APPENDIX J

Establishing NSRS Elevations on 15 Dam and Reservoir Projects in Pittsburgh District

J-1. General. The following example outlines the survey actions performed by Pittsburgh District to establish NAVD88 elevations on 15 dam and reservoir projects throughout the District. The procedures used in this example project are also applicable to levee projects extending over large geographical areas. This work outlined below was performed by Terrasurv, Inc. under a contract to the Pittsburgh District. Adjusted GPS observations, from which NAVD 88 elevations were derived, were submitted to NGS for inclusion in the in the NSRS. NSRS referenced NAVD88 elevations were established at Primary Project Control Points (PPCPs) at each dam and reservoir site.

J-2. Background. As part of a Corps-wide review of project datums initiated in 2007 (i.e., the Comprehensive Evaluation of Project Datums or CEPD), the Pittsburgh District undertook an assessment of all their projects. Part of this effort was to evaluate the origin and accuracy of the vertical datums in use at each of the sixteen dam and reservoir projects within the District's civil works area of responsibility. This CEPD review determined that none of these projects had a documented connection to the NSRS. While all of the projects nominally had NGVD29 elevations, the source and accuracy of many was in question. In addition, the data was not in a format conducive to updating to NAVD88.

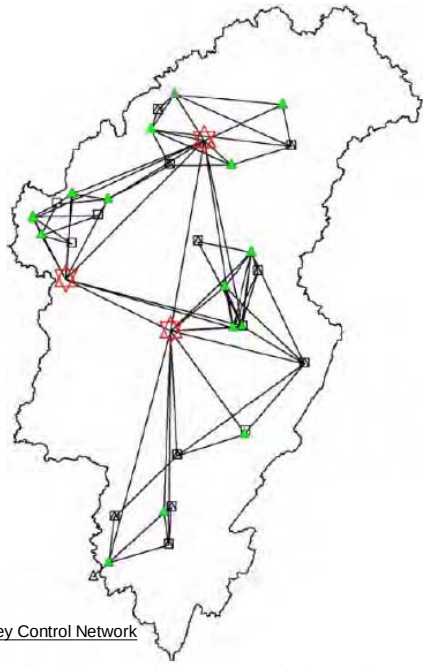
a. East Branch Project. The Clarion River East Branch Reservoir was used as a pilot project. GPS survey methods were used on the East Branch project to provide ties to NSRS bench marks. The data was then formatted and submitted to the NGS for inclusion in the NSRS. Additional details on this specific project are outlined in Appendix F.

b. Remaining reservoir projects. After completing the East Branch Project, the District decided to implement a similar process to establish an NSRS referenced PPCP at each of the remaining 15 reservoir projects. These projects encompassed an area of approximately 26,000 square miles in western Pennsylvania, a small portion of western New York, eastern Ohio, and northern West Virginia.

J-3. Project Description. Figure J-1 depicts the 16 dam and reservoir projects contained in Pittsburg District's civil works boundary. The geodetic survey scheme shown on the right side of the figure was developed to establish vertical (and horizontal) control on an existing primary monitoring bench mark at each of the remaining 15 project sites. These geodetic control surveys were performed during annual O&M programmed deformation monitoring surveys at each dam—significantly reducing costs in updating datum references. (Pittsburgh District estimates the cost to perform the NSRS connection at each site was approximately $8,000). The observed GPS baseline data was then processed, adjusted, and submitted to NGS for inclusion in the NSRS. The District's 23 lock and dam projects shown on Figure J-1 were not included in this overall project. These projects could be linked to this reservoir control network at some future date.

16 Flood Control Dams & Reservoirs (black outlines)

3 on tributaries to Monongahela River
4 on tributaries to Ohio River
9 on tributaries to Allegheny River



Survey Control Network

Green Triangles=New stations at USACE Flood Control Reservoirs (16 PPCPs)
Red Stars=CORS (3)
Squares=NSRS benchmarks (5)
Triangles=HARN stations (1)
Squares/Triangles=HARN/Benchmark (10)

Figure J-1. GPS data collection network used to establish primary control at 16 dam and reservoir projects in Pittsburg District.

J-4. GPS Network Decision. The A-E contractor (Terrasurv, Inc.) had been performing annual deformation surveys at the reservoirs since 2005. Many of these prior surveys utilized GPS to provide external control for the deformation analysis. Although CORS/OPUS observations at each site would have provided adequate NAVD88 elevations (accurate to < ± 0.25 ft), it was decided that previously observed GPS baselines could be readily incorporated into a higher-accuracy geodetic network encompassing all projects. This network would effectively link all the District's projects to the NSRS and to one another. Accordingly, GPS observations from 2005, 2006, and 2007 were examined to extract observations that would be useful in the current network survey. A "Primary Project Control Point" (PPCP) was selected at each reservoir—typically one of the structural deformation monitoring points (pedestals). Some reservoirs had a second point included in the network due to multiple GPS observation in previous years.

J-5. Existing NSRS Control. Because the primary purpose of the project was to establish NAVD88 elevations at each reservoir, emphasis was placed on using NSRS marks that were stable bench marks. Because there were numerous ties to CORS, horizontal accuracy of the existing NSRS stations was secondary. Most of the existing NSRS control stations used in Pennsylvania and West Virginia were both horizontal and vertical control. In Ohio, it was not possible to find any such stations in the vicinity of the reservoirs, therefore three vertical-only

bench marks were used there, along with a local CORS. Table J-1 lists the existing NSRS control used on this project.

Table J-1. Existing NSRS Control.

Station Name	PID	Horizontal Ellipsoidal Accuracy	Ortho Order	State	Comments	Stability	Nearest Reservoir
R HAYES	AA9347	0.65/1.04	GPS	WV	HARN	D	Stonewall
C 317	JW1099	1.22/2.12	I-2	WV	HARN/BM	A	Tygart
P 322	JW1091	1.04/1.67	I-2	WV	HARN/BM	A	Tygart/Stonewall
W 319	JX1767	1.18/1.78	I-2	WV	HARN/BM	B	Stonewall
A 121	JW0568	----	I-2	PA	V only	D	Youghiogheny
T 404	KX1902	1.30/2.27	I-2	PA	HARN/BM	B	Mahoning
E 402	KX1814	0.77/1.33	I-2	PA	HARN/BM	B	Mahoning/Crooked Creek
G 316	KX0579	0.71/1.35	II-0	PA	HARN/BM	D	Youghiogheny
E 313	JW1043	0.61/1.16	I-2	WV	HARN/BM	B	Youghiogheny/Tygart
TTS 64 K	MA0735	0.31/0.51	II-0	PA	HARN/BM	A	East Branch/Kinzua
D 406	MB1777	0.86/1.53	I-2	PA	HARN/BM	B	Woodcock/Union Cty
E 408	MA1819	0.77/1.39	I-2	PA	HARN/BM	B	Tionesta
D 156	MB0852	----	2-0	OH	V only	B	Mosquito/Kirwan
R 147	KY1127	----	2-0	OH	V only	B	Berlin
AAA	MB0984	----	2-0	OH	V only	B	Shenango
PAPT	DF7986	CORS	CORS	PA	CORS		
UPTC	AI8355	CORS	CORS	PA	CORS		
LSBN	DF4054	CORS	CORS	OH	CORS		

J-6. Conemaugh Dam Bench Marks. In addition to the existing NSRS marks described above, two stable NSRS bench marks (PID KX1047 and PID KX1045) were recovered near the Conemaugh Dam, and a short level line was run between them to establish a new mark which was capable of being occupied by GPS receivers. This level line was run twice with invar bar code rods, once in 2005 and again in 2008. The misclosure between these marks relative to the published elevations was 0.0065 m. PBM 52A appeared to have been disturbed.

J-7. Datums. The horizontal datum used for this network project is the NAD83 (NSRS 2007). The vertical datum is NAVD88. The geoid model used was GEOID 2003.

J-8. GPS Observations. Observations were made over a time span from May of 2005 through January of 2009. All observations were made using Trimble dual frequency receivers.

a. The receivers used included the following:

(1) two R8 GNSS models, with integral antennas.

(2) one R6 model, with integral antenna.

(3) two 5700 models, one with a Zephyr Geodetic antenna and the other with a Zephyr antenna.

(4) one 4800 model, with integral antenna.

(5) one 4700 model, with a microcenter L1/L2 antenna without ground plane.

(6) one 4400 model with a compact L1/L2 antenna, without ground plane.

b. Data was obtained from the CORS sessions with a sufficient amount of data to ensure an accurate solution. The survey pedestals were occupied by placing a standard survey tribrach onto the stainless steel plate. The 5/8" rod typically protrudes about 12 mm above the plate. The height of instrument measurement is with respect to the top of this rod. Most of the ground points (disks) were occupied using fixed height tripods as shown in Figure J-2. A few were occupied with standard survey tripods. All height of instrument measurements were reduced to vertical values from the mark to the Antenna Reference Point (ARP), which is the bottom of the antenna housing.

Figure J-2. GPS data collection at a primary structural monitoring point (PPCP) near the dam.

J-9. GPS Data Processing. The GPS observables were downloaded from the receivers and processed using the Weighted Ambiguity Vector Estimator (WAVE) processor in Trimble Geomatics Office, version 1.63. The precise ephemeris (IGS Rapid) was used for processing baselines. Not all baselines were processed—several of the lines had higher than normal statistics, indicating the presence of noise in the data. Many of the baselines were measured

twice, and therefore had an independent verification of correct integer ambiguity resolution. Seven processed baselines were disabled in the data analysis phase. Many of the baselines were measured in more than one session. The independently determined baseline components were transformed from an Earth Centered Earth Fixed (ECEF) system to a local horizon system (N-E-U). All of the new reservoir project stations were occupied at least once. Two existing NSRS control stations, "R HAYES" and "D 406," were occupied a single time.

J-10. Least Squares Adjustments. The data was adjusted using ADJUST, a least squares adjustment program from the NGS. The occupation information was processed to form an ADJUST "B-file." The processed baselines were parsed to form an input file in the ADJUST "G-file" format.

a. Minimally constrained NSRS adjustment. The first adjustment constrained the CORS "PAPT ARP" station to the published NAD83 (epoch 2002.0) position (latitude, longitude, and ellipsoidal height). The resultant standard deviation of unit weight was 6.75. The misclosures at the other NSRS stations and the other two CORS used are shown in Table J-2.

Table J-2. Minimally Constrained Adjustment of NSRS Control Holding "PAPT ARP" Fixed.

Station	Azimuth	Distance (m)	Δ Ellipsoidal Height (m)
R HAYES	196	0.007	-0.010
C 317	315	0.003	-0.012
P 322	188	0.008	-0.031
W 319	214	0.004	0.009
T 404	116	0.013	0.018
E 402	242	0.008	-0.010
G 316	200	0.007	-0.011
E 313	31	0.002	0.028
TTS 64 K	255	0.016	-0.002
D 406	238	0.009	0.005
E 408	251	0.007	0.012
UPTC ARP	129	0.005	-0.007
LSBN ARP	272	0.013	0.002

The misclosures on the above NSRS control stations were considered excellent, especially given the network spans an area of about 65,000 square kilometers (24,000 square miles).

b. Minimally Constrained Orthometric Height Adjustment. Next, a minimally constrained adjustment was done holding the published NAVD88 orthometric height of bench mark "T 404" (PID KX1902), and "PAPT ARP" fixed horizontally. The misclosures at the other NSRS marks with published orthometric heights are shown in Table J-3 and graphically on Figure J-3.

Table J-3. Minimally Constrained Adjustment Holding “T 404” (V) and “PAPT ARP” (3D).

Station	Δ Ortho Height
R HAYES (GPS Derived Ortho Height)	0.010 m
CONEMAUGH BRIDGE	
(leveling by Terrasurv)	-0.022 m
C 317	-0.007 m
P 322	0.000 m
W 319	0.030 m
A 121 (checked by levels to adjacent BM)	0.066 m
E 402	-0.008 m
G 316	-0.030 m
E 313	0.038 m
TTS 64 K	-0.006 m
D 406	-0.001 m
E 408	0.015 m
D 156	-0.015 m
R 147	0.037 m
AAA	0.027 m

c. The bench mark with the highest misclosure, “A 121” (0.066 m), was checked against an adjacent NSRS mark using precise leveling techniques and equipment (Second Order procedures). This mark had four repeat baselines, two in 2005 and two in 2008. The vertical component of the baseline from YOUGHIOGHENY M1 to A 121 was - 49.818 m, - 49.806 m, - 49.815 m, and - 49.800 m, with a range of ± 0.010 m about the mean value of - 49.810 m. Therefore, this mark is believed to be stable and the lines going to it are of high accuracy. This mark is located on the eastern side of two mountain ridges (Chestnut and Laurel Ridges), whereas the rest of the project is located on the western side of the ridges. The geoid model used (2003) may be affected by these ridges. In order to ensure an accurate GPS derived orthometric height at the nearby Youghiogheny Reservoir, this mark was included as a constraint in the final constrained orthometric height adjustment. All of the other existing marks were within ± 0.037 m in the vertical (orthometric height) component.

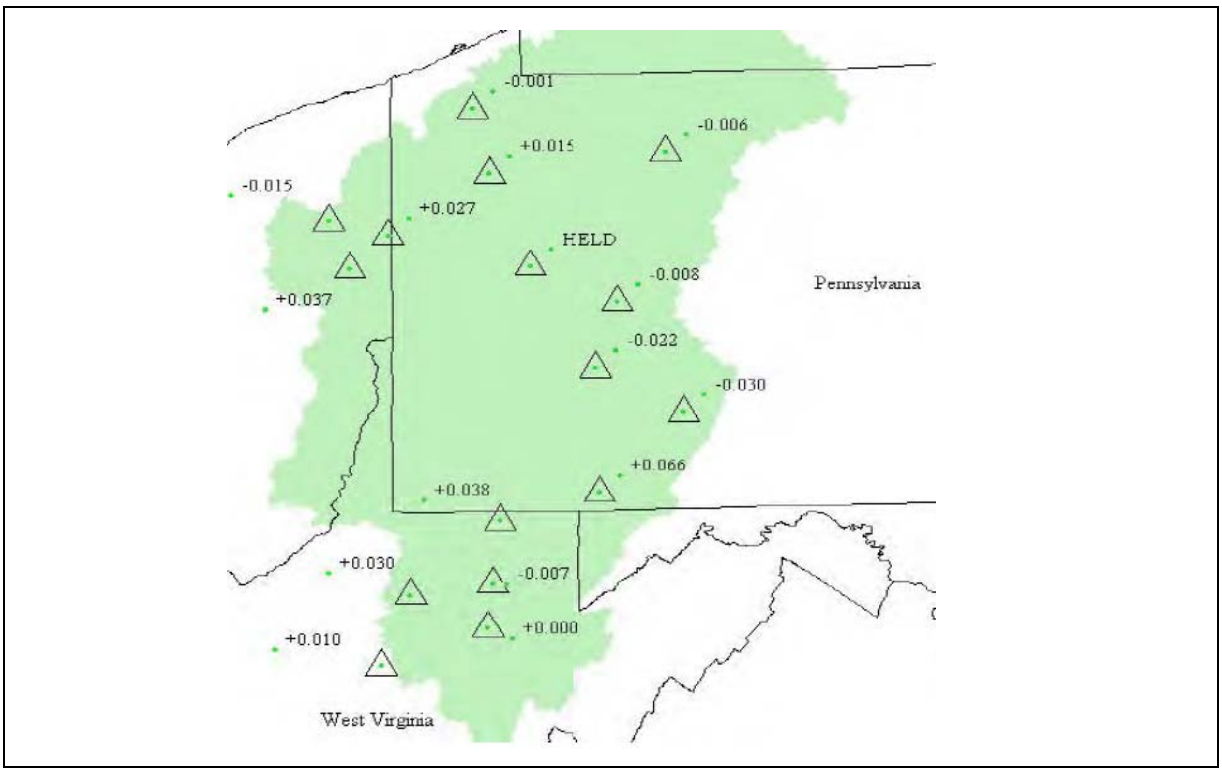


Figure J-3. Misclosures resulting from a minimally constrained vertical adjustment constraining height on a HARN bench mark near the center of the project. (Misclosures shown in meters)

d. Constrained adjustment (ellipsoid heights). The next adjustment was a fully constrained adjustment that held the three CORS and the eleven existing NSRS stations with published NAD1983 (NSRS2007) latitudes, longitude, and ellipsoidal heights. This adjustment had a standard deviation of unit weight of 8.165. This adjustment provided the adjusted latitudes, longitudes, and ellipsoidal heights for the network.

e. Constrained adjustment (orthometric heights). The final constrained adjustment held CORS "PAPT ARP" fixed horizontally, and fifteen stations with leveled NAVD88 orthometric heights were constrained vertically in the NGS ADJUST program. The standard deviation of unit weight was 7.20 and the residual RMS was ± 0.021 m. This adjustment provided the NAVD88 GPS derived orthometric heights for the network. The final adjustment results are listed in Table J-4.

Table J-4. Adjusted Coordinates – NAD83 NSRS 2007/NAVD88.

Station Name	Latitude	Longitude	Ellipsoid Height (m)	NAVD88 Height (m)
TYGART ASE2	39º18'47.16840" N	80º01'45.99898" W	345.026	377.139
CROOKED CK M2	40º42'53.07204" N	79º30'49.51338" W	257.176	290.573
MOSQUITO M4	41º18'06.84178" N	80º45'09.48816" W	246.597	280.407
STONEWALL	39º00'15.54934" N	80º28'24.35241" W	283.918	316.238
R HAYES	38º54'47.26507" N	80º35'44.73360" W	336.208	368.608
YOUGHIOGHENY M1	39º47'55.96185" N	79º22'02.18435" W	424.933	456.671
CONEMAUGH BR	40º27'42.15164" N	79º22'02.71448" W	245.331	278.377
CONEMAUGH M3	40º28'05.77660" N	79º22'29.30277" W	286.840	319.890
LOYALHANNA	40º27'29.96032" N	79º27'09.34669" W	269.118	302.254
TIONESTA	41º28'24.00763" N	79º26'35.72847" W	322.841	355.812
UNION CITY M1	41º55'14.71075" N	79º54'11.33916" W	362.504	396.550
UNION CITY M5	41º55'14.56028" N	79º54'16.09282" W	371.722	405.770
KIRWAN M1	41º08'47.32372" N	81º04'22.71305" W	275.309	308.988
C 317	39º20'38.54354" N	79º58'03.73837" W	325.837	357.872
BERLIN M5	41º02'35.39945" N	81º00'32.70465" W	285.874	319.559
P 322	39º06'38.37991" N	79º59'42.18154" W	525.250	556.874
W 319	39º17'11.27553" N	80º25'31.19084" W	332.512	365.178
A 121	39º48'45.98850" N	79º21'33.77400" W	375.121	406.837
MAHONING	40º55'28.22823" N	79º16'58.28579" W	356.660	389.675
KINZUA M1	41º50'31.50495" N	79º00'02.33348" W	387.903	420.339
WOODCOCK	41º42'05.73148" N	80º06'07.07176" W	339.158	372.986
SHENANGO	41º15'54.80683" N	80º27'45.43598" W	250.654	284.444
KIRWAN	41º09'26.19271" N	81º04'41.85584" W	253.577	287.257
MOSQUITO	41º17'59.95573" N	80º45'30.50304" W	245.336	279.148
T 404	40º59'41.81625" N	79º43'32.90556" W	336.103	369.602
E 402	40º48'07.37960" N	79º14'00.67131" W	338.584	371.572
G 316	40º13'30.90049" N	78º52'17.31696" W	554.614	586.700
E 313	39º40'10.80731" N	79º55'09.32013" W	345.395	377.956
TTS 64 K	41º34'50.57939" N	78º56'06.94800" W	541.539	573.625
D 406	41º49'17.00008" N	80º02'40.75526" W	314.420	348.439
E 408	41º28'42.27988" N	79º57'06.99473" W	356.203	389.618
D 156	41º14'17.11949" N	80º52'54.65838" W	239.435	273.263
R 147	40º59'17.67806" N	80º45'42.03236" W	310.755	344.636
AAA	41º09'49.81358" N	80º32'32.18072" W	247.341	281.222
PAPT ARP	40º26'40.25568" N	79º57'32.12989" W	313.698	347.441
UPTC ARP	41º37'43.70199" N	79º39'50.62173" W	343.186	376.455
LSBN ARP	40º46'08.93523" N	80º48'37.47136" W	314.449	348.434

J-11. Supplemental Ties to LPCPs. At each reservoir project, supplemental ties were made to local project control points around the project. In addition, ties were made to any water level or pool gages at the sites. Differential levels were run from primary PPCP mark to secondary marks using a DiNi 12 digital level. Levels runs to outflow gage reference PBMs were run if feasible, otherwise GPS was used to transfer elevations from the primary PPCP station to the outflow bench mark. Figures J-4 illustrates connections from the primary PPCP to supplemental bench marks at a dam and the down stream outflow PBM reference point. Figure J-5 shows leveling connections to a typical reservoir pool gage.

J-12. Summary. The geodetic control network met NGS height modernization standards and established consistent NAVD 1988 vertical control for the reservoirs in the Pittsburgh District. An overall accuracy of ±0.03 m was achieved in all three dimensions in a network covering the entire 26,000 sq mile district.

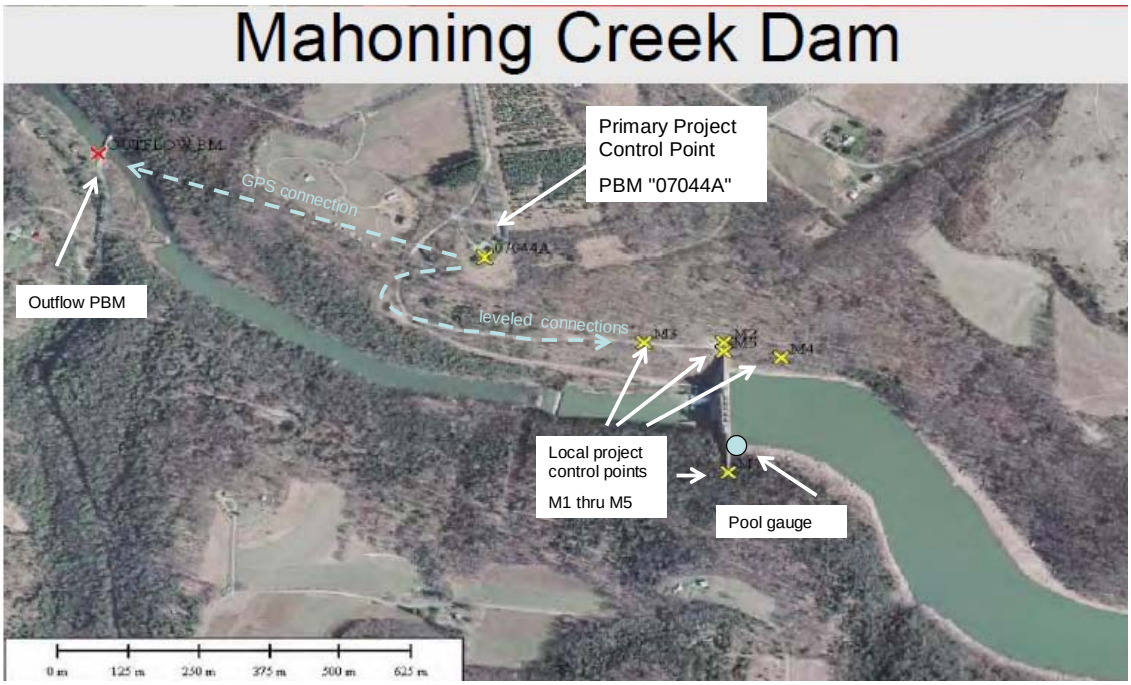


Figure J-4. Differential level connections from the PPCP to supplemental PBMs around Mahoning Creek Dam. The outfall PBM was connected by static GPS from the PPCP.

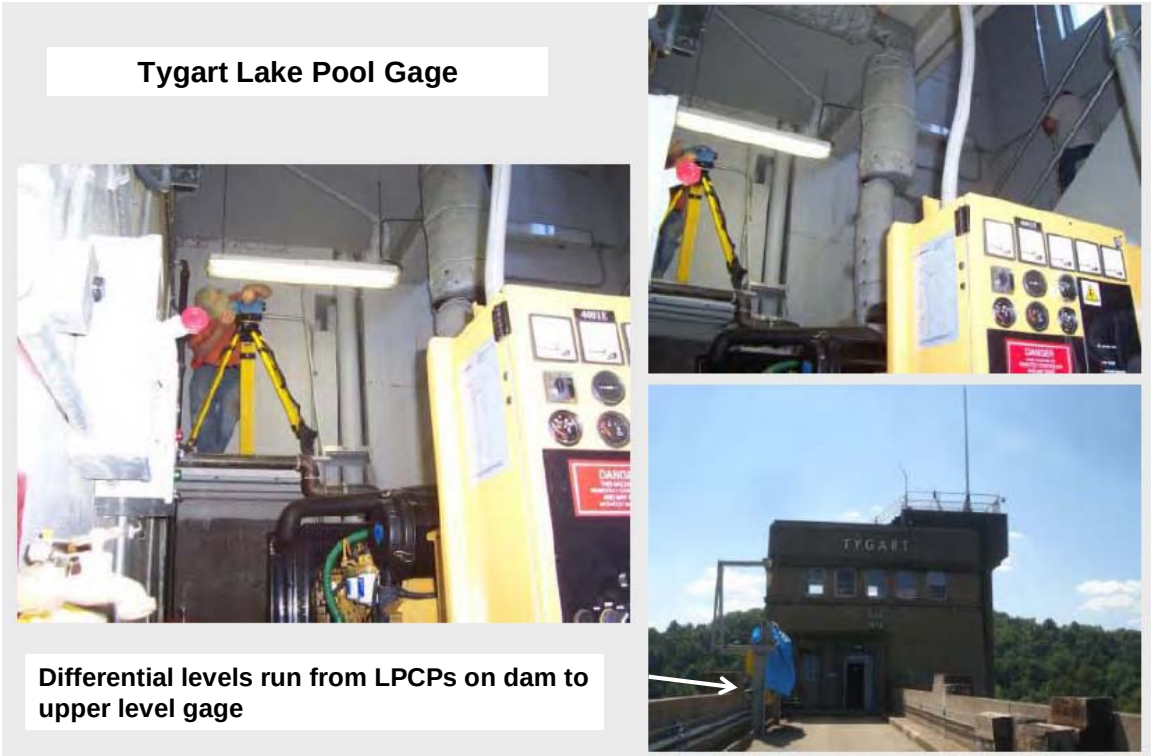


Figure J-5. Differential leveling connections to the pool gage at Tygart Lake Dam and Reservoir.