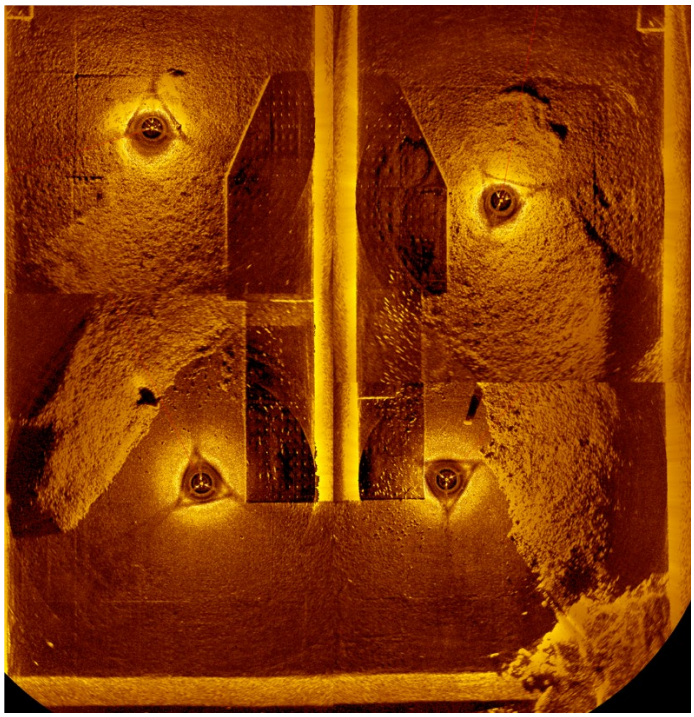
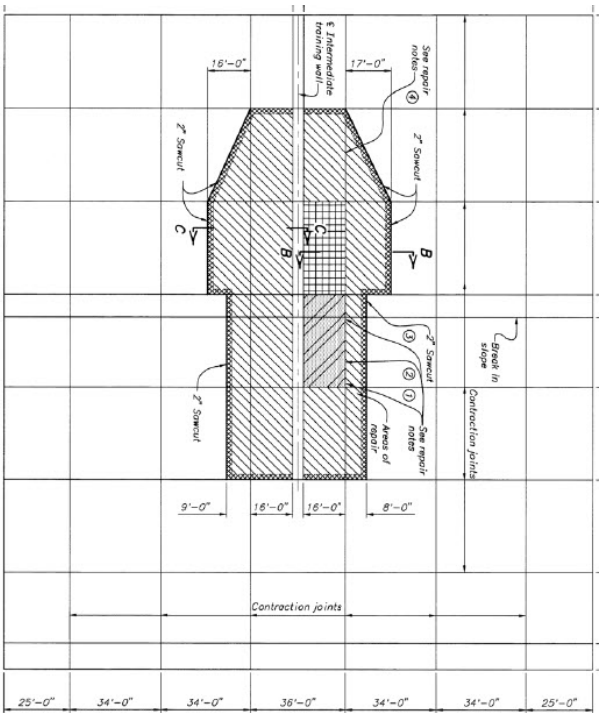
BUREAU OF RECLAMATION

Hydraulic Laboratory Technical Memorandum, PAP-1218

Canyon Ferry Stilling Basin Sonar Inspection

Canyon Ferry Unit, Pick-Sloan Missouri River Basin Project, Montana, Missouri Basin and Arkansas-Rio Grande-Texas Gulf Regions





U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services
Denver, Colorado

June 2022

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Purpose

The purpose of this sonar survey at Canyon Ferry Dam was to determine the effect of operating the river outlet gates at 4,000 cfs, which is a greater than the 2,000 cfs release flow discharge specified in the Standing Operating Procedures, (Bureau of Reclamation 1999). This increase in flow is necessary to accommodate a potential outage of the powerhouse during the winter months when operating the spillway gates could damage the spillway gate seals if they are frozen to the dam face. There is a concern that high releases from the river outlet gates could potentially draw material into the stilling basin and cause ball milling damage. A three-dimensional (3D) point cloud survey was requested by the Bureau of Reclamation's (Reclamation) Montana Area Office to create a difference map of the material in the basin before and after the high flow release. In addition, sonar imagery was collected before and after the test to visualize the difference in stilling basin sediment distribution.

Introduction and Background

Canyon Ferry Dam, located 15 miles east of Helena MT, is a concrete gravity structure approximately 1,000-ft in length along the crest with a structural height of 225 ft. It contains 414,400 cubic yards of concrete. The overflow spillway is a section in the central portion of the dam, controlled by four radial gates with a capacity of 150,000 cfs. The total reservoir capacity is 2,051,000 acre-ft when the water surface elevation is at 3,800.00 ft. Four river outlets, with a capacity of 9,500 cfs, are in the spillway section of the dam. The river outlets are in pairs on either side of the spillway chute. The dam also has a pumping intake pipe near the left abutment for the Helena Valley Pumping Plant. The power plant is on the right downstream toe of the dam adjacent to the spillway apron. It houses three 16,667-kilowatt vertical-shaft generators driven by 23,500-horsepower turbines.

There has been a long history of scour erosion in the stilling basin due to ball milling of material that has been brought into the stilling basin during discharges from both the river outlet and spillway. A hydraulic model was constructed in 1974 to determine the how material was entering the basin, (Burgi 1974). These initial model tests showed that material was drawn into the basin when the outlet works were operating at a discharge of 3,000 cfs or greater. High velocity surface flow from the outlet works swept along the water surface of the stilling basin and formed a large eddy with a return flow along the bottom of the exit channel and stilling basin floor.

Throughout the 1970's material in the basin was a repeated problem. In 1972, a clamshell bucket mounted on a platform barge removed 17,000 yd^3 of rock material. In 1973, 900 yd^3 of material had mobilized into the basin. In 1974, the spillway was operated for 3 hours at a discharge of 28,000 cfs to flush the material out of the basin, which was justified by the hydraulic model study results. An underwater dive inspection verified that the rock material had been removed from the basin. The outlet works discharge was further restricted to 3,000 cfs or less to prevent rock from being mobilized into the basin. However, in 1977 an underwater inspection revealed that 1,350 yd^3 of rock had again been drawn into the basin. Thus, the model test results might not have duplicated prototype rock movement at low discharges and the outlet works discharge was further restricted to 2,000 cfs, (Zeigler,1980). Further tests were done in 1976 and 1982 that concluded: "The evidence is

strong that at low discharges, the model does not represent prototype action. Possibly rock will again be drawn into the basin, even with the lower outlet works discharge limitation of 2,000 cfs." (Zeigler,1982).

The stilling basin floor was repaired in 2004. The concrete scour on the basin floor near the center training wall reached a maximum depth of 1.79 feet, which exposed reinforcing steel. The repair design was documented in TM No. CF-8130-TM-2003-1 and a Report of Construction was completed in 2006. The repair was composed of a slab of silica-fume concrete placed over the central portion of the basin on both sides of the splitter wall. In 2008, an underwater examination of the stilling basin was performed. The spillway was operated for a total of 49 days with flows up to 8,880 cfs. A large amount of gravel and cobbles has accumulated on the top surface of the repair but it showed no damage, indicating active movement of material on the concrete. The edges of the repair extend 4 inches above the surrounding concrete floor and showed virtually no deterioration, (Bureau of Reclamation, 2016).

Instrumentation and Methods

To compare the stilling basin conditions before and after the high flow test, the following test plan was completed between June 6 and 10, 2022:

1.) Baseline data were collected using 3D point cloud data and scanning sonar imagery of the spillway face and stilling basin floor.
2.) High flow river outlet gates were operated at 4,000 cfs for 72 hours (Appendix A).
3.) Test data were collected using 3D point cloud data and scanning sonar imagery of the spillway face and stilling basin to compare to baseline data.

To accomplish these tasks, a handheld GPS unit was used in conjunction with a MS1000 scanning sonar system as described below.

Garmin Map76CS

Differentially corrected GPS (dGPS) positions from a Garmin Map76CS handheld GPS receiver were used to provide horizontal positions to the MS1000 software. The accuracy of dGPS positions (±2 to 3 m) were deemed sufficient for this project given the limited number of available satellites. All measured geographic coordinates were referenced to the WGS-84 Datum. In post-processing, the MS1000 software was used to convert dGPS positions into Montana's State Plane Coordinate System in North American Datum 1983 (NAD83). Reclamation's project vertical datum was used to report the Canyon Ferry Dam tailwater elevation and was used to compute bathymetric elevations for this project. No attempt was made to convert dGPS coordinates to the project's local horizontal datum.

Scanning Sonar

A Kongsberg-Mesotech Ltd (KML) 1171 scanning sonar (Figure 1) and the MS1000 software package were used for the scanning sonar imaging in the spillway stilling basin. The MS1000 system, with a high-resolution geared fan/cone sonar head, was used to collect sonar images of underwater structural features. This sonar uses a 675 kHz transducer with an acoustic range from 1.5 to 450 ft with a resolution of about 0.06 ft. A detailed specification sheet for the scanning sonar system is included in Appendix B.

Figure 1. Photograph of the KML MS1000 scanning sonar system (courtesy of KML).

For the 3D point cloud, the sonar was mounted with a C-clamp so that the sonar was off the bow of a work boat. The boat was tied off to walls using a concrete anchor and a high strength static line. This ensured there would not be any vertical or horizontal movement.

In imaging mode, the scanning sonar used a fan-shaped acoustic beam, which has a 30° wide beam angle. This 30° beam angle caused a blind spot directly below the sonar system called a nadir. This can be seen in all the sonar images that were taken for this report. This effect was minimized by mounting the sonar on a tripod that was on the floor of the basin.

Stilling Basin Sonar Images

Acoustic imaging of the stilling basin floor, retaining walls, and the end sill was conducted before and after the river outlet gate high flow test. The scanning sonar was mounted in a 6-ft-high tripod to image the tailrace floor (see Figure 1). The tripod was lowered to the tailrace bottom at several locations. When the tripod was on the bottom the pitch and roll sensors were checked to make sure the tripod was upright. A GPS waypoint was recorded to geo-reference each tripod location. Several 360° sonar scans were recorded at various acoustic ranges to provide coverage at different image resolutions (shorter ranges provide higher resolution).

Stilling Basin Point Cloud Survey

A Kongsberg Mesotech Ltd (KML) 1171 scanning sonar and the MS1000 software package was used for 3D point cloud surveys. Integrating the scanning sonar with a mechanical single-axis rotator provides 3D point cloud surveying capability. A Kongsberg mechanical rotator was used to rotate the scanning sonar at precise increments during point cloud data collection. The point cloud surveys were performed using a cone beam which has a 1.7° beam angle. After collecting a single axis profile, the sonar was moved by the rotator through pre-set increments and the profiling process repeats. This technique produces a radial pattern of profiles from a single sonar location. Data are post-processed to generate a 3D point cloud projection. Figure 2 shows the sonar and

rotator mounted off the side of the boat. During data collection, the boat was secured to a tag line which spanned the entire stilling basin. The purpose of the tagline was to minimize any motion of the boat and sonar equipment and to assist with positioning the sonar in the same location for the post-test survey.

Figure 2. Sonar and rotator mounted on the front of the boat for 3D point cloud data collection.

Sonar Point Cloud Processing

Scanning sonar point cloud data are x,y,z points that are relative to the sonar transducer location. To be analyzed the x,y,z points need be converted to a known coordinate system (northing/easting) and elevation (Reclamation project datum). The first step in the processing is to assign origin coordinates for each point cloud. For this project, an arbitrary origin of (10,000, 10,000) was used because the GPS positions were inaccurate due to the tight canyon geometry surrounding the tailwater. Once the origin was established, BathyXYZ software was used to process the raw point cloud data sets. Elevations were computed using the tailwater elevation at the time of the survey, e.g, El. 3650.77 (before test) and 3650.68 ft (after test), and a sonar depth of 1.66 ft. The processed point clouds were imported into Tecplot Focus software to visualize the data. Figure 2 is a color contour map of the point cloud collected in the right side of the stilling basin for pre-test conditions. A review of the post-processed data revealed significant errors in point cloud data caused by boat motion associated with waves in the stilling basin and undetected pitch/roll error in the boat orientation. As a result, it was concluded that volumetric comparisons of sediment deposits for pre- and post-test surveys would produce unreliable estimates of sediment accumulation. For future point cloud surveys, it is recommended that a saddle mount be designed to mount the sonar on the intermediate training wall. This would remove boat movement errors so that the point cloud data would be precise enough to compare the volume before and after a high flow test. Additionally, mounting the sonar on a saddle mount in the center of the stilling basin would allow for repeatable

point cloud surveys. Lastly, having more overlap between the scans would allow for cloud-to-cloud registration to produce a complete point cloud for the entire stilling basin rather than each individual bay.

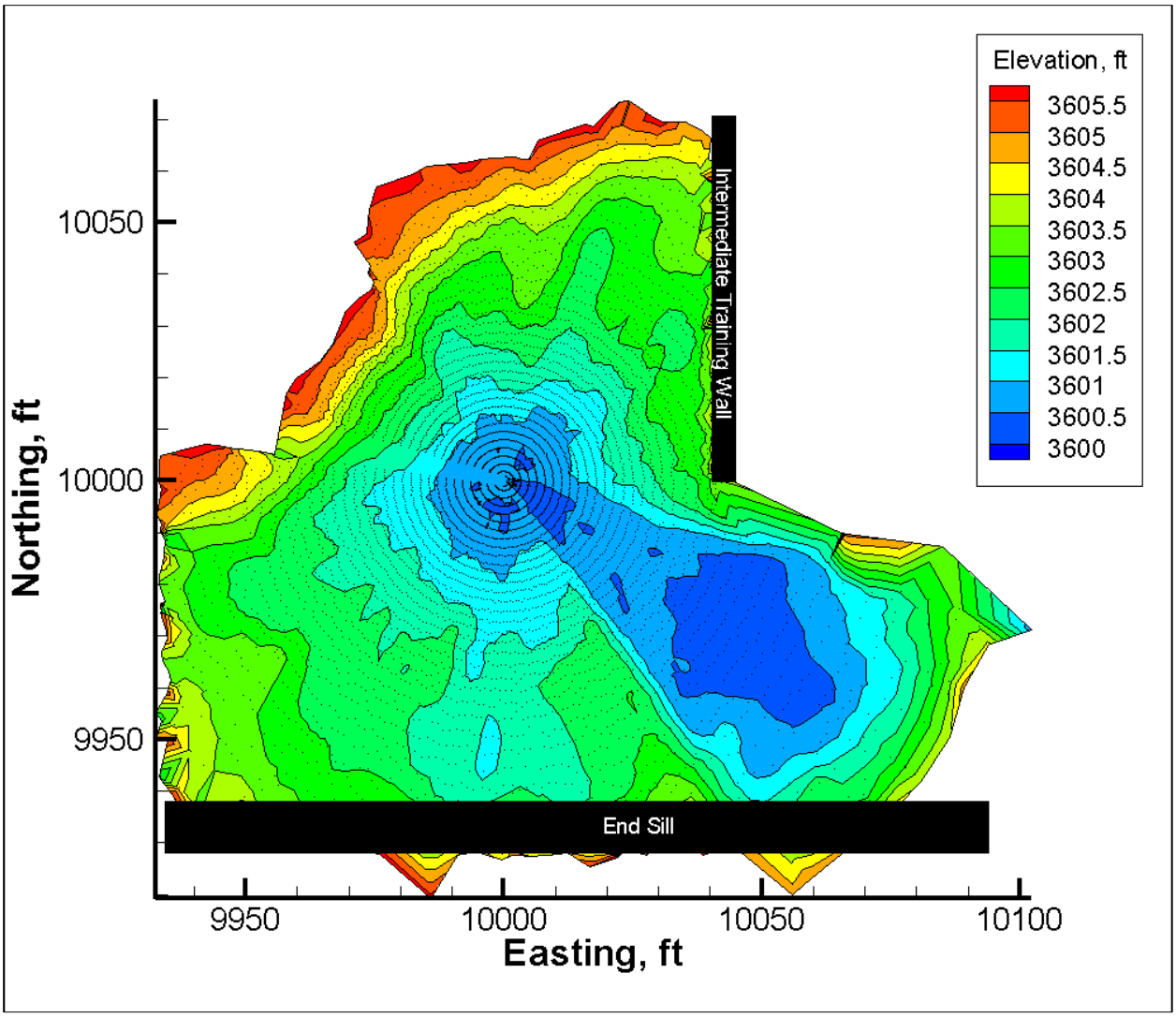

Figure 3. Color contour map of point cloud data collected for pre-test conditions in the right bay of the Canyon Ferry Dam stilling basin.

Results

Comparisons of the sonar images collected before and after the 4,000 cfs river outlet gates flow test were created using images taken with the MS1000 scanning sonar. Using the start of the narrower section of the previously repaired patch in the stilling basin as a consistent reference, the area of material was compared before and after the test. Originally, 3D point clouds were going to be used

to generate a volumetric difference in material but, due to the boat datum shifting slightly through the scans, the point clouds were not similar enough to generate a reliable difference in volume.

Complete Basin Overview

The basin was imaged using the MS1000 sonar in four locations (two in each bay) and with 5-6 different ranges (225, 150, 120, 90, 60, and 45 ft) to determine the extent of the material on the basin floor. Given the relatively shallow slope of the stilling basin, the tripod mounted sonar was able to image almost the entire basin at each location but having two points in each basin allowed for more overlap of the images.

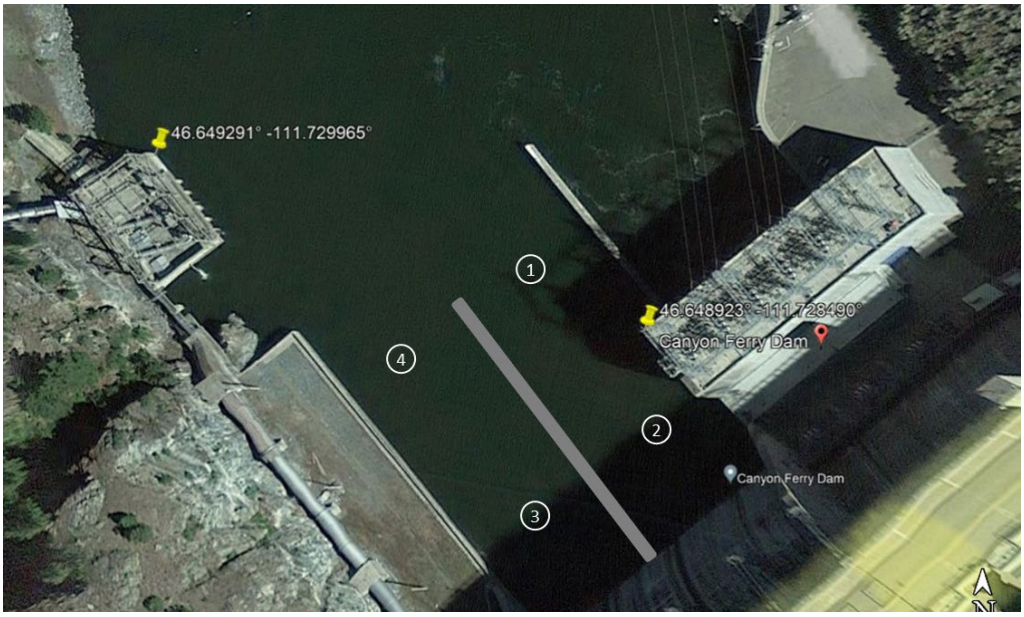

Figure 4. Satellite imagery of the dam site. The sonar imagery locations are indicated by the white numbers, submerged splitter wall is shown in grey, and GPS locations of the edge of the power plant and Helena Valley pumping plant are shown with yellow pins.

According to the control board in the powerhouse, the tailwater was El. 3650.77 ft, meaning the central splitter wall was submerged under about 5 ft of water (Figure 15). This provided enough depth for the boat to pass over the wall, but it fully blocked the sonar from scanning into the adjacent bay whether it was mounted to the bottom of the boat or on the bottom of the stilling basin.

Figure 5 shows the four sonar records overlaid to create a composite image of the entire stilling basin. Prior to the test, the basin has a significant debris pile in each bay that is concentrated in the downstream half of the bay. In the areas around the large debris piles the stilling basin floor is clear enough that construction joints in the concrete floor are visible.

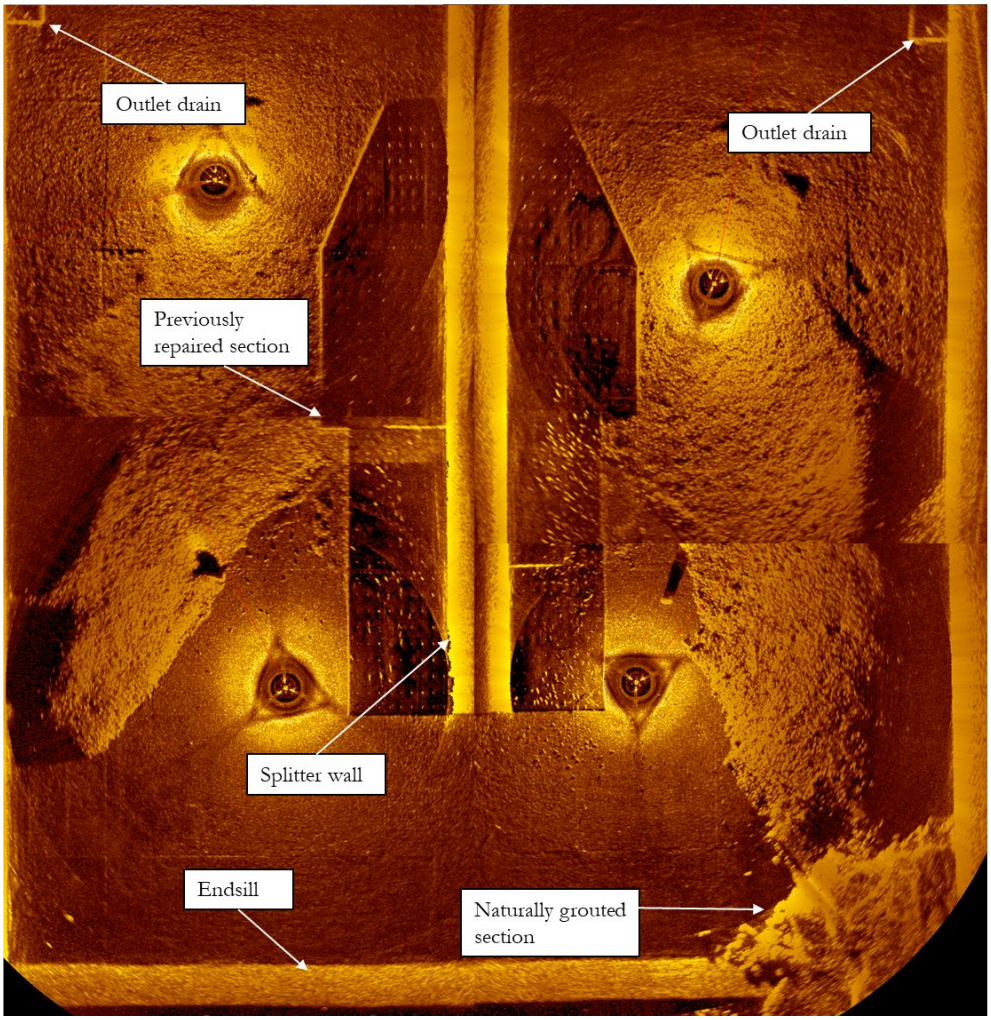

Figure 5. This composite image is made from four sonar scans taken at a range of 120 ft. Notable features include the endsill, previously repaired floor section, and outlet drains near the top of the image. Areas with uneven color contrast indicate locations with sediment deposition.

The previously repaired floor patch on either side of the splitter wall has well defined bright edges, indicating that the debris in the stilling basin is less than four inches tall (Figure 19). After the outflow test, the Montana Area Office conducted a quick inspection of the stilling basin using a Frontier Precision M2 Submersible ROV. Figure 6 and Figure 7 show images taken with the ROV of the naturally grouted section on the end sill and the outlet drains, respectively.

Figure 6. Naturally grouted section at the end of the stilling basin. The rock section has a small overhang and overlaps the end sill on the left side. This image was taken using the Montana Area Office's Frontier Precision M2 Submersible ROV.

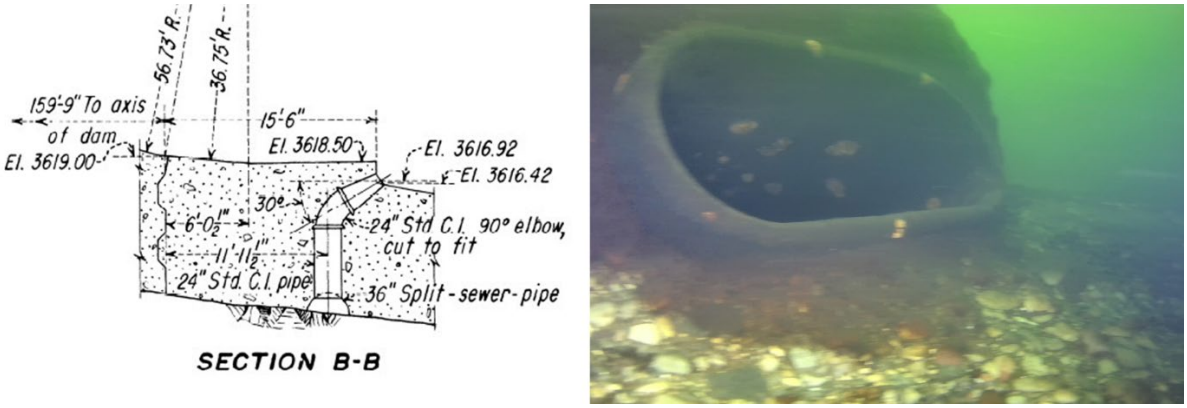

Figure 7. Outlet drains seen at the top of the of the composite sonar record. This image was taken using the Montana Area Office's Frontier Precision M2 Submersible ROV. The drawing to the left is Section B-B from Drawing 296-D-378.

After the test, the sonar imagery was taken in the same four sonar locations using the same ranges. During the downstream left bay scan, the area behind one of the debris piles was obscured so an additional scan on top of the mound was taken to confirm the extents. As shown in Figure 8, the endsill is still completely clear except for the naturally grouted section on the left bank, just as in the images from before testing.

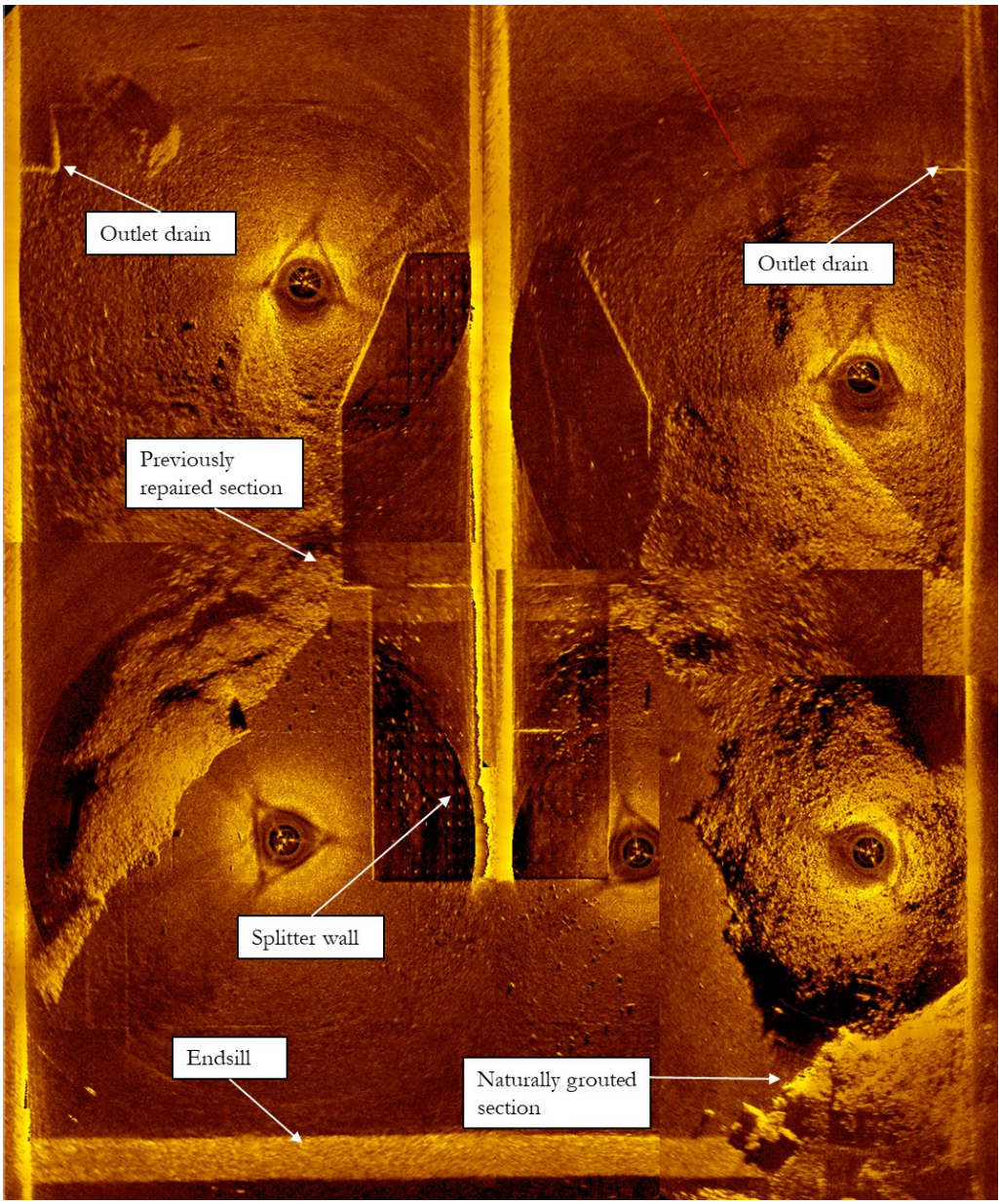

Figure 8. This after test composite sonar image is made up of five images taken at 120-ft range. The four primary images were taken in the same locations as the before test scans with a fifth taken on the left debris pile. Similar to the before test scans, the outlet drains, previously repaired patch and end sill are all clearly visible.

During the test period, the material appeared to move but was not being flushed out or pulled into the basin. For further analysis, the most well-defined and deepest section of debris near the narrow section of the patch will be used for the direct comparison.

Right Bay

An acoustic shadow is defined as the area through which sound waves fail to propagate due to some obstruction or disruption. In the sonar images, these are shown by the darker regions. Conversely, areas with a strong acoustic return produce a brighter orange/yellow color. The use of acoustic shadows allows for sonar images to be interpreted at a deeper level than just analyzing the strength of the return as they can indicate the height of an object. A structural feature will not move between sonar scans whereas material that is mobile in the basin will move relative to those features.

Before the test, the area of material along the narrower section of the repair patch was measured to be 2,932 ft^2. This area was defined by the section below where the patched section widens to 32 ft from the training wall. The area not covered in debris is assumed to be clear due to the faint construction joints visible in both images. Additionally, a 2.15-ft-tall object and its acoustic shadow were observed in an identical location in both the pre- and post-test images.

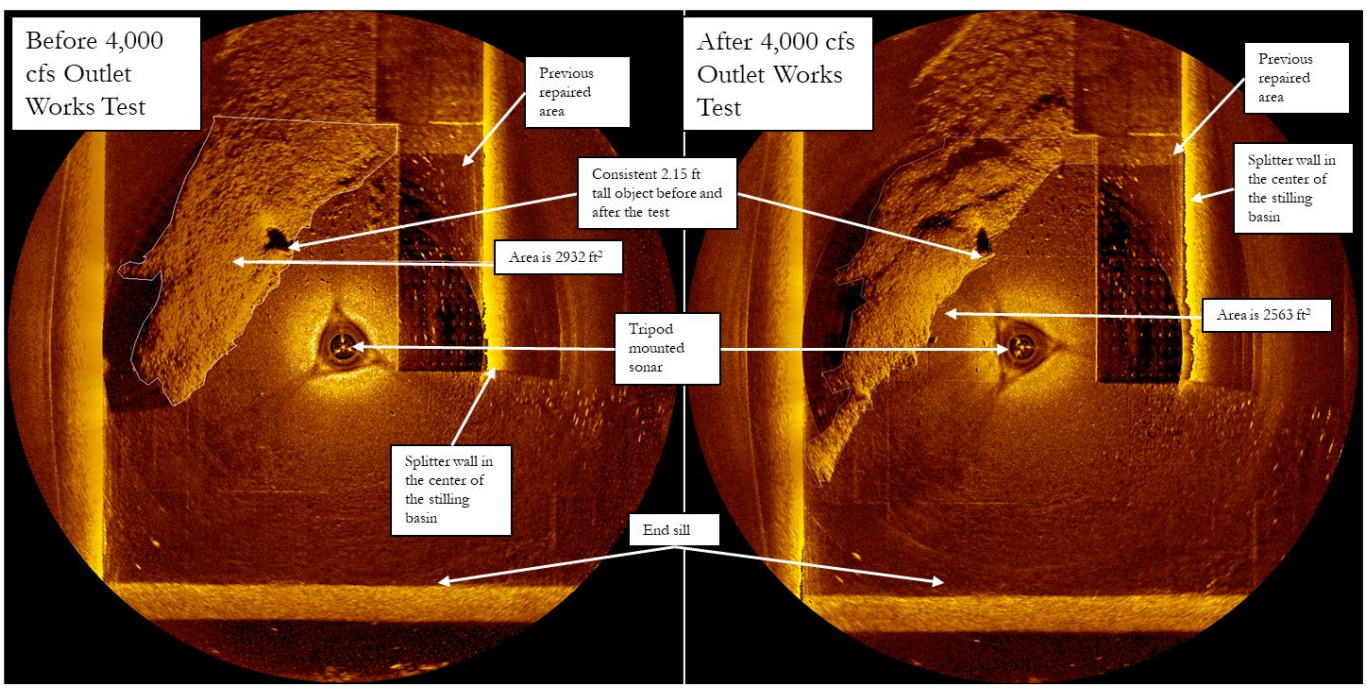

Figure 9. Right bay of the stilling basin before and after the 4,000-cfs river outlet gates test. There are several consistent objects between the imagery before and after the test including the end sill, splitter wall, a 2.15-ft tall object and the previously repaired area.

After the test, the area of material in the same section of the basin was 2,563 ft^2, indicating an area reduction of 369 ft^2. This difference is likely explained by the dark striations that run through the area of material in the after test image. These darker areas are consistent with taller ridgelines casting a shadow behind them. It can be reasonably assumed that there is minimal material being brought into the basin due to the clear end sill before and after the test. The similarity in the shape of the debris pile indicates that the shear forces from the river outlet gate releases are enough to move material within the basin, but not high enough to flush it out. However, without an accurate

volumetric comparison it is not possible to know for certain if any new material was transported into the basin. It is also important to note that upon starting the high flow test, an unknown volume of fine material was entrained into the flow as indicated by turbid water exiting the basin.

Left Bay

Before the test, the area of material along the narrower section of the repair patch was measured to be 4,633 ft^2. The patch is clearly visible before and after the test, indicating that the debris depth is less than four inches (the height of the repaired concrete). Additionally, the left bay has a 2.9-ft-tall object that is consistent between the two images, indicating that the shear forces were not high enough to move it.

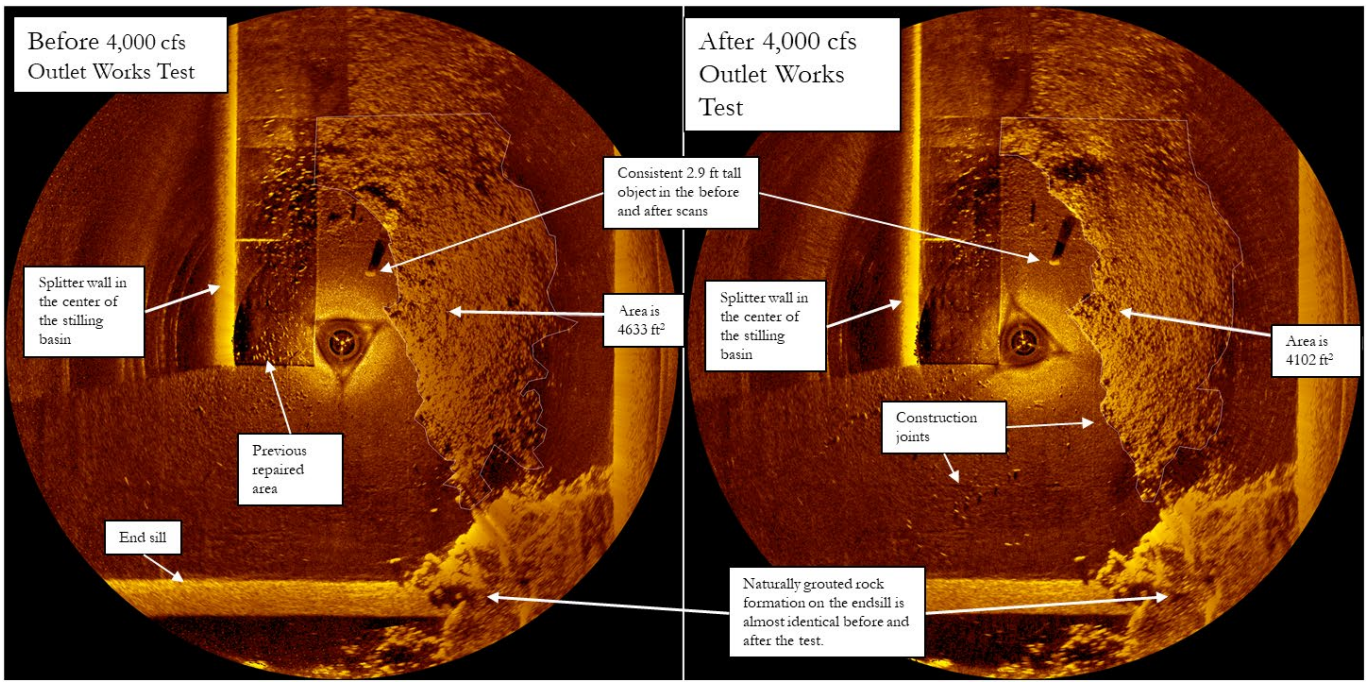

Figure 10. Left bay of the stilling basin before and after the 4,000 cfs river outlet gates test. The location of the 2.9-ft-tall object is consistent before and after the test and the shape of the debris pile is similar. This indicates that the debris did not move much during the test.

After the test, the area of material next to the narrow section of the patch was 4,102 ft^2, creating a reduction of 531 ft^2. The material post-test shows a stronger return on the leading edge closest to the sonar. This is typically associated with a taller steeper edge, indicating the height of the material increased after the test was run. The naturally grouted rock formation on the end sill of this bay is unchanged in the before and after images.

Conclusions & Recommendations

High resolution sonar images were taken in both bays of the Canyon Ferry Dam stilling basin before and after a 4,000 cfs river outlet gate release test. The images were compared to determine if debris was transported into the basin during the high flow test. Prior to the test, sonar images showed that both bays had debris in them with large sections of exposed concrete that were clear of debris. The contrast between debris piles and exposed concrete in the stilling basin allowed for identification of features consistent with the drawings.

After the test, the sonar images indicated that the debris pile areas were smaller than their pre-test size. This, combined with more acoustic shadowing on the central area of the debris piles, suggests that the debris was redistributed rather than flushed out of the basin. Additionally, the endsill was clear of debris before and after the test, which suggests that minimal material entered or was evacuated from the stilling basin during the 72-hour test period. However, observations of increased turbidity in the stilling basin at the beginning of the flow test is consistent with the resuspending of fine materials. While a significant amount of coarse material was not transported into or out of the stilling basin during the 72-hour test, there was evidence that material inside the stilling basin was moving during the test and this ball milling could cause concrete damage over time.

For future point cloud surveys, it is recommended that a saddle mount be designed to mount the scanning sonar and rotator on the intermediate training wall. This mounting system would remove boat movement errors so that the point cloud data would be precise enough to compare the stilling basin volume before and after a high flow test. Additionally, mounting the sonar on a saddle mount in the center of the stilling basin would allow for repeatable point cloud surveys. Lastly, having more overlap between the scans would allow for cloud-to-cloud registration to produce a complete point cloud for the entire stilling basin rather than each individual bay.

References

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E. R. Zeigler. February 1982. "Hydraulic Model Tests of Rock Material in Canyon Ferry Dam Spillway Stilling Basin". PAP-425, Bureau of Reclamation.

P.H. Burgi. December 1974. "Hydraulic Model Studies of Canyon Ferry Dam Spillway Stilling Basin". REC-ERC-74-27.

Appendix A – Photos of the 4,000 cfs Outlet Works Release.

Figure 11. River outlet gates flow test as viewed from the Helena Valley Pumping Plant.

Figure 12. View from the spillway gates. Top: before test. Bottom: during test.

Figure 13. River outlet gate releases taken from the grass on the left bank stilling basin retaining wall.

Appendix B – MS1000 Data Sheet

3000 m "High Resolution" Geared Fan/Cone Sonar Head Digital Telemetry

P/N 974-23050000

KONGSBERG

This version of the 1071-Series Sonar has been specifically designed to produce the highest resolution scanning sonar images possible with 675 kHz. Its design is targeted at bottom clearance, body recovery, underwater construction, pipeline inspection, cable route survey, bridge/pier inspection and applications where data clarity supercedes any other requirement.

This sonar head should also be considered in conditions where the in-water temperatures are lower than 4° C, or higher than 20° C. Domed, oil-filled heads may acoustically defocus beyond these temperature ranges. This sonar head incorporates the electronic advantages of increased sampling rates, wider receiver bandwidth, increased power output, and a very narrow horizontal beam pattern with the fan transducer. The telemetry is RS 485 and RS 232 compatible, and is automatically sensed and configured. The transducer is of a bare-shaft design, but the motor-end is oil compensated to prevent water ingress into the main electronic stack via the transducer shaft.

The sonar head is compatible with the MS1000 and MS900D Surface Processors. To take full advantage of the advanced features and high resolution this head has to be operated with the MS1000 processor.

Operating Frequency	675 kHz
Beam Width	0.9° X 30° Fan/1.7 X 1.7° Cone (nominal)
Range	0.5 - 100 Metres typical; 150 Metres obtainable
Range Resolution	≥ 19 mm (@ 1500m/sec speed of sound, 25 μs transmit pulse)
Sampling Resolution	≥ 2.5 mm
Scan Angle	360° continuous
Mechanical Step Size	≥ 0.225°
Scan Speed	nom 11 sec/360° @ 10 m and 1.8° step size (@ 230 kbits/sec.) nom 36 sec/360° @ 100m and 1.8° step size (@ 230 kbits/sec.)
Transmit Pulse Lengths	25 - 2500 μs
Transmit Power	OFF, 50 W nom, 500 W nom
Receiver Bandwidth	12/100 kHz
TVG Control	-20 to +100 dB
Telemetry	RS 485/RS 232 auto switching asynchronous serial data
Telemetry Rates	Downlink: 9600 Baud Uplink selectable: 230K, 115K, 57K, 38K, 19K, 9600 bits/sec automatic (to suit cable telemetry)
Power Requirements	33W, 22 - 60VDC
Temperature Ranges	-10 to +40° C operating -30 to +40° storage
Operating Depth	3000 meters
Connector	Seacon RMG-4-BCL (optional connectors; inquire to factory)
Materials	Aluminum 6061-T6, 300-Series SS
Dimensions	Diameter 3.5"/89 mm Length 22.4"/569 mm Transducer width 5.5"/140 mm
Weight	In air 13.5 lbs/6.1 kg, In water 6.5 lbs/2.9 kg
Options:	-7801 Built-in Security Key

Figure 14. MS1000 Scanning Sonar technical specification sheet.

Appendix C – Select Drawings of the Stilling Basin

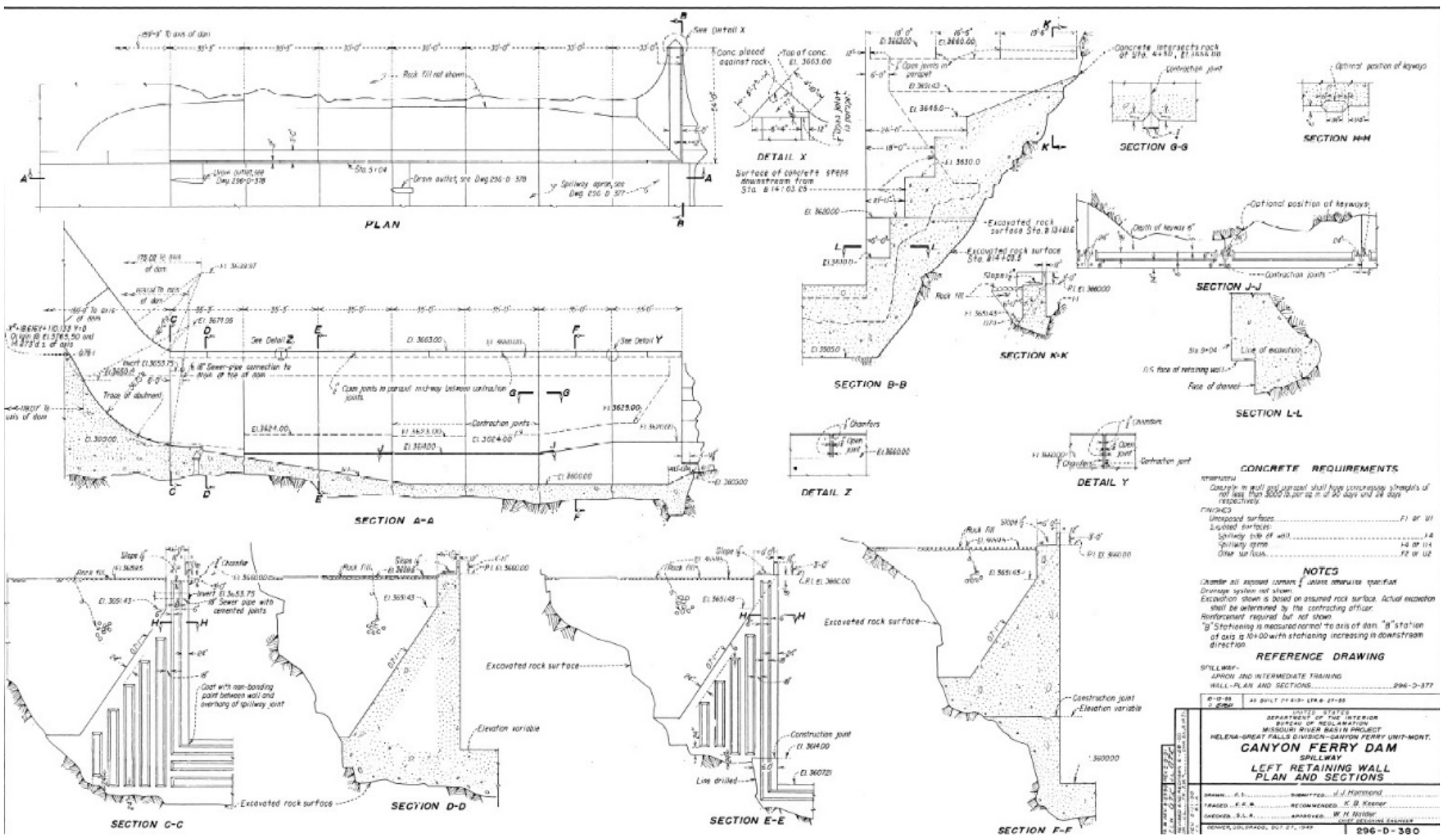

Figure 15. Drawing 269-D-380 "Left Retaining Wall Section and Plane"

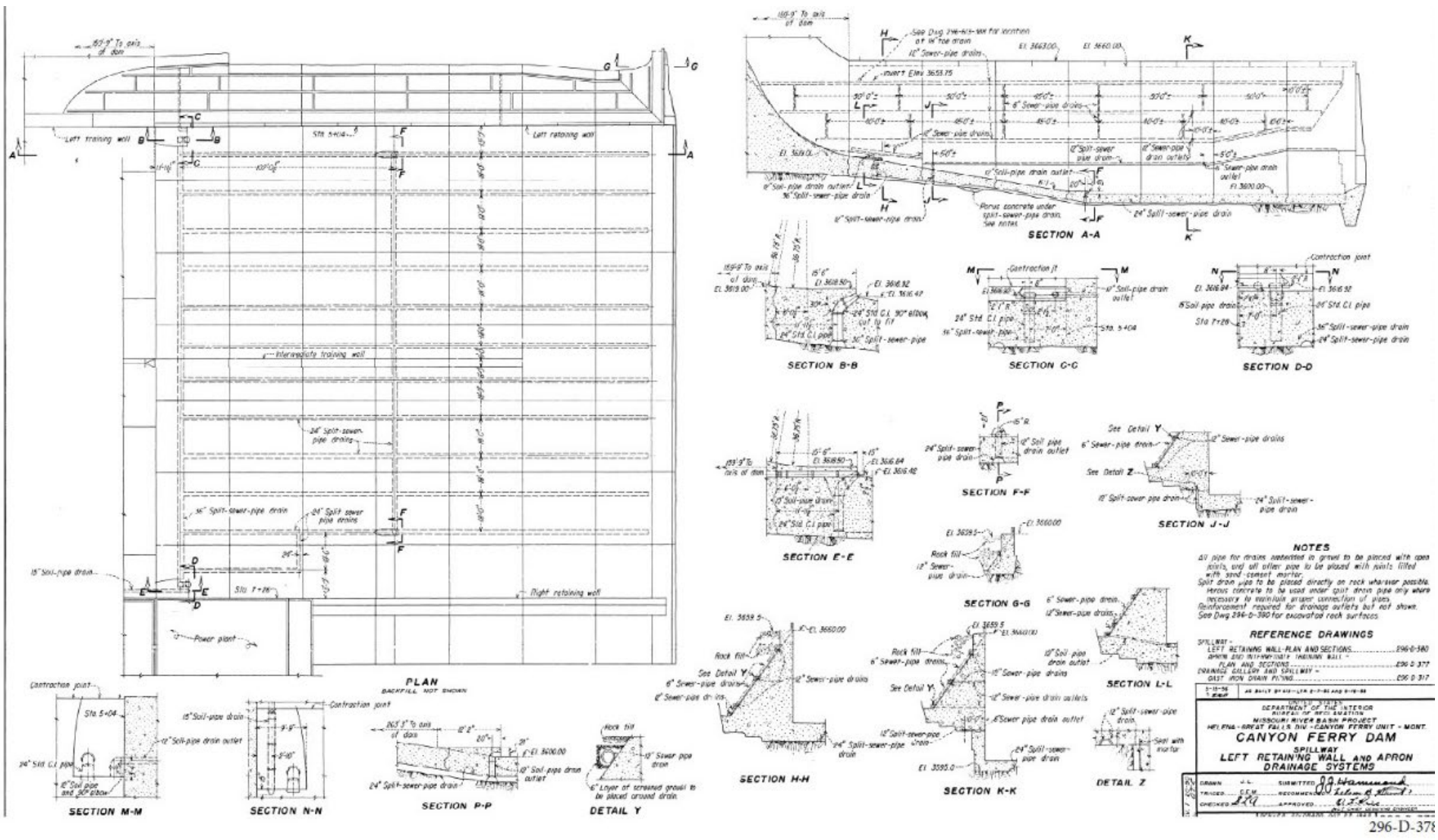

Figure 16. Drawing 296-D-378 "Left Retaining Wall and Apron Drainage Systems".

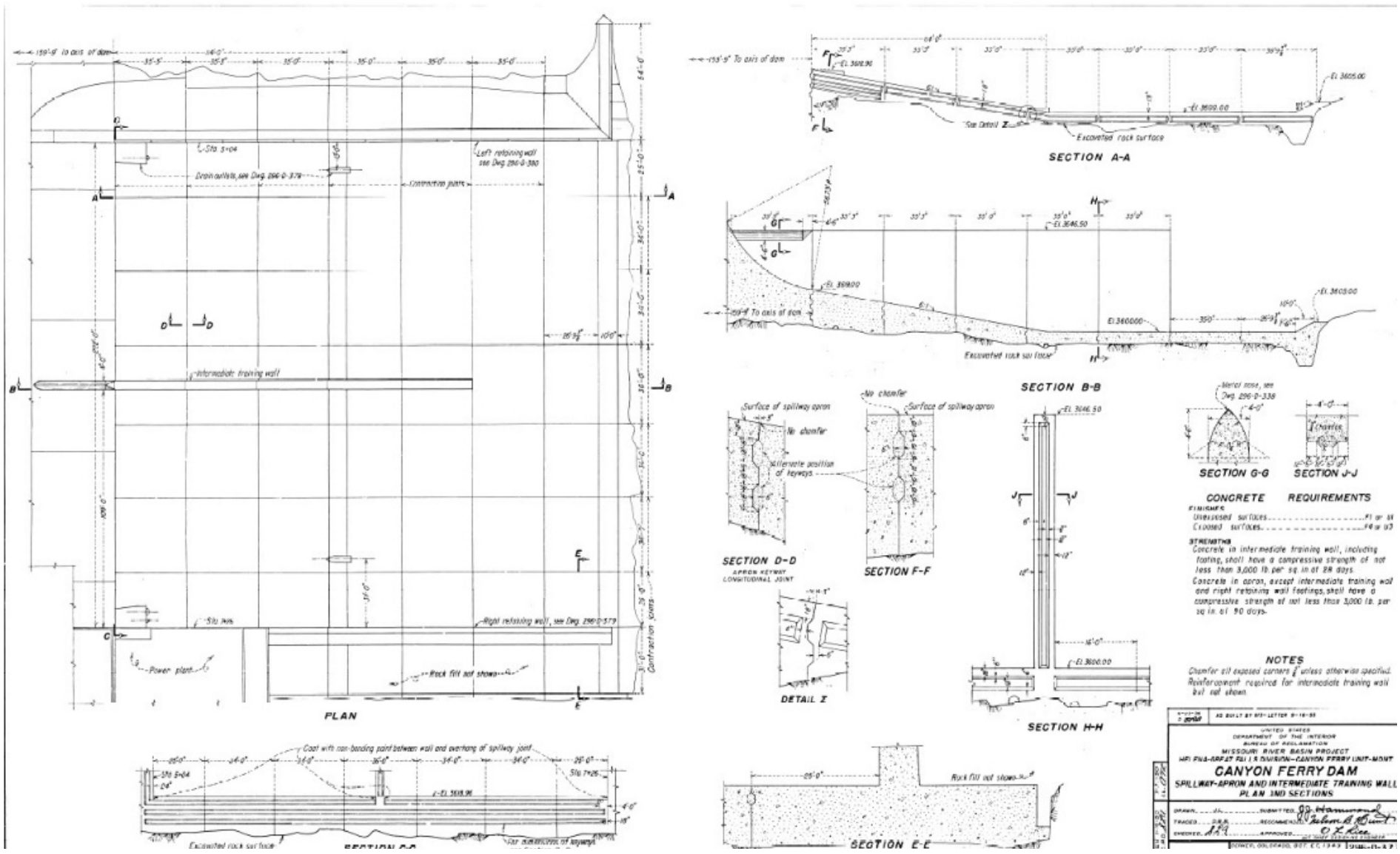

Figure 17. Drawing 296-D-379 "Spillway Apron and Intermediate Training Wall Plan and Sections".

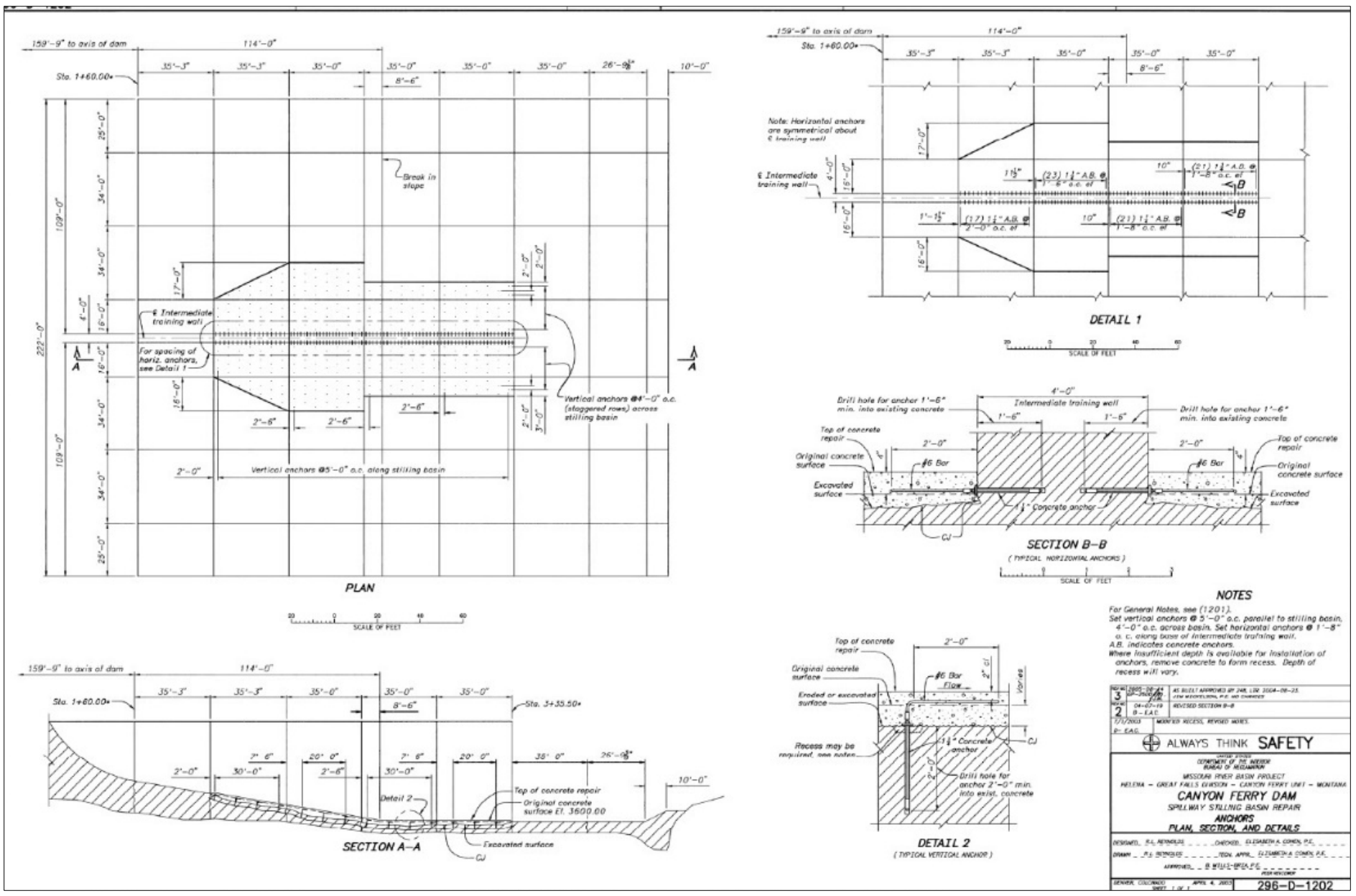

Figure 18. Drawing 296-D-1202 "Anchors Plan Section and Details".

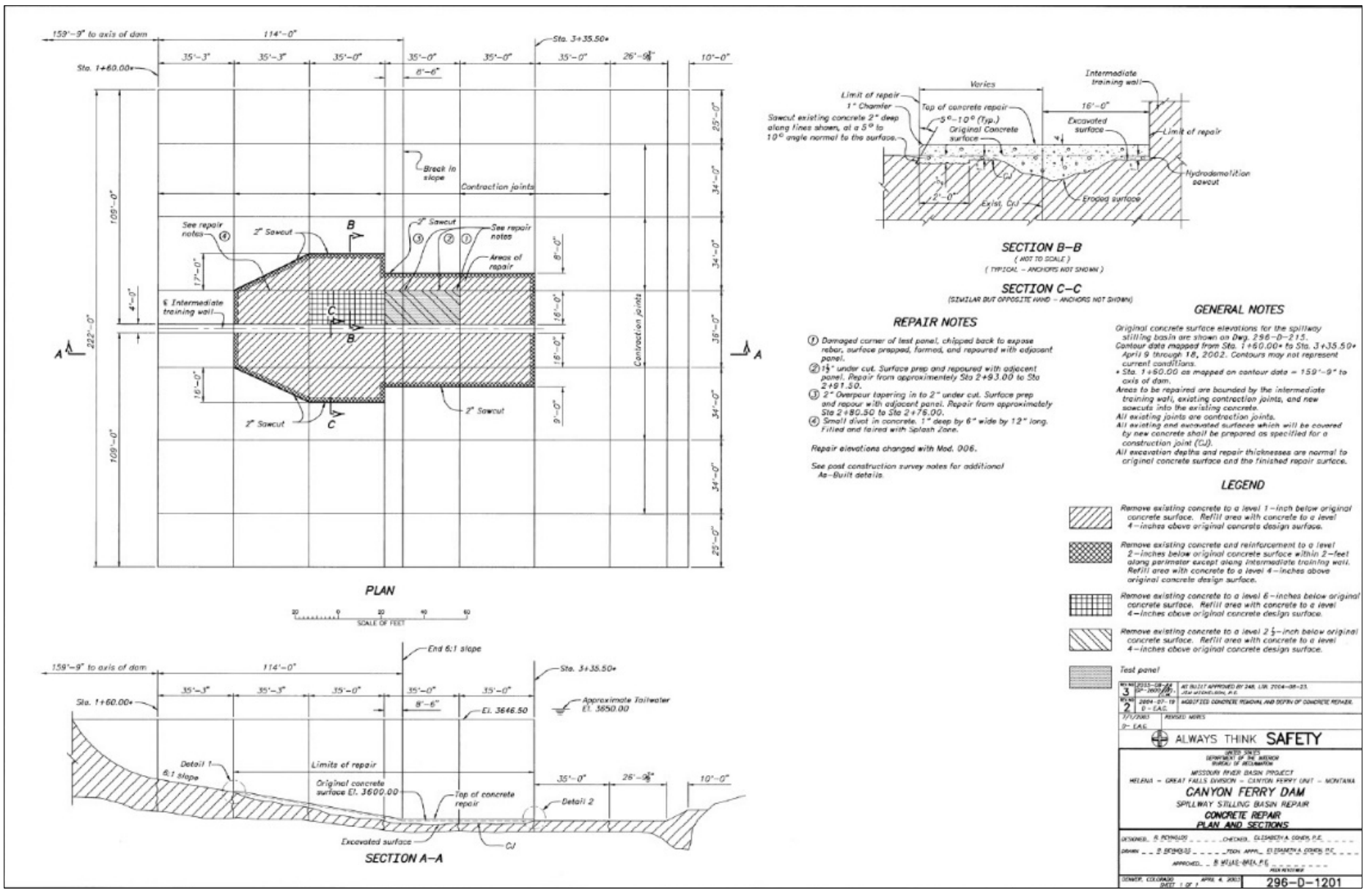

Figure 19. 296-D-1201 "Concrete Repair Plan and Sections".