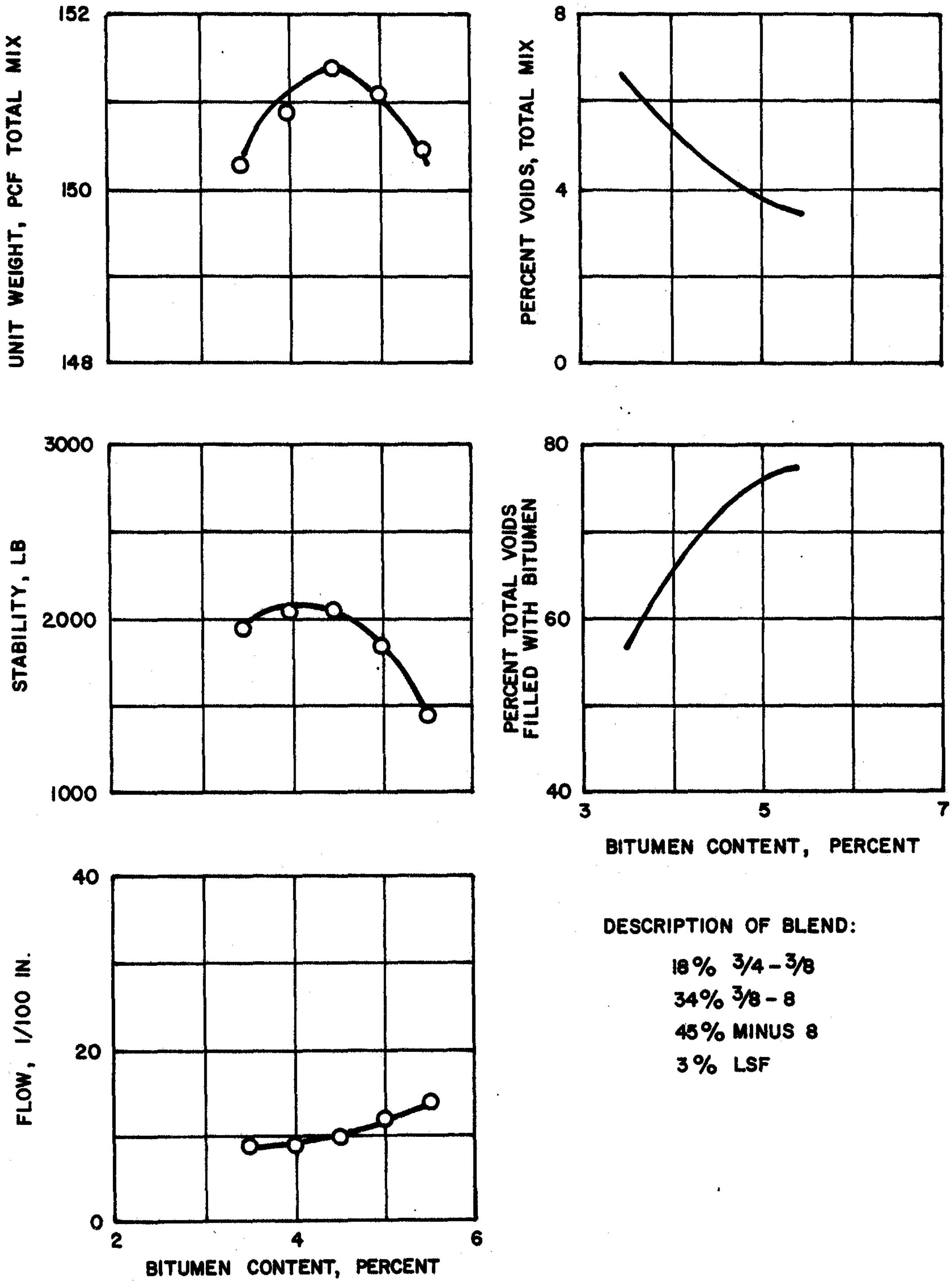


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FIGURE A-9. ASPHALT PAVING MIX DESIGN (TYPICAL MIX) the corrected specific gravity thus obtained is entered in column G; it is called the "curve" specific gravity in figure A-8. The curve specific gravity values for each bitumen content, whether they are corrected or original values, are used to compute the voids data shown in columns I, J, and K. The data from columns J and K are used to plot curves for percent voids total mix and voids filled with bitumen, respectively on figure A-9.

f. Relationship of test properties to bitumen content. Test property curves, plotted as described above, have been found to follow a reasonably consistent pattern for mixes made with penetration grades of asphalt cement, tar cement, and rubberized tar. Trends generally noted are outlined as follows.

(1) Flow. The flow value increases with increasing bitumen content at a progressive rate except at very low bitumen contents.

(2) Stability. The Marshall stability increases with increasing bitumen content up to a certain point, after which it decreases.

(3) Unit weight. The curve for unit weight of total mix is similar to the curve for stability, except that the peak of the unit-weight curve is normally at a slightly higher bitumen content than the peak of the stability curve.

(4) Voids total mix. Voids total mix decreased with increasing bitumen content in the lower range of bitumen contents. There is a minimum void content for each aggregate blend and compaction effort used herein, and the voids cannot be decreased below this minimum without increasing or otherwise changing the compaction effort. The void content of the compacted mix approaches this minimum void content as the bitumen content of the mix is increased.

(5) Voids filled with bitumen. Percent voids filled with bitumen increases with increasing bitumen content and approaches a maximum value in much the same manner as the voids total mix discussed above approaches a minimum value.

g. Requirement for additional test specimens. Curves illustrated in figure A-9 are typical of those normally obtained when penetration grades of asphalt cement, tar cement, or rubberized tar are used with aggregate mixes. Aggregate blends may be encountered that will furnish erratic data such that plotting of the typical curves is difficult. In a majority of these cases, an increase in the number of specimens tested at each bitumen content will normally result in data that will plot as typical curves.

A2-5. Optimum bitumen and design test properties.

a. Selection of bitumen content. Investigational work has indicated that the optimum bitumen content is one of the most important factors in the proper design of a bituminous paving mixture. Extensive research and pavement behavior studies have resulted in establishment of certain criteria for determining the proper or optimum bitumen content for a given blend of aggregates. Criteria have also been established to determine whether the aggregate will furnish a satisfactory paving mix at the selected optimum bitumen content.

b. Determination of optimum bitumen content and satisfactoriness of mix.

(1) Marshall method. Data plotted in graphical form in figure A-9 are used to determine optimum bitumen content. In addition, optimum bitumen content and satisfactoriness of the mix are determined on table A-1 if the water absorption of the aggregate blend is not more than 2.5 percent. If the water absorption is greater than 2.5 percent and the bulk impregnated procedure is used in the mix design tests, table A-2 is used to determine the optimum bitumen content and satisfactoriness of the mix. Separate criteria are shown for use where specimens were prepared with 50- and 75-blow compaction efforts.

(a) Typical example. The application of the above criteria for determinations of optimum bitumen content and probable satisfactoriness of the paving mix, and using the curves in figure A-9, is illustrated below. The illustration is for a mix compacted with 75-blow effort.

Determination of Optimum Bitumen Content

| | |
|---|---|
| Peak of stability curve | 4.3 percent |
| Peak of unit-weight curve | 4.5 percent |
| Four percent voids in total mix (bituminous concrete) | 4.8 percent |
| Seventy-five percent total voids filled with asphalt (bituminous concrete) | 4.9 percent |
| Average | 4.6 percent |

The optimum bitumen content of the mix being used as an example is considered to be 4.6 percent based on the weight of the total mix.

(b) Determination of the probable satisfactoriness of the paving mixture.

Table A-1. Design Criteria For Use With ASTM Apparent Specific Gravity

This table is for use with aggregate blends showing water absorption up to 2.5 percent

| Test Property | Type of Mix | Optimum Bitumen Content | | Satisfactoriness of Mix | |
|---|---|---|---|---|---|
| | | 50 Blows | 75 Blows | 50 Blows | 75 Blows |
| Marshall stability | Bituminous-concrete surface course | Peak of curve | Peak of curve | 500 lb. or higher | 1,800 lb. or higher |
| | Bituminous-concrete intermediate course | Peak of curve (a) | Peak of curve (a) | 500 lb. or higher | 1,800 lb. or higher |
| | Sand asphalt | Peak of curve | (b) | 500 lb. or higher | (b) |
| Unit weight | Bituminous-concrete surface course | Peak of curve | Peak of curve | Not used | Not used |
| | Bituminous-concrete intermediate course | Not used | Not used | Not used | Not used |
| | Sand asphalt | Peak of curve | (b) | Not used | Not used |
| Flow | Bituminous-concrete surface course | Not used | Not used | 20 or less | 16 or less |
| | Bituminous-concrete intermediate course | Not used | Not used | 20 or less | 16 or less |
| | Sand asphalt | Not used | Not used | 20 or less | (b) |
| Percent voids total mix | Bituminous-concrete surface course | 4 | 4 | 3-5 | 3-5 |
| | Bituminous-concrete intermediate course | 5 | 5 | 4-6 | 5-7 |
| | Sand asphalt | 6 | (b) | 5-7 | (b) |
| Percent filled with bitumen | Bituminous-concrete surface course | 80 | 75 | 75-85 | 70-80 |
| | Bituminous-concrete intermediate course | 70 (a) | 60 (a) | 65-75 | 50-70 |
| | Sand asphalt | 70 | (b) | 65-75 | (b) |

Notes:

(a) If the inclusion of bitumen contents at these points in the average causes the voids total mix to fall outside the limits, then the optimum bitumen content should be adjusted so that the voids total mix are within the limits.

(b) Sand asphalt will not be used in designing pavements for traffic with tire pressures in excess of 100 psi.

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Table A-2. Design Criteria For Use With Bulk Impregnated Specific Gravity

This table is for use with aggregate blends showing water absorption greater than 2.5 percent

| Test Property | Type of Mix | Optimum Bitumen Content | | Satisfactoriness of Mix | |
|---|---|---|---|---|---|
| | | 50 Blows | 75 Blows | 50 Blows | 75 Blows |
| Marshall stability | Bituminous-concrete surface course | Peak of curve | Peak of curve | 500 lb. or higher | 1,800 lb. or higher |
| | Bituminous-concrete intermediate course | Peak of curve (a) | Peak of curve (a) | 500 lb. or higher | 1,800 lb. or higher |
| | Sand asphalt | Peak of curve | (b) | 500 lb. or higher | (b) |
| Unit weight | Bituminous-concrete surface course | Peak of curve | Peak of curve | Not used | Not used |
| | Bituminous-concrete intermediate course | Not used | Not used | Not used | Not used |
| | Sand asphalt | Peak of curve | (b) | Not used | Not used |
| Flow | Bituminous-concrete surface course | Not used | Not used | 20 or less | 16 or less |
| | Bituminous-concrete intermediate course | Not used | Not used | 20 or less | 16 or less |
| | Sand asphalt | Not used | Not used | 20 or less | (b) |
| Percent voids total mix | Bituminous-concrete surface course | 3 | 3 | 2-4 | 2-4 |
| | Bituminous-concrete intermediate course | 4 | 5 | 3-5 | 3-5 |
| | Sand asphalt | 5 | (b) | 4-6 | (b) |
| Percent filled with bitumen | Bituminous-concrete surface course | 85 | 80 | 80-90 | 75-85 |
| | Bituminous-concrete intermediate course | 75 (a) | 65 (a) | 70-80 | 55-75 |
| | Sand asphalt | 75 | (b) | 70-80 | (b) |

Notes:

(a) If the inclusion of bitumen contents at these points in the average causes the voids total mix to fall outside the limits, then the optimum bitumen content should be adjusted so that the voids total mix are within the limits.

(b) Sand asphalt will not be used in designing pavements for traffic with tire pressures in excess of 100 psi.

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| Test Property | At Optimum or 4.6 percent Bitumen | Criteria for Satisfactoriness |
|---|---|---|
| Flow | 11 | Less than 16 |
| Stability | 2,050 | More than 1,800 |
| Percent voids in total mix | 4.3 | 3-5 percent (bituminous concrete) |
| Percent total voids filled with bitumen | 72 | 70-80 percent (bituminous concrete) |

The paving mix under discussion would be considered satisfactory for normal airfield traffic, since it meets the criteria for satisfactoriness at the bitumen content determined to be optimum.

(2) Gyratory method. Paragraph 4.4 of Method 102, MIL-STD-620 describes the procedure for selecting optimum bitumen content using the gyratory method of design. The principal criteria are the peak of the unit weight aggregate only curve and the gyrograph recordings. Generally, optimum bitumen content occurs at the peak of the unit weight aggregate only curve and at the highest bitumen content at which little or no spreading of the gyrograph trace occurs. The bitumen content determined by these two criteria will usually be nearly identical; if there is a difference, an average figure can be used. In no case, however, should a bitumen content be selected that would be high enough to cause more than faint spreading of the gyrograph trace.

(a) The optimum binder content in most cases will produce a bituminous mixture that will have satisfactory characteristics without resorting to further test procedures. However, it is recommended that the mix be tested for stability and flow; density and voids data should also be obtained. Stability and flow criteria shown in paragraph 2-5.b.(1) for the Marshall procedures should be applied to paving mixtures designed by the gyratory method. It is necessary to determine density at optimum bitumen content to establish field rolling requirements. If the 240 psi, 1-degree, 60 revolutions compaction effort described in paragraph 3.1.1 of Method 102, MIL-STD-620 is used in design of a paving mixture, density values will result that require greater rolling effort in the field to obtain 98 percent of laboratory density than by the Marshall design method.

(b) Selection of optimum bitumen content by the gyratory method may result in the paving mixture having lower percent voids total mix than would be permissible with the Marshall procedure. For example, the voids total mix of a paving mixture designed for traffic by aircraft with tire pressures of 200 psi or higher might be only 2.5

percent, as compared to a specified range of 3 to 5 percent in the Marshall criteria. The lower percent voids total mix is acceptable when using the gyratory procedure. This is because the compaction effort used the laboratory design results in densities in the mix sufficiently high that further densification under traffic is minimized, as compared to lower densities obtained by the Marshall procedure.

c. Selection of paving mix. When two or more paving mixes have been investigated, the one used for field construction should be the most economical mix that satisfies all of the established criteria. The mix showing the highest stability should be selected, if economic considerations are equal.

d. Tolerances for pavement properties. Occassionally it may not be possible, for economic or other reasons, to develop a mix that will meet all of the criteria set forth above. A tolerance of 1 percent of voids in the total mix and 5 percent of total voids filled with bitumen may be allowed in some circumstances, but under no circumstances will the mix be considered satisfactory if the flow value is in excess of 20 or the stability value is less than 500 pounds for mixes compacted with the 50-blow effort, or if the flow is in excess of 16 or the stability less than 1,800 pounds for mixes compacted with the 75-blow effort.

A3. Plant control.

A3-1. Plant operation.

a. Types of plants. Figures A-10, A-11, and A-12 show a typical batch plant, a typical continuous-mix plant, and a dryer drum mixing plant, respectively. It is generally necessary, in the operation of a bituminous paving plant, to combine aggregates from two or more sources to produce an aggregate mixture having the desired gradation. Aggregates from the different sources are fed into the aggregate dryer in the approximate proportions required to produce the desired gradation. This initial proportioning generally is accomplished by means of a hopper-type mechanical feeder on one or more bins that feeds the aggregates into a cold elevator, which, in turn, delivers them to the dryer. The mechanical feeder generally is loaded by a clam shell or other suitable means in the approximate proportions of aggregates desired. The aggregates pass through the dryer where the moisture is driven off and the aggregates are heated to the desired temperature. In the dryer drum mix plant, the binder is added to the aggregate during drying and leaves the dryer as mixed pavement material ready for truck loading. Upon leaving the dryer of batch and continuous-mix plants, the aggregates pass over vibrating screens where they are separated according to size. When using emulsified asphalt as the binder, the dryer operation is omitted. The usual screening equipment for a three-bin plant consists of a rejection screen for eliminating oversize material and screens for dividing the coarse aggregate into

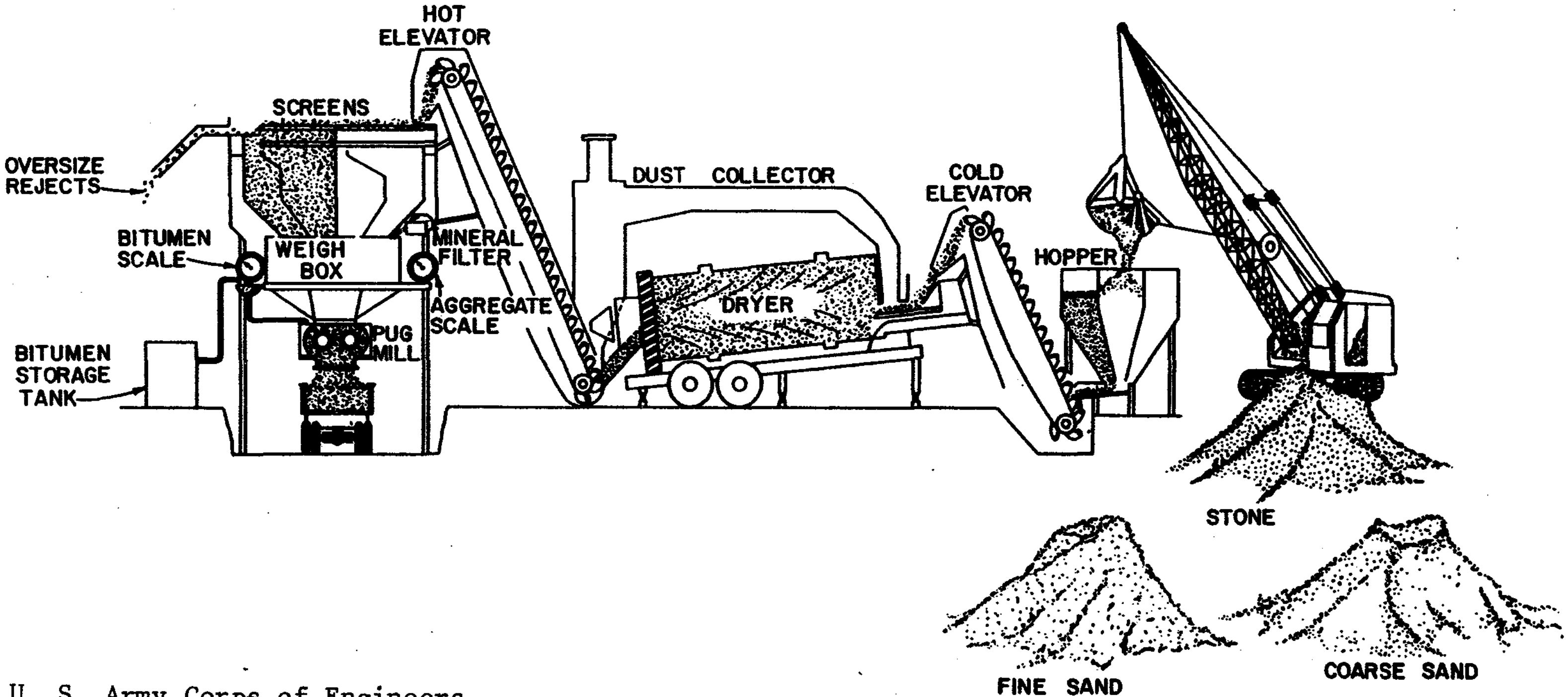


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FIGURE A-10. BATCH PLANT

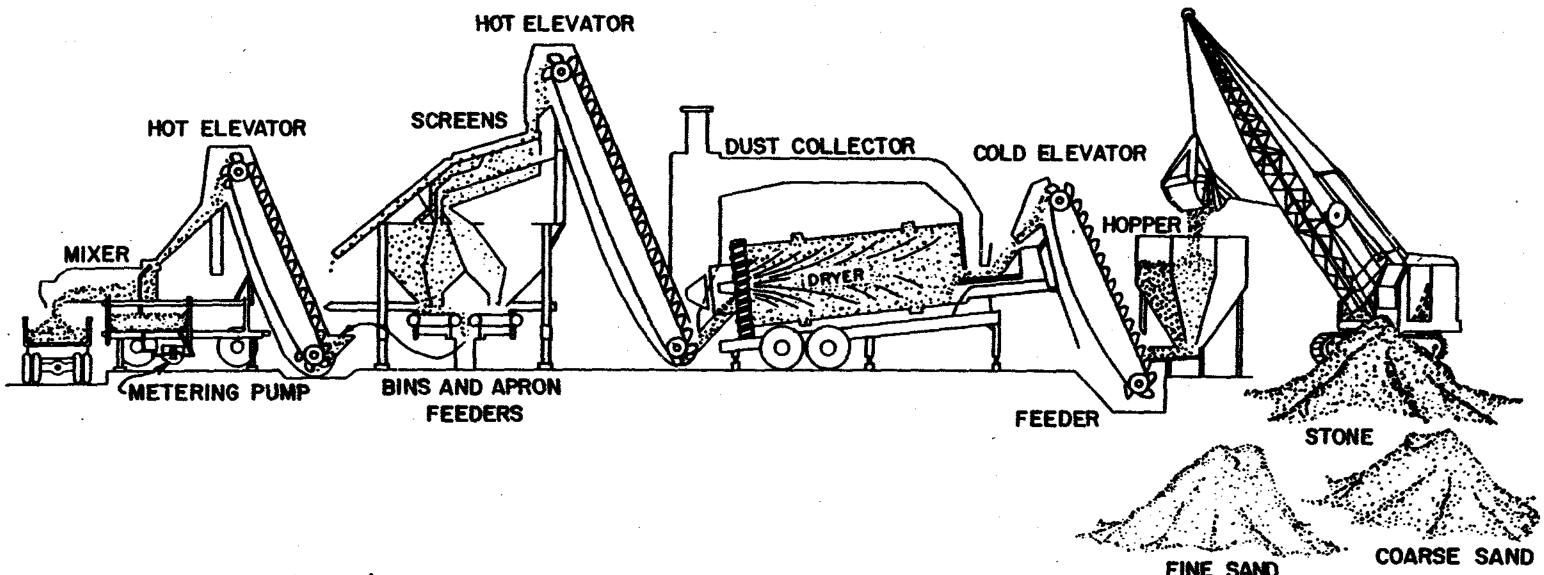


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FIGURE A-11. CONTINUOUS MIX PLANT

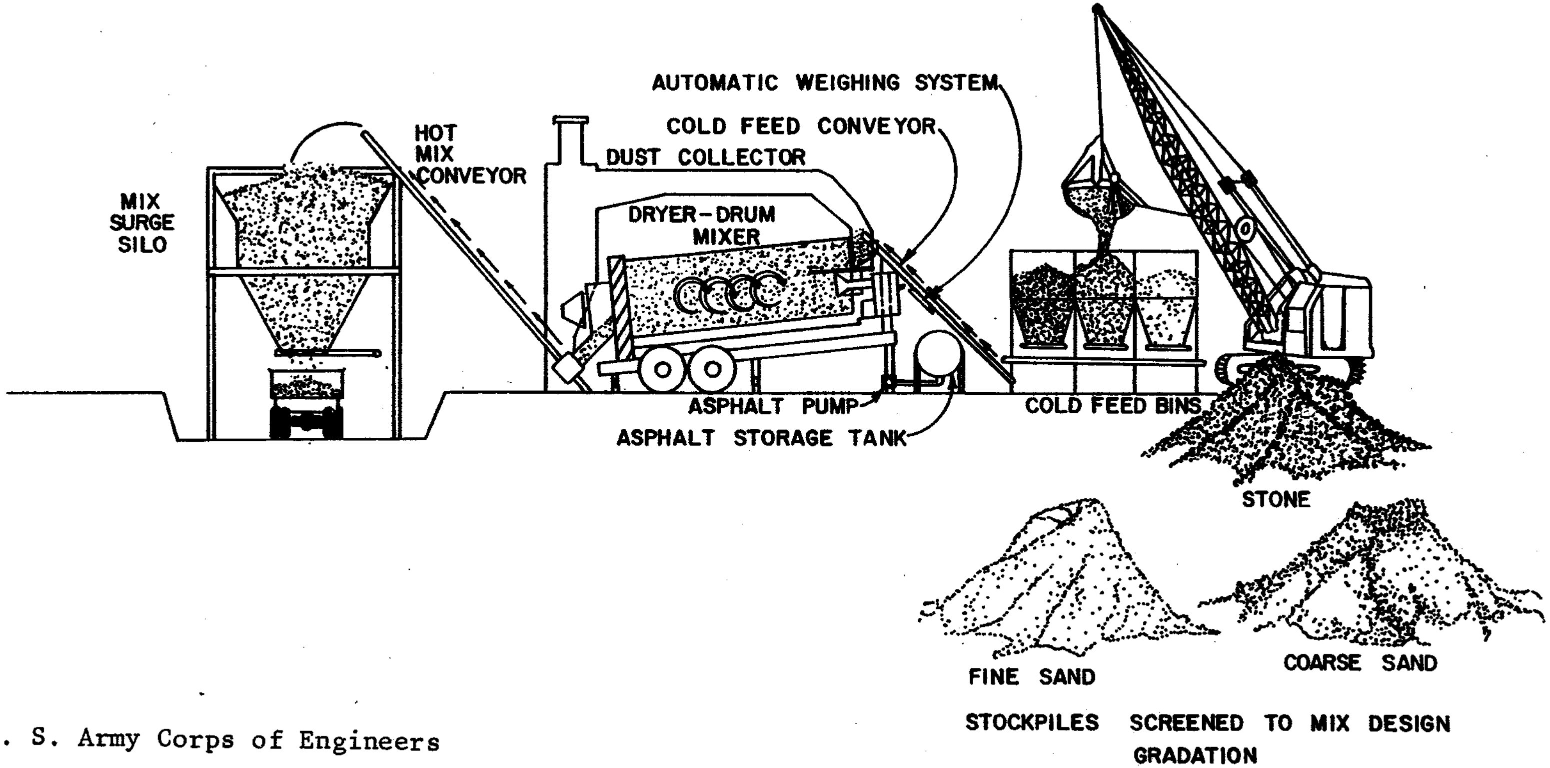


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FIGURE A-12. DRYER DRUM MIXING PLANT

two separate bins with the fine dried, the fine bin screen size should not be smaller than 3/8 inch. An additional screen is provided for further separation of the coarse aggregate in a four-bin plant. When additional mineral filler is required, usually it is stored and weighed or proportioned into the mix separately. Plant screens vary in size of opening, and the size employed is largely dependent upon the type of mixture being produced. In some cases, it may be necessary to change the size of screens to obtain a proper balance of aggregate sizes in each bin.

b. Adjustments to maintain proper proportions. The aggregates must be fed through the plant uniformly, preferably by a mechanical feeder, in order to obtain efficient plant operation and produce a mixture conforming to the desired gradation. The proper proportion of aggregates to be fed into the dryer may be determined approximately from the laboratory design. However, it is usually necessary to make some adjustments in these proportions because (a) a screen analysis of the stockpile aggregates generally will not entirely duplicate the screen analyis of the aggregate samples obtained for laboratory design use; (b) fines may be lost while passing through the dryer unless the equipment includes an effective dust collector; (c) aggregate may degrade in the dryer; and (d) the plant screens are not 100 percent efficient in separation of the aggregate and some fines are carried over into the coarser bins.

A3-2. Plant laboratory.

a. Equipment and personnel requirements. In order to control the plant output and secure the best possible paving mixture, a reasonably complete plant laboratory is necessary. The laboratory should be located at the plant site and should contain about the same equipment as is listed in Method 100 of MIL-STD-620. Due to the large capacity of most asphalt plants now in use, it is recommended that two technicians be assigned to conduct control tests; otherwise, the testing will fall too far behind, and considerable quantities of unsatisfactory mix could be produced and placed before the laboratory test results revealed that the mix is not in conformance with job specifications.

b. Laboratory work to initiate plant production. The heaviest demands on plant laboratory facilities arise at the initiation of plant production. Preliminary computations may be made to determine the weight of material from each bin that will provide the gradation on which the mixture design was based. However, it should be recognized that the gradation of the aggregate supplied by the plant in accordance with computed bin weights may not precisely reproduce the desired gradation. The gradation of the plant-produced aggregate generally approximates the gradation used in design, within reasonable tolerances, if initial sampling for design purposes has been accomplished properly and if the plant is operated efficiently.

Certain steps should be taken, however, to insure that satisfactory mixtures are produced from the beginning and throughout the period of plant production. Procedures subsequently outlined will insure satisfactory paving mixes.

c. Sieve analysis. All sieve analyses should be conducted in accordance with the appropriate ASTM procedures. Recommended sieves for plant sieve analysis are: 3/4- and 3/8-inch, Nos. 4, 8, 30, 100, and 200. Sieves larger than 3/4 inch should be used, if necessary. Sieve analysis should be made on material from each plant bin. Samples for these sieve analyses should be obtained after a few tons of aggregate have been processed through the dryer and screens in order that the sample will be representative. Final bin proportions may be determined on the basis of these analyses.

d. Provision for redesign of mix. The aggregates obtained from the bins (as described in the previous paragraph) sometimes cannot be proportioned to reproduce satisfactorily the gradation of the aggregate used in the laboratory design. It then is necessary to redesign the mix using plant-produced aggregates. Specimens are prepared and tested for the new design in the same manner as for the original design tests. Optimum bitumen content and probable satisfactoriness of the mix that will be produced by the plant are determined thereby. Occasions may arise where the gradation of the plant-produced aggregate will differ from that on which the laboratory design was based to the extent that a part of the aggregates must be wasted. Consideration should be given to redesigning the mix on the basis of additional tests of the plant-produced material in order to use all of the available aggregate. Sufficient additional tests should be performed to establish optimum bitumen requirements and ensure that the mix will meet applicable criteria for satisfactoriness.

e. Controlling plant production. A plant inspector should obtain a sample of paving mix from a truck as it leaves the plant after the plant has been in production about 30 minutes. The sample should be large enough to prepare four Marshall specimens and should be obtained by digging far enough into the load in several locations to obtain a representative sample of the paving mixture. The four specimens should be compacted and tested as rapidly as possible, in accordance with standard procedures cited previously. Plant production must be suspended until data from the tests are available and a determination made that the plant-produced mix conforms to final design data. If the test data on the plant mix show it to be within reasonable tolerances, plant production can be resumed; otherwise, necessary adjustments should be made to secure a conformable mix. Such procedures to insure initial production of satisfactory mixes will generally delay plant production less than 2 hours.

(1) Flow and stability. Resumption of plant production may be expedited by comparing only the values of flow, stability, and unit

weight of specimens compacted from plant-produced mixtures with corresponding data from the final design. Data from tests of the plant-produced mix for voids in the compacted mix and percent of voids filled with bitumen may be compared with corresponding design data after plant production has been resumed. When the plant is in continuous operation, the average flow and stability values obtained from truck samples should be in substantial agreement with flow and stability values from the final design. Variations of not more than two points in flow and not more than 10 percent in stability are allowable. In no case, however, will the plant-produced mix be considered acceptable if the flow or the stability does not meet the requirements of design criteria.

(2) Variations. If test property variations exceed those noted above, plant production should be delayed until the cause of the variations is determined. Computations for scale weights should be checked first. If no error is found in these computations, the plant proportioning equipment should be recalibrated. Variations of only a few tenths of 1 percent in bitumen content may cause variations of two or three points in the flow values. Small variations in aggregate weight generally are not particularly effective in changing test properties. Plant proportioning equipment found to be inaccurate should be adjusted and after an additional 30 minutes of plant operation, the paving mix should be sampled and tested; the plant will not be placed in continuous operation until the variations in test properties are within allowable tolerances. Once the plant has been placed in continuous operation, test specimens should be prepared for each 5-hours operation or fraction thereof. The tests conducted should include stability, flow, unit weight, voids in the total mix, and percent voids filled with bitumen. Normal variations in plant-produced aggregates will require minor adjustments in bin proportions, which will cause slight variations in test properties. Variations cited above are allowable for continuous plant production.

f. Significance of changes in mixture properties. A material increase in flow value generally indicates that either the gradation of the mix has changed sufficiently to require a revision in the optimum bitumen content for the mix, or too much bitumen is being incorporated in the mix. Substantial changes in stability or void content also may serve as an indication of these factors. As a general rule, however, the flow and stability values are obtainable quickly and are reasonably reliable indicators of the consistency of the plant-produced mix. The satisfactoriness of the plant produced mix may be judged quickly by maintaining close observance of the flow and stability values. Mix proportions must be adjusted whenever any of the test properties falls outside of the specified tolerances. In the case of batch plants, failure of the operator to weigh accurately the required proportions of materials or use of faulty scales are common causes for paving-mixture deficiencies. The total weight of each load of mixture produced should not vary more than plus or minus 2 percent from the total of the batch weights dumped into the truck. Improper weighing or faulty scales may be detected readily and corrective measures taken by maintaining close check of load weights. Other probable causes of paving-mixture deficiencies for both batch-and continuous-mixing plants are shown in figure A-13.

g. Other tests. In addition to the design and control tests described above, certain tests are desirable for record purposes and to insure quality and consistency of materials.

(1) Extraction tests. Representative samples of paving mixture should be obtained twice daily for extraction tests to determine the percentage of bitumen in the mix and the gradation of the extracted aggregates. Extraction tests are to be made in accordance with ASTM D 2172 using trichloroethylene as the extraction solvent. Sieve analyses of recovered aggregates should be in accordance with procedures specified previously.

(2) Hot-bin gradations. Hot-bin gradation tests should be determined on the aggregate in the fine bin at 2-hour intervals during operation. Hot-bin gradations must be determined on all bins in conjunction with sampling of the pavement mixture. Washed sieve analyses are to be determined initially and when gradations vary to establish a correction factor to be applied to unwashed (dry) gradation. Dry sieve analyses should be conducted frequently as required to maintain control.

h. Construction control. It has been determined that well-designed mixes can be compacted readily by adequate field rolling to about 98 percent or greater of the density obtained by compacting specimens with previously specified laboratory procedures. Every reasonable effort is to be made, within practicable limits, to provide an in-place pavement density of at least 98 percent of the compacted density as determined by the laboratory tests. Bituminous intermediate or base course mixes are to be rolled to the density specified in applicable Corps of Engineers guide specifications.

(1) Pavement sampling. Samples for determining pavement density and thickness may be taken either with a coring machine or by cutting out a section of pavement at least 4 inches square with a concrete saw and should include the entire thickness of the pavement. A set of the samples will be taken from areas containing mix that was previously sampled from trucks and from which specimens were compacted in the plant laboratory. A set of samples will consist of at least three sawed or cored samples. Density samples of each day's production should be taken and delivered to the project laboratory by noon of the following day, and the density determinations made by the end of that day. This will permit any changes in placing technique necessary to obtain the required density to be made before too much pavement is placed. One-half the total number of all density samples will be taken

## Probable Causes Of Deficiencies In Hot Plant Mix Paving Mixtures

1. Aggregate scales out of adjustment
2. Bridging of hot aggregate in bin
3. Bitumem scales out of adjustment
4. Lack of proper weighing by operator
5. Faulty pug mill dump gate
6. Bitumen temperature too high
7. Drum feed not uniform
8. Improper dryer operation
9. Too little bitumen
10. Too much bitumen
11. Sampling method not uniform
12. Excessive moisture content of aggregate
13. Bin overflow pipes not functioning
14. Leaky bins
15. Segregation of aggregates in bins
16. Mixing time not uniform
17. Mineral filler feed not uniform
18. Aggregate temperature too high
19. Temperature mechanism out of adjustment
20. Improper feed of aggregates to dryer
21. Overrated dryer capacity
22. Faulty screen operation
23. Overload pug mill
24. Improper set on pug mill
25. Bitumen and aggregate feed out of adjustment
26. Bitumen pump not functioning properly
27. Not sufficient hot aggregate in storage bins
28. Aggregate gates not properly set

| Types Of Deficiencies That May Be Encountered In Producing Hot Plant Mix Paving Mixtures (Types Of Hot Mix Trouble) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bitumen content fails to check job-mix formula | X | | X | X | X | | | | X | X | X | | X | X | | / | X | | | X | | | | X | X | X | X | X |
| Gradation fails to check job-mix formula | X | X | | X | X | | | | | | X | | X | X | X | | X | | | X | | | | X | X | | X | X |
| Poorly mixed loads | | | | | X | X | | | | | | | | | | X | | | | | | | X | X | | | | |
| Fat, rich mixtures | X | | X | X | X | X | | | | X | X | | | X | | | X | | | X | | | | | X | X | | X |
| lean or burned mixtures | X | | X | X | X | X | | X | X | | X | | | X | | | | X | X | X | | | | | X | X | | X |
| Mixture temperature fails to check job mix | | | | | | X | X | X | | | | | | | | | | X | X | | X | | | | | | | |
| Smoking loads | | | | | | | X | X | | | | | | | | | | X | X | X | | | | | | | | |
| Steaming loads | | | | | | | X | X | | | | X | | | | | | | X | X | X | | | | | | | |
| Overweight or underweight loads | | X | X | X | X | | | | | | | | | | | | | | X | | | | | | | | | |
| Lack of uniformity of mixtures in loads | | X | X | X | X | X | | | X | X | | X | X | X | X | X | X | | X | X | X | X | X | X | X | | X | X |

Items 6 to 23 incl. are applicable to all types of plants. Items 1 to 5 incl. and items 24 to 28 incl. are applicable to batch plants and volumetric plants respectively.

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FIGURE A-13. TYPES OF HOT PLANT MIX PAVING MIXTURE DEFICIENCIES AND PROBABLE CAUSES at a joint so that the joint is approximately in the center of the sample to be tested.

(2) Testing pavement samples. Pavement samples are to be prepared for testing by carefully removing all particles of base material or other matter. All broken or damaged edges of sawed samples for density tests will be carefully trimmed from the sample. Thickness measurements are to be made prior to splitting. A sample consisting of an intermediate course and surface course will be split at the interface of these layers prior to testing. The density of the sawed samples then will be determined by weighing in air and in water as previously described. Samples from which density measurements are desired should be discarded if they are damaged.

(3) Density data. Density data obtained from specimens in the manner previously described will be compared to the laboratory densities that have been determined from the sample plant-mix material previously taken from loaded trucks.

i. Pavement imperfections and probable causes. There are many types of pavement imperfections resulting from improper laying and rolling operations as well as from improper mixes or faulty plant operation. These imperfections can be controlled only by proper inspection. Pavement imperfections that may result from laying improper mixes or using faulty construction procedures are shown in figure A-14.

**Probable Causes of Imperfections in Finished Pavements**

| Types of Pavement Imperfections That may be Encountered in Laying Hot Plant Mix Paving Mixtures | Excessive primecoat | Improper proportioning | Unsatisfactory batches in load | Poor handwork behind spreader | Excessive segregation in laying | Inadequate rolling | Poor spreader operation | Mixture too hot or burned | Mixture too cold | Rolling mixture when too hot | Rolling mixture when too cold | Poorly graded mixture | Unstable basecourse | Faulty allowance for compaction | Roller standing on hot pavement | Mixture too coarse | Lack of bitumen in mixture | Excess of bitumen in mixture | Inadequate cross rolling | Not cut back to uniform thickness | Excessive moisture in mixture |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bleeding | X | X | X | | X | | | | | | | X | | | | X | | X | | | |
| Brown, dead appearance | | | | | | | | X | | | | | | | | | X | | | | X |
| Poor surface texture | | X | X | | X | | | | | | | X | | | | X | | | | | |
| Rough uneven surface | | X | X | X | X | X | X | | X | X | X | | X | | X | | | | X | | |
| Uneven joints | | | | X | | | X | | X | | X | | | X | | | | | | X | |
| Roller marks | | | | | | X | | | | | X | | | | | | | | X | | |
| Shoving | | X | X | | | | | X | X | X | | X | | | | | | X | | | X |
| Waves | | | | X | | | X | | X | X | | | X | | X | | | | | | |
| Cracking | | X | X | | X | | | | X | | X | X | | | | X | X | | | | |
| Honeycomb | | X | X | X | X | | X | | X | | | | | | | X | | | | | |
| Tearing of surface during laying | | | X | | | | X | | X | | | | | | | | X | | | | |

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FIGURE A-14. TYPES OF HOT PLANT MIX PAVEMENT IMPERFECTIONS AND PROBABLE CAUSES

# APPENDIX B

# REFERENCES

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EM 1110-3-137 — Soil Stabilization for Pavements.

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T 27-74 — Sieve Analysis of Fine and Coarse Aggregates.

T 88-72 — Mechanical Analysis of Soils.

T 89-68 — Determining the Liquid Limit of Soils.

T 90-70 — Determining the Plastic Limit and Plasticity Index of Soils.

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| T 96-74 | Abrasion of Coarse Aggregate by Use of the Los Angeles Machine. |
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| T 104 | Soundness of Aggregates by use of Sodium Sulfate or Magnesium Sulfate |
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