APPENDIX G

Application: Structural Deformation Reference Network Survey--Dworshak Dam, Idaho (Walla Walla District and Topographic Engineer Center)

G-1. General. High precision GPS control surveys may be performed to establish reference locations for structural deformation monitoring surveys. Accurate reference control in the vicinity of the structure is critical. Absolute NGRS coordinate on monitoring points is of lesser importance. NGRS control may be brought into one of the reference points with GPS. Only the NGRS coordinates of this fixed point are held fixed for all subsequent adjustments in the vicinity of the structure.

G-2. Project Description. This project was conducted in the vicinity of Dworshak Dam, Idaho and was performed to establish permanent reference points in the vicinity of the dam. A diagram of the project is shown in Figure G-1. Baseline data from the NGRS control to one point (Fish Hatchery - 4001) at the project site were collected and other baseline data for baselines between 4001, BIG EDDY (4002), and four points on the Dworshak Dam and Reservoir (4003, 4004, 4005, and 4006) as shown in Figure G-1. Loop closure checks were done for the complete network by using the loop closure routine shown in Figure G-2. The resultant precision for the loop is 0.43 ppm (1:2,300,000).

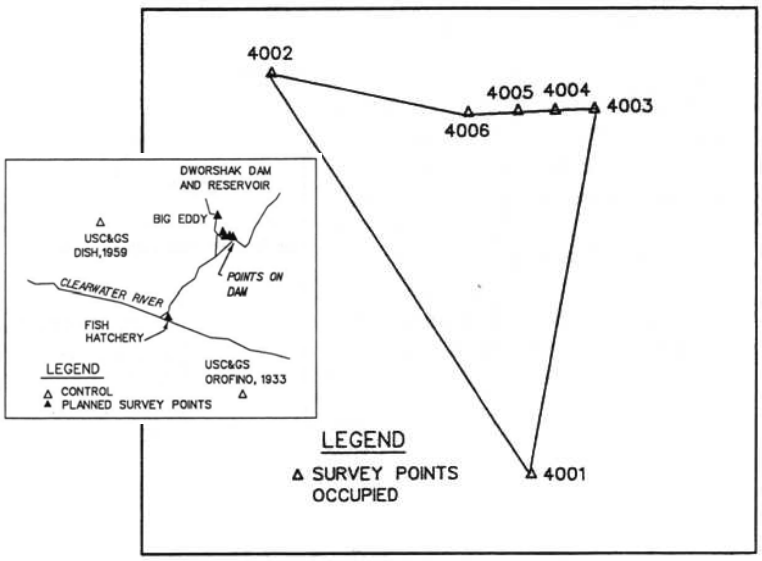

Figure G-1. Dworshak Dam locale and GPS project diagram

G-3. Adjustment. An IOB file for the adjustment based on the formulated baselines was set up. Station USC&GS Dish, 1959, and USC&GS Orofino, 1933, were held fixed to establish NGRS control on Corps of Engineers Station 4001 at the project site. Then, for the next adjustment, 4001 was held fixed to adjust station 4002, 4003, 4004, 4005, and 4006. The resultant adjustment statistics are shown in Figure G-3 (a-h). The 2-D station confidence is on the order of 0.04 m

(95%) in the horizontal and ±0.06 m in the vertical. The largest line accuracy is 36.322 ppm (1:27,000) over a short (62 meter) baseline. This would be acceptable even though a 1:100,00 relative accuracy is required. Due to fixed centering errors, maintaining 1:100,000 relative accuracies over lines less than 200 to 500 meters is unrealistic.

```
Trimble Loop Closure Utility

Start Traverse at Station:  4006
Starting Coords :  46x30'56.88832"ØN   116x17'48.33684"ØW          489.943

Baseline 1
File Name: 06053001.FIX
From Station:  4006                    To Station:  4005
Distance Travelled (m):          62.829
Current Coords  :  46x30'55.20552"ØN   116x17'46.75486"ØW          500.412

Baseline 2
File Name: 05042993.FIX
From Station:  4005                    To Station:  4004
Distance Travelled (m):         124.262
Current Coords  :  46x30'54.30015"ØN   116x17'44.23756"ØW          489.809

Baseline 3
File Name: 04032991.FIX
From Station:  4004                    To Station:  4003
Distance Travelled (m):         214.384
Current Coords  :  46x30'51.68841"ØN   116x17'42.38493"ØW          497.376

Baseline 4
File Name: 01032992.FIX
From Station:  4003                    To Station:  4001
Distance Travelled (m):        2872.755
Current Coords  :  46x30'05.98881"ØN   116x19'27.67811"ØW          308.887

Baseline 5
File Name: 01023012.FIX
From Station:  4001                    To Station:  4002
Distance Travelled (m):        6122.940
Current Coords  :  46x31'41.46032"ØN   116x18'24.06337"ØW          490.036

Baseline 6
File Name: 02063001.FIX
From Station:  4002                    To Station:  4006
Distance Travelled (m):        7695.981
Current Coords  :  46x30'56.88826"ØN   116x17'48.33690"ØW          489.941

End Traverse at Station:  4006
Distance Travelled (m):        7695.981    Precision (ppm):        0.43
dx:    -0.001     dy:     0.001    dz:    -0.003     dh:    -0.002
Ending Coords   :  46x30'56.88826"ØN   116x17'48.33690"ØW          489.941
Reference Coords:  46x30'56.88832"ØN   116x17'48.33684"ØW          489.943
```

Figure G-2. Loop Closure (Dworshak)

```
-----------------------------------------------------------------
          U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                        DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
PREPARE:

ASCII input file: <wal_1.iob>.

PREPARE successfully completed.

-----------------------------------------------------------------
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```

```
-----------------------------------------------------------------
          U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                        DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
GETUP:
```

PARAMETERS		OBSERVATIONS	
Description	Number	Description	Number
All Stations	6	Directions	0
Fixed Stations	1	Distances	0
Free 3-D Stations	5	Azimuths	0
Free 2-D Stations	0	Vertical Angles	0
Free 1-D Stations	0	Zenithal Angles	0
Coord. Parameters	15	Angles	0
Astro. Latitudes	0	Heights	0
Astro. Longitudes	0	Height Difference	0
Geoid Records	0	Auxiliary Params.	0
All Aux. Pars.	0	2-D Coords.	0
Direction Pars.	0	2-D Coord. Diffs.	0
Scale Parameters	0	3-D Coords.	0
Constant Pars.	0	3-D Coord. Diffs.	60
Rotation Pars.	0		
Translation Pars.	0		
Total Parameters	15	Total Observations	60

Degrees of Freedom = 45

```
-----------------------------------------------------------------
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```

Figure G-3a. GEOLAB adjustment output (Dworshak Dam Reference Network)

```
-----------------------------------------------------------------
          U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
GETUP


-----------------------------------------------------------------
                  SUMMARY  OF  SELECTED  OPTIONS
-----------------------------------------------------------------
 OPTION                            |     SELECTION
-----------------------------------|-----------------------------
 Computation Mode                  |     Adjustment
 Linear Unit                       |     Metre
 Maximum Iterations                |     2
 Confidence Regions Selected       |     All
 Confidence Region Dimensions      |     1-D and 2-D only
 Print Input Station Data          |     Off
 Variance Factor Knowledge         |     Known
 Confidence Level for Statistics   |     95.000
 Dual-Height Mode                  |     Off
 Print Solution Mode               |     Only Adjusted Values
 Printed Ellipsoidal Coordinates   |     5 Decimal Places
 Print Adjusted X, Y, Z            |     On
 Print Histograms                  |     On
 Print Misclosures                 |     On
 Print Residuals                   |     On All Iterations
 Variance Factor Usage             |     Scale Confidence Regions
 Residual Rejection Criterion      |     Tau Max
 Angular Misclosure Limit Factor   |     10
 Linear Misclosure Limit Factor    |     10
 Convergence Criterion             |     0.001000
-----------------------------------------------------------------

SETUP successfully completed.




-----------------------------------------------------------------
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```

Figure G-3b. GEOLAB adjustment output (Dworshak Dam Reference Network)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM

A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

FORMEQ:

NOTE 6: Reordering was done.

AT	TO	OBS TYPE	OBSERVATION	APPROX.SIG.	MISCLOSURE
4001	4003	3-D X-Coord Diff	2408.6880	0.0029	22.8708
4001	4003	3-D Y-Coord Diff	-193.5840	0.0016	25.8258
4001	4003	3-D Z-Coord Diff	1108.0180	0.0021	-26.6407
4004	4003	3-D X-Coord Diff	7.1790	0.0007	22.7040
4004	4003	3-D Y-Coord Diff	-74.6270	0.0003	21.7690
4004	4003	3-D Z-Coord Diff	-50.0120	0.0006	-25.7900
4001	4004	3-D X-Coord Diff	2401.5070	0.0055	.1688
4001	4004	3-D Y-Coord Diff	-118.9530	0.0065	4.0528
4001	4004	3-D Z-Coord Diff	1158.0230	0.0062	-0.8437
4001	4002	3-D X-Coord Diff	2108.6340	0.0061	-1.6862
4001	4002	3-D Y-Coord Diff	1204.4260	0.0079	36.7548
4001	4002	3-D Z-Coord Diff	2160.2690	0.0067	-27.6797
4001	4003	3-D X-Coord Diff	2408.6870	0.0055	22.8718
4001	4003	3-D Y-Coord Diff	-193.5780	0.0072	25.8198
4001	4003	3-D Z-Coord Diff	1108.0110	0.0062	-26.6337
4001	4005	3-D X-Coord Diff	2359.1380	0.0047	-0.9472
4001	4005	3-D Y-Coord Diff	-83.5390	0.0122	5.9208
4001	4005	3-D Z-Coord Diff	1184.9630	0.0073	-7.2267
4005	4004	3-D X-Coord Diff	42.3580	0.0008	1.1270
4005	4004	3-D Y-Coord Diff	-35.4190	0.0015	-1.8630
4005	4004	3-D Z-Coord Diff	-26.9330	0.0006	6.3760
4001	4002	3-D X-Coord Diff	2108.6240	0.0045	-1.6762
4001	4002	3-D Y-Coord Diff	1204.4190	0.0104	36.7618
4001	4002	3-D Z-Coord Diff	2160.2710	0.0063	-27.6817
4001	4006	3-D X-Coord Diff	2348.8140	0.0033	32.4128
4001	4006	3-D Y-Coord Diff	-28.3330	0.0019	24.3928
4001	4006	3-D Z-Coord Diff	1213.1260	0.0021	-23.8437
4006	4005	3-D X-Coord Diff	10.3400	0.0008	-33.3760
4006	4005	3-D Y-Coord Diff	-55.2020	0.0004	-18.4760
4006	4005	3-D Z-Coord Diff	-28.1650	0.0007	16.6190
4002	4006	3-D X-Coord Diff	240.1770	0.0031	34.1020
4002	4006	3-D Y-Coord Diff	-1232.7570	0.0020	-12.3640
4002	4006	3-D Z-Coord Diff	-947.1440	0.0019	3.8370
4002	4005	3-D X-Coord Diff	250.5120	0.0027	0.7310
4002	4005	3-D Y-Coord Diff	-1287.9560	0.0040	-30.8430
4002	4005	3-D Z-Coord Diff	-975.3050	0.0031	20.4520
4001	4005	3-D X-Coord Diff	2359.1440	0.0055	-0.9532
4001	4005	3-D Y-Coord Diff	-83.5400	0.0067	5.9218
4001	4005	3-D Z-Coord Diff	1184.9690	0.0063	-7.2327
4001	4006	3-D X-Coord Diff	2348.8070	0.0054	32.4198
4001	4006	3-D Y-Coord Diff	-28.3370	0.0066	24.3968
4001	4006	3-D Z-Coord Diff	1213.1310	0.0062	-23.8487
4002	4003	3-D X-Coord Diff	300.0520	0.0022	24.5590
4002	4003	3-D Y-Coord Diff	-1398.0030	0.0043	-10.9360

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Figure G-3c. GEOLAB adjustment output (Dworshak Dam Reference Network)

```
-----------------------------------------------------------------
            U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
FORMEQ:

AT    TO    OBS TYPE          OBSERVATION  APPROX.SIG. MISCLOSURE
----- ----- ---------------- ------------ ----------- ----------
4002  4003  3-D X-Coord Diff  -1052.2550       0.0024      1.0430
4006  4003  3-D X-Coord Diff     59.8780       0.0007     -9.5460
4006  4003  3-D Y-Coord Diff   -165.2500       0.0015      1.4320
4006  4003  3-D Z-Coord Diff   -165.2500       0.0006     -2.7900
4001  4002  3-D X-Coord Diff   2108.6250       0.0045     -1.6772
4001  4002  3-D Y-Coord Diff   1204.4170       0.0104     36.7638
4001  4002  3-D Z-Coord Diff   2160.2740       0.0063    -27.6847
4001  4002  3-D X-Coord Diff   2108.6270       0.0043     -1.6792
4001  4002  3-D Y-Coord Diff   1204.4160       0.0028     36.7648
4001  4002  3-D Z-Coord Diff   2160.2680       0.0029    -27.6787
4001  4002  3-D X-Coord Diff   2108.6320       0.0063     -1.6842
4001  4002  3-D Y-Coord Diff   1204.4280       0.0078     36.7528
4001  4002  3-D Z-Coord Diff   2160.2620       0.0062    -27.6727
4001  4002  3-D X-Coord Diff   2108.6250       0.0045     -1.6772
4001  4002  3-D Y-Coord Diff   1204.4170       0.0101     36.7638
4001  4002  3-D Z-Coord Diff   2160.2780       0.0061    -26.6887

FORMEQ successfully completed.
-----------------------------------------------------------------
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-----------------------------------------------------------------
            U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
SOLVE:

SOLVE successfully completed.

-----------------------------------------------------------------
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-----------------------------------------------------------------
            U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
FORMEQ:

FORMEQ successfully completed.

-----------------------------------------------------------------
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```

Figure G-3d. GEOLAB adjustment output (Dworshak Dam Reference Network)

```
            U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
SOLVE:

Adjusted Values (Iteration Count = 2):

CODE IDENT. TYPE                INITIAL        DX         ADJUSTED
---- ----- --------- ---------------- -------- ---------------
 14  4001  LATITUDE    46  30  5.78733    FIXED
 14  2006  LONGITUDE -116  19 17.36405    FIXED
 14  2006  HEIGHT            312.18200    FIXED

 24  4003  LATITUDE    46  30 51.48677  0.00000  46  30 51.48677
 24  4003  LONGITUDE -116  17 42.07099  0.00000 -116 17 42.07099
 24  4003  HEIGHT            500.68216  0.00001         500.68217

 24  4004  LATITUDE    46  30 54.09853  0.00000  46  30 54.09853
 24  4004  LONGITUDE -116  17 43.92366 -0.00000 -116 17 43.92366
 24  4004  HEIGHT            493.11850  0.00000         493.11851

 24  4002  LATITUDE    46  30 41.25876  0.00000  46 31  41.25876
 24  4002  LONGITUDE -116  18 23.74916 -0.00001 -116 18 23.74917
 24  4002  HEIGHT            493.34210  0.00003         493.34213

 24  4005  LATITUDE    46  30 55.00394 -0.00000  46 30  36.93927
 24  4005  LONGITUDE -116  17 46.44097 -0.00000 -116 17 46.44097
 24  4005  HEIGHT            503.72111  0.00000         503.72111

 24  4006  LATITUDE    46  30 56.68676  0.00000 46 30  56.68676
 24  4006  LONGITUDE -116  17 48.02294  0.00001 -116 17 48.02294
 24  4006  HEIGHT            493.25364  0.00003         493.25367
-----------------------------------------------------------------
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-----------------------------------------------------------------
            U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
Adjusted Cartesian Coordinates:

CODE IDENT.      X-COORDINATE     Y-COORDINATE     Z-COORDINATE
---- ------ ---------------- ---------------- ----------------
 24  4003       -1948002.5548    -3942346.3361     4605137.8787
 24  4004       -1948009.7358    -3942271.7102     4605187.8935
 24  4002       -1948302.6080    -3940948.3316     4606190.1331
 24  4005       -1948052.0934    -3942236.2903     4605213.8271
 24  4006       -1948062.4335    -3942181.0887     4605242.9935

SOLVE successfully completed.

-----------------------------------------------------------------
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-----------------------------------------------------------------
            U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
INVERT:

INVERT successfully completed.

-----------------------------------------------------------------
GeoLab-V1.82S,(C)1985/86/87BitWise Ideas Inc.[103207687] Page  9
```
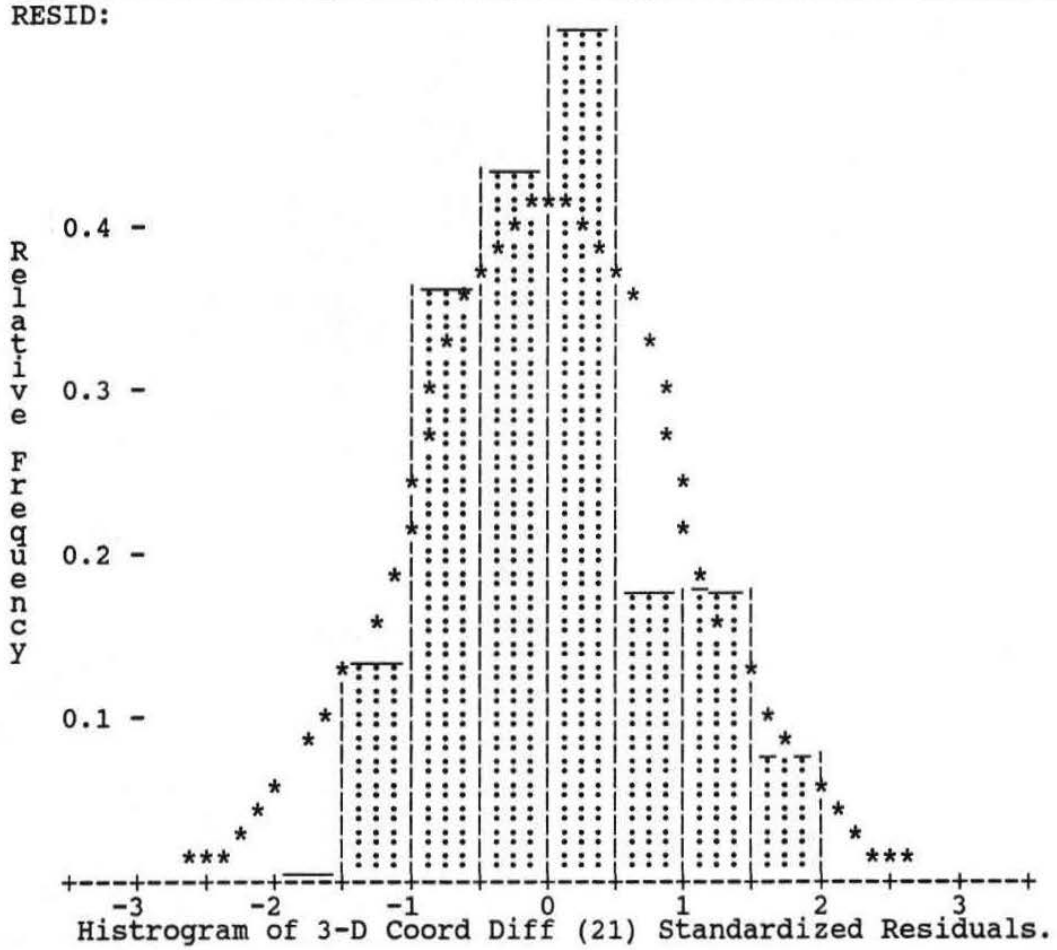

Figure G-3e. GEOLAB adjustment output (Dworshak Dam Reference Network)

```
-----------------------------------------------------------------
          U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-----------------------------------------------------------------
RESID:
```




```
-----------------------------------------------------------------
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```

Figure G-3f. GEOLAB adjustment output (Dworshak Dam Reference Network)

```
              U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-------------------------------------------------------------------
RESID:

 -------------------------------------------------------------
|                                                             |
|              S T A T I S T I C S   S U M M A R Y            |
|-------------------------------------------------------------|
|                                          |                  |
|  Residual Critical Value Type            |        Tau Max   |
|  Residual Critical Value                 |         3.3469   |
|  Convergence Criterion                   |       0.001000   |
|  Final Iteration Counter Value           |                2 |
|  Confidence Level Used                   |        95.0000   |
|  Number of Flagged Residuals             |                0 |
|  Estimated Variance Factor               |         0.8676   |
|  Number of Degrees of Freedom            |             45   |
|-------------------------------------------------------------|
|                                                             |
|          Chi-Square Test on the Variance Factor:            |
|                                                             |
|          5.9685e-001  <  1.0000  <  1.3763e+000  ?          |
|                                                             |
|                      THE TEST PASSES.                       |
|                                                             |
 -------------------------------------------------------------

RESID successfully completed.
-------------------------------------------------------------------
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-------------------------------------------------------------------
              U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          DWORSHAK DAM
A=  6378137.000 B=  6356752.314 X0=  0.000 Y0=  0.000 Z0=  0.000
-------------------------------------------------------------------
ELLIPSE:

 -------------------------------------------------------------
|                                                             |
|  NOTE:  All confidence regions were                         |
|                 computed using the following factors:       |
|   -----------------------------------------------------      |
|       Variance factor used        =    0.86755              |
|                                                             |
|       Estimated variance factor   =    0.86755              |
|                                                             |
|       1-D expansion factor        =      1.960              |
|                                                             |
|       2-D expansion factor        =      2.448              |
|                                                             |
|       3-D expansion factor        =      2.795              |
|                                                             |
|   Note that, for relative confidence regions, precisions    |
|   are computed from the ration of the major semi-axis       |
|   and the spatial distance between the two stations.        |
|                                                             |
|   Error ellipses for which all covariance matrix elements   |
|   were not computed by INVERT, are marked with an asterick(*)|
|                                                             |
 -------------------------------------------------------------
-------------------------------------------------------------------
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```

Figure G-3g. GEOLAB adjustment output (Dworshak Dam Reference Network)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM

A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

ELLIPSE:

2-D AND 1-D STATION CONFIDENCE REGIONS (95.000 %):

IDENT.	MAJOR SEMI-AXIS	MINOR SEMI-AXIS	AZ(MAJ)	VERTICAL
4003	0.0034	0.0022	76.62	0.0056
4004	0.0036	0.0023	82.71	0.0057
4002	0.0035	0.0026	89.02	0.0061
4005	0.0035	0.0023	82.89	0.0057
4006	0.0035	0.0022	79.03	0.0056

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U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
DWORSHAK DAM

A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

ELLIPSE:

2-D and 1-D RELATIVE STATION CONFIDENCE REGIONS (95.000 %):

FROM	TO	MAJ.SEMI	MIN.SEMI	AZ(MAJ)	VERT.	SPAT.DIST.	PREC.
4003	4004	0.0023	0.0008	89.79	0.0033	90.1225	25.220PPM
4003	4002	0.0033	0.0026	96.46	0.0057	1775.2993	1.847PPM
4003	4005	0.0025	0.0016	104.89	0.0038	143.1265	17.408PPM
4003	4006	0.0018	0.0014	130.30	0.0027	204.7957	8.998PPM
4004	4002	0.0035	0.0027	97.42	0.0059	1685.7014	2.064PPM
4004	4005	0.0019	0.0014	128.56	0.0027	61.4342	30.745PPM
4004	4006	0.0026	0.0016	102.27	0.0039	118.4286	21.633PPM
4002	4005	0.0033	0.0025	92.33	0.0056	1634.8752	2.019PPM
4002	4006	0.0033	0.0024	85.85	0.0056	1573.0376	2.098PPM
4005	4006	0.0023	0.0009	88.94	0.0033	62.8290	36.322PPM

ELLIPSE successfully completed.

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Figure G-3h. GEOLAB adjustment output (Dworshak Dam Reference Network)