RECLAMATION

Managing Water in the West

TR-2009-05

Site Visit to Horseshoe Dam Outlet Works and Spillways, AZ

Dates of travel: September 2-4, 2008

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

September 2008

BUREAU OF RECLAMATION
TECHNICAL SERVICE CENTER
TRAVEL REPORT

PRJ-13.00

Code: 86-68130 Date: January 22, 2009

To: Daniel Drake
Manager, Hydraulic Equipment Group (86-68420)

Richard Dent
Supervisory Civil Engineer, Engineering Division, Phoenix Area Office (PXAO-2000)

From: John LaBoon, 86-68130; Tony Wahl, 86-68260, Gary Rood, 86-68420 and Rodney Tang, PXAO -2200

Subject: Site Visit to Horseshoe Dam Outlet Works and Spillways, AZ

1. **Dates of travel**: September 2 – 4, 2008

2. **Places or offices visited**: Phoenix, AZ, Horseshoe Dam and vicinity.

3. **Purpose of travel**: To address two predetermined objectives:

   a) Objective #1. - Evaluate and provide recommendations to address the binding (racking) of spillway gate No. 3 when the gate is being closed under hydrodynamic loading (i.e., spillway is discharging).

   b) Objective #2. - Evaluate and provide both short- and long-term recommendations to address the. –

      i. Vibration/shaking of the outlet works intake tower during operations;

      ii. Sediment/silt build-up around the outlet works intake tower and within the outlet works conduit; and

      iii. The adverse hydraulics associated with specific flow ranges.

4. **Synopsis of travel**: Tony Wahl (86-68260), Gary Rood (86-68420) and John LaBoon (86-68130) traveled to Phoenix, Arizona on the afternoon of Tuesday, September 2, 2008. On the morning of Wednesday, September 3, 2008, Rodney Tang (PXAO-2200) picked up Tony, Gary

- Also discussed, but considered minor friction are: Sticking idlers, pulleys and floats.

- Trunnions creating some additional resistance (although they have been recently inspected and greased).

- Reinforced concrete wall extensions associated with gate No. 1 and No. 3, might cause some additional frictional resistance on the outside edge of each gate.

- Although there are gate guides and seals on the outside edges of both gates No. 1 and 3, only gate No. 3 experiences binding/racking during closure under unbalanced conditions.

- The concrete balance weights have been re-concreted, and recoated, as a safety of dams (SOD) recommendation. (See April 15, 1999 photographs in the September, 1999 Comprehensive Facility Review for Horseshoe Dam). The balance of gate No. 3 may have been affected by this work.

- Stiffening plates and balance weights were added as part of gate modifications. Gate balance was to be preserved (From the 1997 Radial Gate Evaluation conclusions - "Balance weights will be permanently added to each gate arm after modifications, in order to maintain previous gate operating characteristics."), but the balance of gate No. 3 may have been affected by this work.

As an explanation about why gate No. 3 does not bind under balanced conditions, the following is offered: The steel tank counterweight (noted as part #11 in Figure 4) is neutrally buoyant during automatic operation, and partly buoyant when operated by hoist with water loading against the gates (and counterweight chamber partially filled). When operated in dry conditions, the counterweight experiences no buoyant force and thus exerts maximum force to close the gate. This helps to explain why binding is not observed when the gate is operated under balanced conditions (even large binding forces can potentially be overcome by the full force of the counterweight).

- Terminal Structure. - As previously noted, the outlet works was passing baseflow, approximately 100 to 150 ft^3/s (see Figure 6). Periodic surging was observed, which may indicate that there was some unstable flow occurring (probably an intermittent release of air at the nozzle). The original outlet nozzle was a 7-ft wide by 8-ft high rectangular section. Drawing AD-9-325 (see Figure 9) shows that a smaller, circular steel nozzle was added in 1947. Other points of discussion/observation include:

  - Based on drawing B-159-1, see (Figure 10), an air vent or inlet channel constructed from steel plate was added in 1958. The plates form a channel in the crown of the steel nozzle, which appears to provide either air admission or release. At low flows, such as those that were observed, the channel seems to allow a controlled escape of air that has accumulated at the tunnel crown just upstream from the nozzle (the crown of the conduit drops at the upstream end of the nozzle as a result of the 1947 modification, thus blocking downstream air movement along the crown of the pipe). Without this modification, it seems likely that air would be released in a more irregular manner and may significantly disrupt the jet issuing from the nozzle. A deflector plate at the upstream end of this channel suggests a second possible purpose, which is the admission of air near the throat (upstream end) of the nozzle to produce a free surface in the flow through the nozzle extension. The deflector plate appears to have been configured to create a local low-pressure zone that would draw air into the conduit. This may improve the flow out of the nozzle at higher flow rates than those observed. It remains unresolved which of these two purposes the air channel serves; it may even serve both purposes.

  - This is an unusual outlet works design, as the control (regulating) gate is at the upstream end of the tunnel, but the tunnel nozzle actually restricts the flow at large gate openings, thus causing pressurized flow in the tunnel. Normally, Reclamation dams with upstream control gates have free-flow tunnels with supercritical flow.

  - This outlet as originally designed has 113 ft^2 of inlet area at the cylinder gate entrance (fully raised gate = 4 foot opening with 9-ft diameter), 63.6 ft^2 of conduit area just below the gate seat (9-ft diameter pipe), 124.6 ft^2 of flow area through the 12-ft horseshoe tunnel, and 56 ft^2 of flow area at the original nozzle exit (7-ft wide by 8-ft high rectangle). Since the minimum flow area is at the exit, the outlet nozzle controls the flow at maximum gate opening and the tunnel was thus designed to operate in pressure flow. The hydraulic grade line for the tunnel at the design maximum flow rate begins at approximately reservoir water surface elevation at the upstream end and reduces to the nozzle elevation at the exit. This tendency toward pressure flow and outlet control has been increased through the

to maintain an increased water level inside of the hollow cylinder.

- The drain pipe at the outlet of the nozzle is probably clogged with sediment. A grated inlet was found in previous inspections, but the outlet has never been located. A small diameter (perhaps less than 1 inch) valve and outlet pipe are visible just below the access walkway, but their purpose and condition are not known.

- Air Vent. – As has been well documented in past inspections, there is significant release of air (and associated water) from the air vent (see Figure 7) located just downstream from the horizontal elbow in the tunnel. Air and water releases are greatest at intermediate gate openings (200 to 625 ft^3/s referenced in past reports). Baffles were added to the vent pipe in 2004 and 2005 and have helped to reduce the volume of water being discharged. The observed air releases are consistent with the known performance of cylinder gates at partial openings, where they typically entrain air, which is drawn down through the center of the hollow cylinder. As a result, cylinder gates are not typically used as control (regulating) gates. At most Reclamation dams with cylinder gates, they are used as guard gates set either fully closed or fully open. The greatest problem with the current situation at the air vent is the intermittent water discharge, which has the potential to cause erosion and unsafe walking conditions along the path leading to the outlet works control tower. One modification that might further reduce the volume of water released would be to add an enlarged section of pipe at the top of the riser, between the riser and the gooseneck pipe section.

- Intake Tower. – Areas of focus for the inspection of the intake tower (see Figure 8) included:

  - The interior of the cylinder gate was inspected via a bosons' chair. Gary Rood, Rodney Tang and Roger Baker participated in this effort. Overall condition of the cylinder gate was satisfactory, but there was some evidence of corrosion. Specifically, three corrosion conditions were noted along the interior of the gate. Area No. 1: Between approximately elevation 1910 and elevation 1955, some rusting was noted, but overall condition is good (see Figure 11); Area No. 2: Between approximately elevation 1955 and elevation 2000, some rust under coating and some swelling from rusting was noted (see Figure 12); and Area No. 3: Between approximately elevation 2000 to top of gate, there were minor and isolated loss of coating with little rusting underneath.(see Figure 13). All the connection bolts and nuts that were observed were still in very good condition. None of the rusting condition would prevent the gate from being used, but corrosion protection and re-coating would not be out of the question if use of the gate is planned for the long-term (next 50 years).

- There are currently 13 of the 19 levels of the intake tower open from the top to the water/silt line (i.e., the bottom 6 levels are below the water/silt level).

A close-out meeting was held at the end of the day which summarized observations and potential recommendations (see the following section, "**5. Conclusions**" for details). Reclamation and SRP Staff returned to Phoenix during the late afternoon on Wednesday, September 3, 2008. On the morning of Thursday, September 4, 2008, Tony, Gary and John returned to Denver, CO.

5. Conclusions: The following conclusions are in the form of key observations, evaluations and recommendations, which are grouped by objective (noted in the previous section, "**3. Purpose of Travel**"):

a) Objective #1. - Evaluate and provide recommendations to address the binding (racking) of spillway gate No. 3 when the gate is being closed under unbalanced conditions.

- Detecting Unusual Displacements. - To establish baseline conditions for both loaded and unloaded conditions, survey the gates under balanced and unbalanced conditions. The intent is to verify the relative displacements of the gates and the crest structure. To dismiss unusual displacements as a source of the binding (racking), the expectation would be that there would be very small, uniformly varying displacements; along with similar, but opposite displacements for gate No. 1 and No. 3. Possible survey ideas include: Establish fixed position mounts for installation of survey equipment. Start with a base survey station on the left end of the spillway gate structure (easily accessible), or the top of ridge from the right abutment (would be accessible during a flood.). Set up should be before flood or spillway operations or gate exercising. Take measurements at different gate positions during both opening and closing of gate to check targets on top of gate, painted target markers for horizontal travel distances and differential between the right, left and center of the gates. An optional approach would be to install optical survey prisms on the top of gates and add distance measurements. Surveyor could be Reclamation or SRP staff. Expectations would be to verify that there is uniform raising and lower of the gates and there is no set or residual racking in the gate No. 1 No. 3, and No. 2.

- Visual Observation During Operations. – Install horizontal scribe marks on the balance weights (large concrete curved features) for gate No. 3, No. 2 and No. 1. Scribe marks would be placed on outer faces of the balance weights with reference zero mark when gates are closed and no water on them. Also place scribe marks on the side of the balance weights under balanced conditions. The intent is to possibly note a loaded offset measurement during closed and open positions. These scribe marks should be visible from the operation deck. The idea is to easily and quickly observe any differences between the right and left sides of gate No. 3, and any

reservoir bottom) of a radius of 50 to 100 feet, then continuing the dredging to create a mild slope (< 5 degrees or flatter than 1V:12H) for an additional until the top of the present sediment/debris is reached. This should prevent the existing sediment from entering the intake tower, but future sedimentation will still be a problem. For a more permanent solution, a reservoir sedimentation study would have to be conducted to develop alternatives for reducing future problems. Generic examples include upstream check dams, discharge of density currents, reservoir drawdown and flushing, and dredging. As examples of using check dams or barriers, Reclamation's Yellowtail and Altus Dams have highway structures that have trapped sediment in the upper reservoirs and can be easily dredged during low reservoir levels. The mobilization cost for dredging may be significant, so the additional cost of dredging larger volumes and restoring more capacity may not be so great. One key consideration will be where to deposit the dredged sediment. As noted in the following section (Other Topics), any sediment/debris deposal must be limited to upland areas.

- Inspect/repair cylinder gate guides and seat. - Once the previous step is accomplished, an inspection of the lowest gate guides (below elevation 1931) and the cylinder gate seat (about elevation 1909) should be undertaken. Depending on the findings of the inspection, repair/replacement may be warranted. After the cylinder gate base and seat is unwatered/dewatered, lift the cylinder gate to a position that the base and seat ring can be removed from the gate body. Remove the base assembly and seat ring from the gate body and if the base ring is still useable, remove the seat ring from the base assembly and machine and fabricate a new seat. Perform any repairs that may be necessary to the cylinder gate, base ring, seat ring, seat, and outlet tube. Fabricate any new parts, including fasteners, which need replacing. Assemble the seat ring to the base ring and reinstall the finished assembly to the body. Open and close the gate at least three times and check that the seat ring is in complete contact with the gate seat.

- Replace/modify outlet works features. - In lieu of the previous step of repairing/replacing the lowest gate guides and gate seat, a more expensive, but more reliable and less risky alternative would be to replace the existing intake tower with a new tower that would be part of an overall rehabilitation alterative. This rehabilitation alternative could involve: replacing/modifying the intake tower (if a new tower is the best alternative, then gates could be placed at different elevations which would provide selective level withdrawal or just the possibility of withdrawing water at different locations as the reservoir is emptied. These gates would serve as emergency or guard gates in that they would either be fully open or fully closed.); providing two gates/valves in series (both guard and regulating) at the intake tower and/or downstream (such as a gate chamber); and

works. This rehabilitation alternative could involve: replacing/modifying the intake tower (if a new tower is the best alternative, then gates could be placed at different elevations which would provide selective level withdrawal or just the possibility of withdrawing water at different locations as the reservoir is emptied. These gates would serve as emergency or guard gates in that they would either be fully open or fully closed.); providing dual gate/valve controls (both guard and regulating) at the intake tower and/or downstream (such as a gate chamber or control structure); and replacing/modifying the terminal structure (such as removing the steel nozzle and armoring the exit channel). Enhancing operational reliability, including remote operations, along with minimizing maintenance efforts would be the focus.

iii. The adverse hydraulics associated with specific flow ranges. –

- Short-Term recommendations include. -

  - Based on some preliminary hydraulic analysis performed by TSC staff, it is recommended that:

  - Improve cylinder gate operations. – Operation at small gate openings should be avoided when possible. At gate openings much less than 1 ft, the potential for cavitation damage around the gate seat and air entrainment into the tunnel are highest. Gate openings at or around 1 foot are likely to produce shifting hydraulic control and irregular flow conditions, with increased structural vibration and increased discharge of air and water through the air vent pipe. Vibration problems probably continue up to larger gate openings (up to 600 ft^3/s is reported, which corresponds to different gate openings depending on reservoir level); SRP's past experience is probably the best guide for establishing operational limits for preventing excessive vibration.

  - Reduce air vent surging. - The discharge of water at the air vent pipe might be further reduced by adding an enlarged section of pipe at the top of the riser, between the riser and the gooseneck pipe. Slugs of water would expand in the larger pipe, allowing the air to bypass them, and the water could then fall back into the riser.

- Long-Term recommendations include. –

  - Control sediment in conduit. - Based on some preliminary hydraulic analysis performed by TSC staff, it is suggested that a control structure with dual gates (guard and regulating) should be evaluated as one of several long-term

- Permitting. – Reclamation's PXAO staff provided the following related to permitting for the clean water and endangered species acts.

  Clean Water Act. - After reviewing the discussions regarding revisions made to the 2007 Nationwide Permits,[1] Sandy Eto concluded there is one Nationwide Permit (NWP) that may apply to the intake tower and/or outlet works activities, depending upon whether or not certain conditions are met. Following is a brief description of NWP No. 3, as it relates to the currently proposed project. A copy of the complete description and general conditions for using this NWP are attached.

  The Nationwide Permit No. 3, Maintenance permit covers the repair, rehabilitation, or replacement of any previously authorized, currently serviceable, structure, or fill; or any currently serviceable structure or fill that was completed before December 18, 1968. The structure or fill is not to be put to uses that are different from what was specified or contemplated originally or in the most recently authorized modification. Minor deviations in the structure's configuration including those due to changes in materials, construction techniques, or current construction codes or safety standards are authorized.

  This NWP also authorizes the removal of accumulated sediments and debris in the vicinity of and within existing structures (including water intake structures), and the placement of new or additional riprap to protect the structure. The removal of sediment for a waterway is limited to the minimum necessary to restore the waterway in the immediate vicinity of the structure, but cannot extend further than 200 feet in any direction from the structure. Maintenance dredging to remove accumulated sediments blocking or restricting outfall and intake structures does NOT have a length restriction.

  All dredged or excavated materials must be deposited and retained in an upland area unless otherwise specifically approved by the district engineer under separate authorization. The placement of riprap must be the minimum necessary to protect the structure or to ensure the safety of the structure. Any bank stabilization measures not directly associated with the structure will require a separate authorization from the district engineer.

  The NWP also authorizes temporary structures, fills, and work necessary to conduct the maintenance activity. Appropriate measures must be taken to maintain normal downstream flows and minimize flooding to the maximum extent practicable, when

1 See http://www.usace.army.mil/cw/cecwo/reg/nwp_final.htm.

- Regarding use of the reservoir for equipment access, I strongly recommend that initial discussions be undertaken as early as possible with SRP and the consultant who prepared the HCP (Craig Sommers, ERO Resources, 303-830-1188) to determine mobilization/access options and restrictions that need to be taken into consideration, vis. dam operation modifications to alter reservoir water levels.

- Comprehensive, staged, long-term plan. - To take care of all the concerns with some additional data collection and construction sequenced in a staged approach.

  - Create permanent access to the tunnel and cylinder gate seat. With the current outlet discharge features, the tunnel is always full of water and silt. Changing the flow to upstream control, and modifying the exit nozzle so that the tunnel operates in gravity flow would cause the tunnel to empty itself (as much as possible) when the cylinder gate is closed. This scope of work may be possible to construct in a season with the current gate condition, with temporary leakage reduced. This would allow better and periodic access to the tunnel, and better, but limited access (the gooseneck sump would need to be unwatered) to the seal area. The access would allow for better evaluation of the seat and repair options.

  - If repair of the cylinder gate seat is not feasible, another stage would be the installation of a gate chamber or control structure (dual control gates/valves in series) and bypassing any leakage flows from the existing cylinder gate during construction.

  - Next available season would allow for either rebuilding/rehabilitating the cylinder gate, or removal of cylinder gate and use the existing intake tower without a gate. Sediments and debris accumulation around the tower may not be a concern then. New gate chamber or control structure gates/valves will need to pass existing debris load.

  - Other contracts for construction may be required.

6. Action/correspondence initiated: As previously agreed to with SRP, based on this site visit and subsequent evaluations, this travel report has been prepared and transmitted to SRP. The intent is to provide recommendations to address/mitigate issues associated with operating the spillway gate No. 3 and provide short- and long-term recommendations to address/mitigate issues associated with operating the outlet works.

7. Client Feedback: Roger Baker conveyed his and SRP's appreciation for Reclamation involvement.

SIGNATURES AND SURNAMES FOR:
Horseshoe Dam Outlet Works and Spillway Inspections

Travel to: **Horseshoe Dam, Arizona**

Date or Dates of Travel: **September 2-4, 2008**

Names and Codes of Travelers: **John LaBoon, 86-68130; Gary Rood, 86-68420; Tony Wahl, 86-68460); Rodney Tang, PXAO-2200**

Travelers:

John LaBoon	1/22/09 Date
Gary Rood	1/26/09 Date
Tony Wahl	1/26/09 Date
Rodney Tang	2/2/09 Date

Noted by:

Dan Drake Manager, Hydraulic Equipment Group, TSC	6 Feb 09 Date
Richard Dent Supervisory Civil Engineer, Engineering Division, PXAO	2-3-09 Date

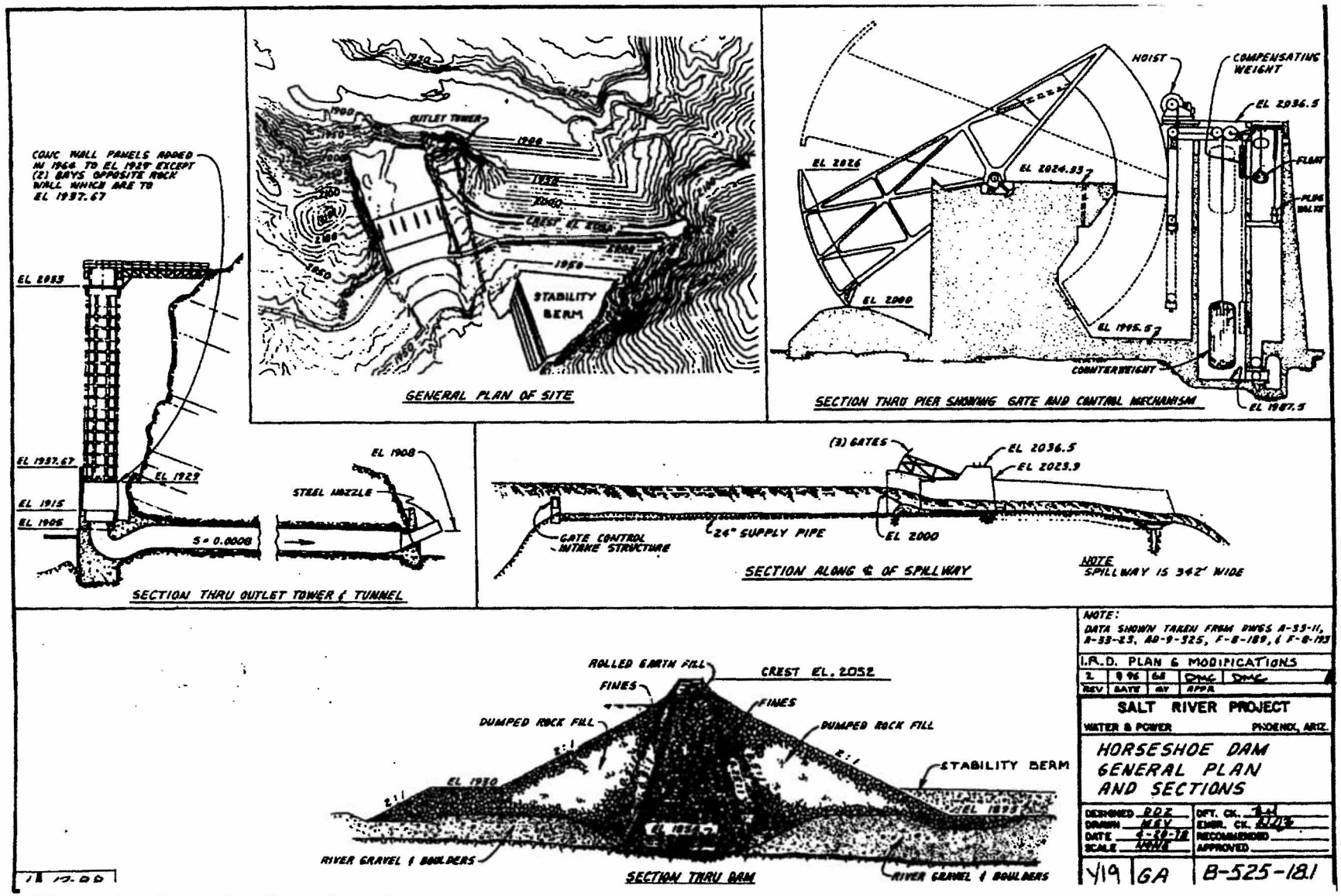

Figure 1. – Horseshoe Dam Overview – General Plan of Site; Section of Embankment Dam; Section along Centerline of Spillway; Section thru Spillway Pier showing Gate and Control Mechanism; Section thru Outlet Works.

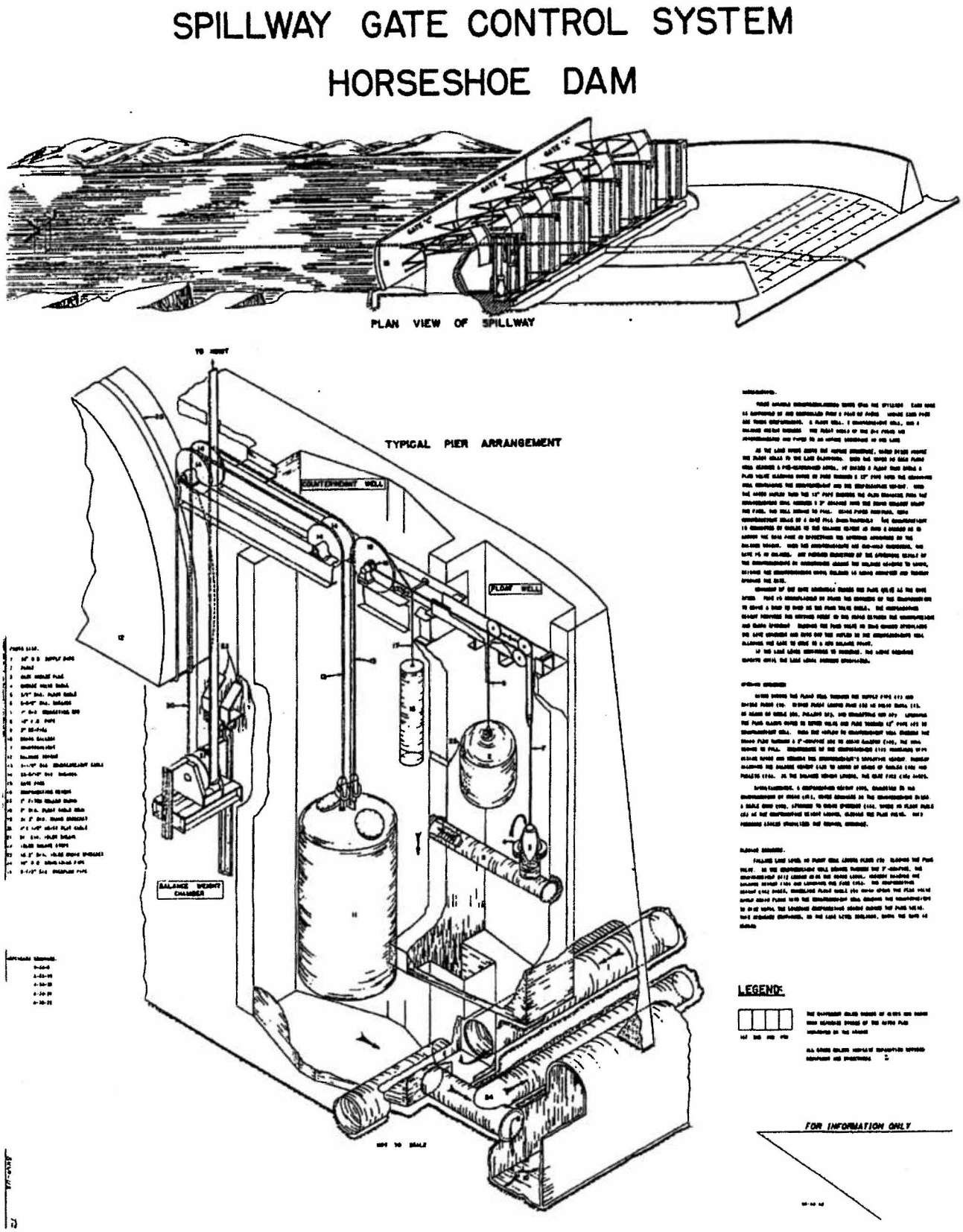

Figure 4. – Horseshoe Dam Service Spillway – Isometric View of Spillway Gate Control System.

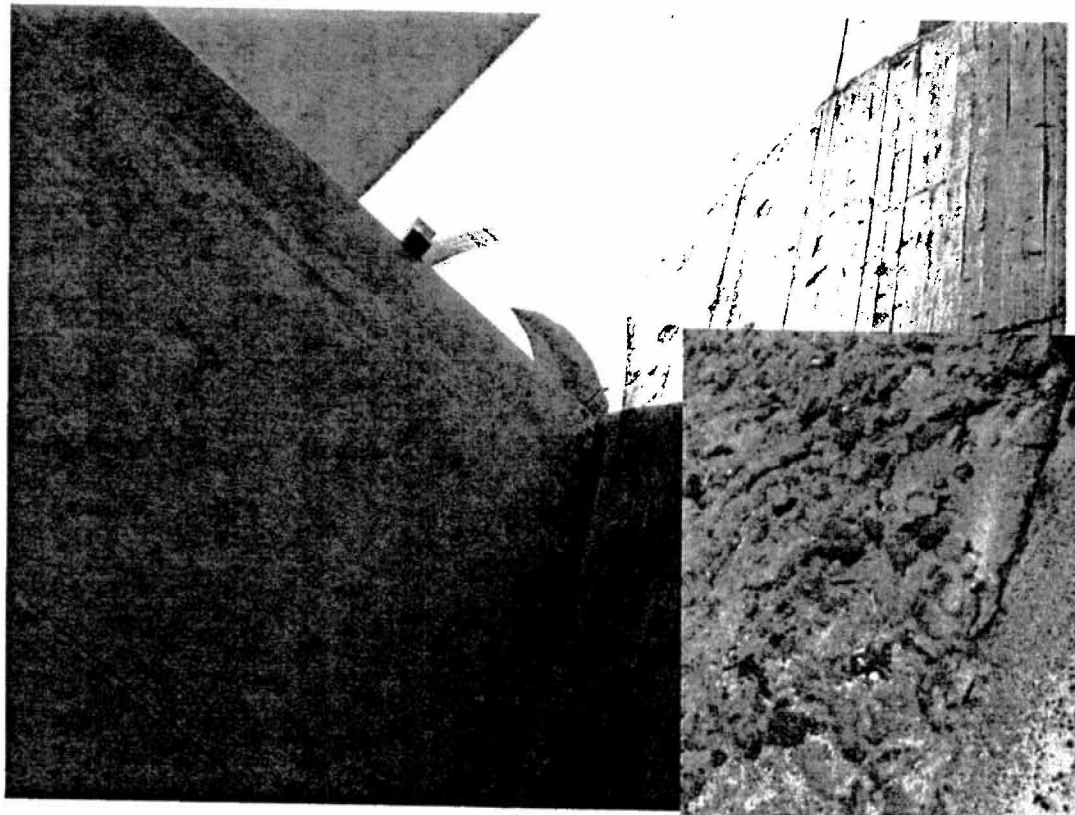

Figure 5c. – Horseshoe Dam Service Spillway – Another view of spillway gate No. 3 and end wall which contains the gate guide and seal and end wall extension which contains a "non-contact slot for the raised gate..

Figure 5d. – Horseshoe Dam Service Spillway – Close-up view of spillway gate No. 3 the gate guide and seal.

Figure 7. – Horseshoe Dam Outlet Works Air Vent.

Figure 8. – Horseshoe Dam Outlet Works Intake Tower – View from embankment dam crest.

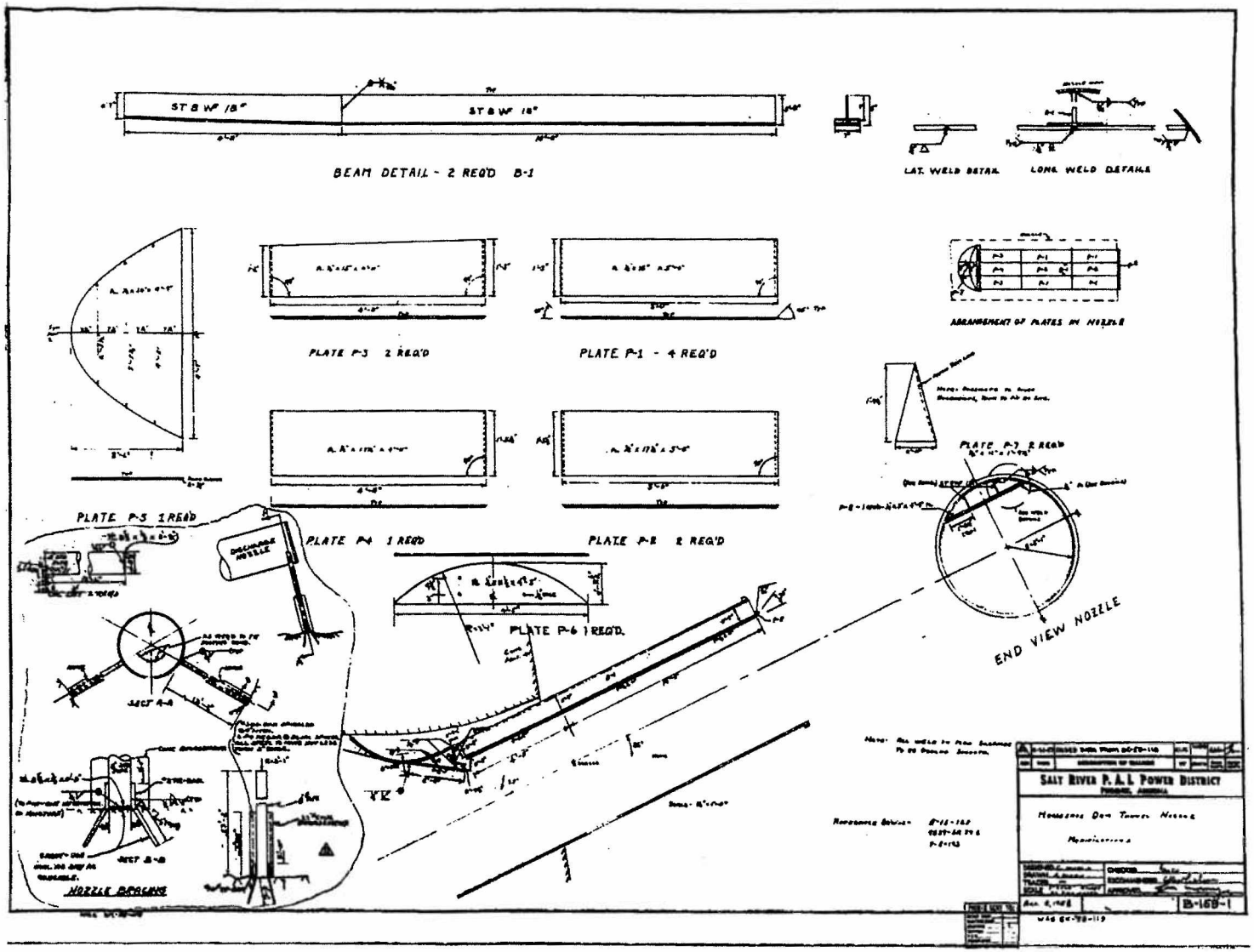

Figure 10. – Horseshoe Outlet Works Tunnel Portal Nozzle (Drawing B-159-1) – Channel formed in crown of steel nozzle, installed in 1958.

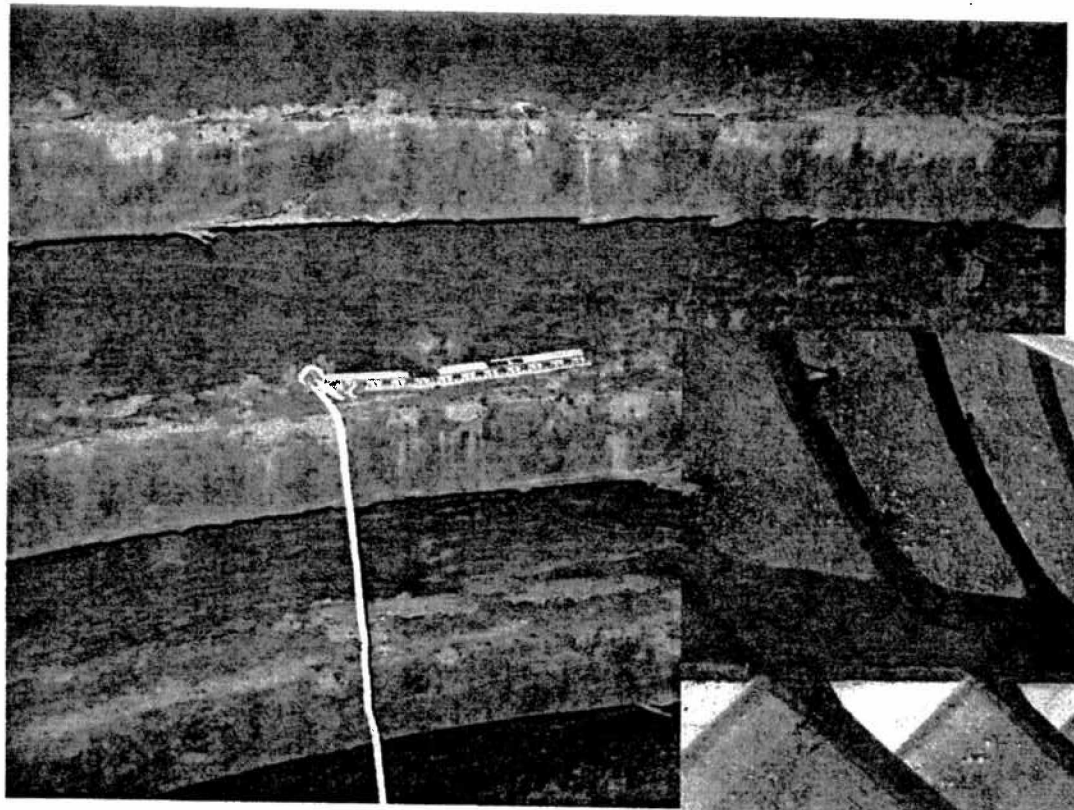

Figure 13. – Horseshoe Dam Outlet Works Intake Tower Cylinder Gate Interior– Area 3: Approximately Elevation 2000 to Top of Cylinder Gate.

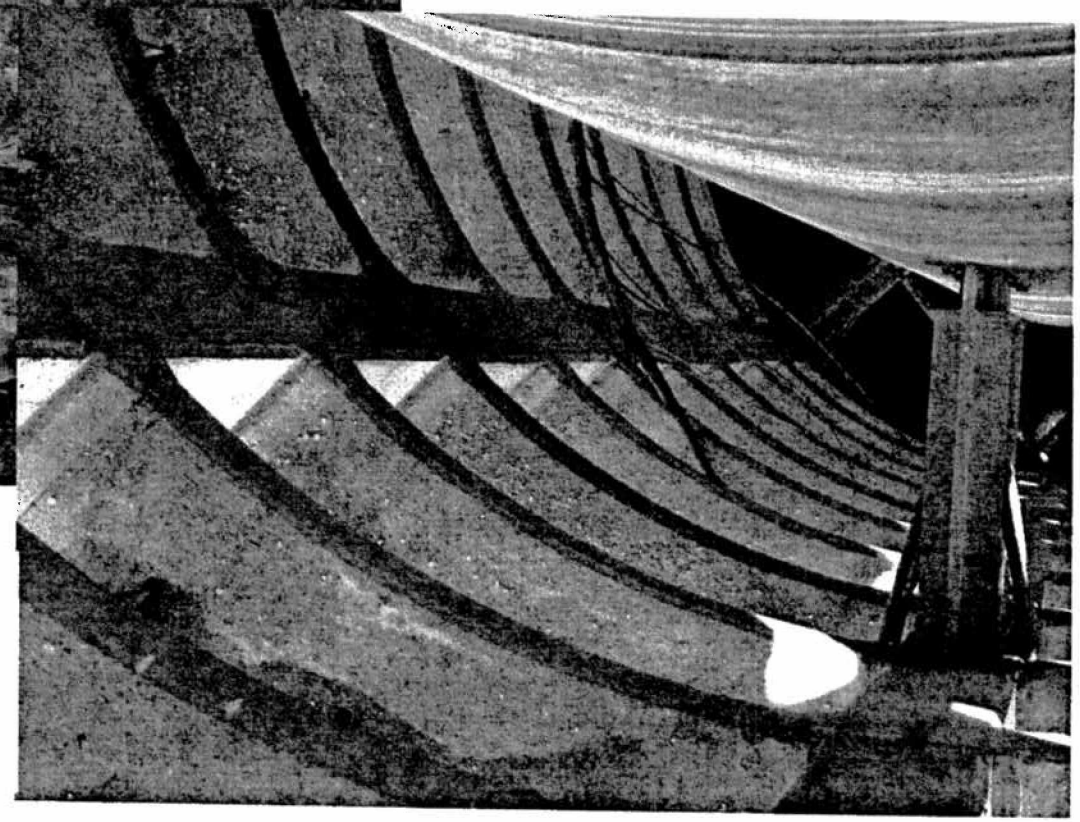

Figure 14. – Horseshoe Dam Outlet Works Intake Tower Cylinder Gate Guides– Visible gate guides in foreground below elevation 2009 and in background above 1951. Not shown are roller guides below 2028 and gate guides below RWS and sediment below elevation 1931.

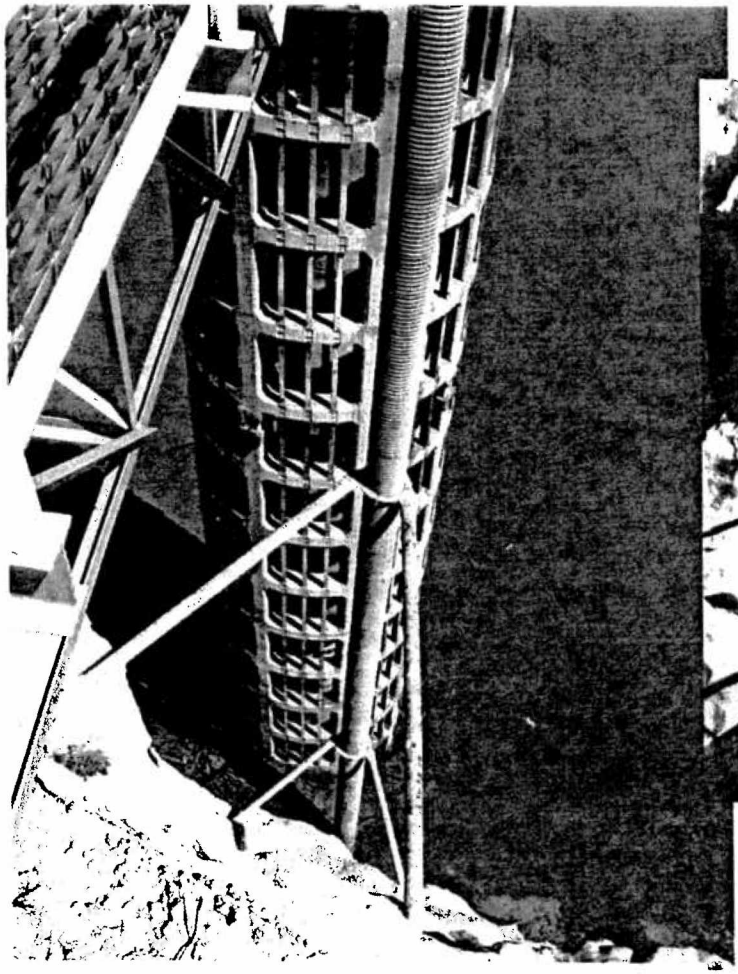

Figure 16a. – Horseshoe Dam Outlet Works Intake Tower Inflow of water appears to be limited to Northeast side of intake tower...

Figure 16b. – Horseshoe Dam Outlet Works Intake Tower Sediment and debris appears to be above RWS on cliff side of intake tower, suggesting that there is limited or no inflow on this side of the intake tower...