WATER OPERATION AND MAINTENANCE BULLETIN

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This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Bureau of Reclamation personnel and water user groups in operating and maintaining project facilities.

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***Cover photographs**: (Left column) Underwater repair; (Right column) Underwater inspection.*

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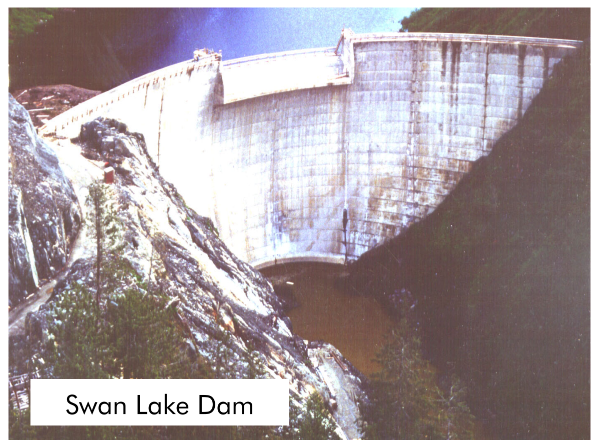
REPAIR OF A LEAKING CONDUIT THROUGH THE SWAN LAKE ARCH DAM NEAR KETCHIKAN, ALASKA

by John K. Magee, P.E., R&M Consultants, Inc.;
James H. Rutherford, P.E., Acres International; and
Donald E. Bowes, P.E., Consulting Engineer

Project Description

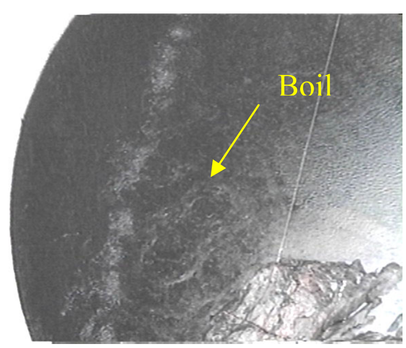
The Swan Lake Hydroelectric Project, owned by the Four Dam Pool Power Agency (FDPPA), is operated and maintained under agreement by Ketchikan Public Utilities (KPU). At the time of the leak repair described in this paper, the project was owned by the Alaska Energy Authority (AEA) and operated by KPU. The project began service in June 1984. It is located approximately 23 air miles north-northeast of Ketchikan, Alaska. A 174-foot-high concrete arch dam located on Falls Creek forms the Swan Lake Reservoir. The dam has a crest length of 430 feet and an uncontrolled, 100-foot-long ogee spillway with a crest at El. 330.0. The project's 11-foot-diameter concrete-lined power tunnel has an overall length of 1,922 feet to the 22.5 MW powerhouse at tidewater.



Swan Lake Dam

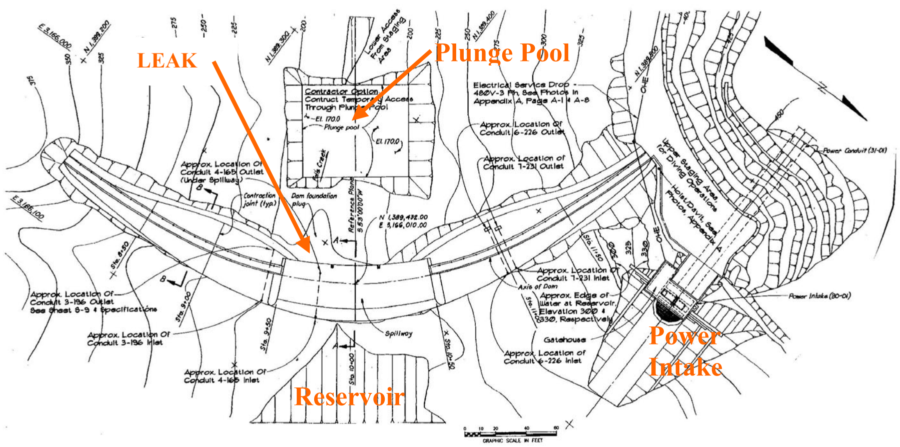
Leakage Incident

The Swan Lake Dam had been spilling for about 6 weeks between June 15 and July 31, 1999. On August 10, 1999, the on-site project staff noted an unusual increase in flow from the spillway plunge pool and a surface "boil" in the plunge pool at the dam. The KPU operations center was immediately notified, then reported to AEA in Anchorage and the FERC Portland Regional Office, and then the Emergency Action Plan was implemented. AEA contacted Donald E. Bowes, P.E., the FERC Dam Safety Independent Consultant, to perform an inspection of the conditions.



Boil in plunge pool.

A weir was installed in Falls Creek downstream from the plunge pool to monitor the flow, which was about 4 cfs. Foundation drains and dam/foundation groins were monitored, and no changes in seepage or pressures were noted. Surveys to detect if there was any unusual dam movement revealed no new movements, and a new hydrographic survey showed no change in bottom contours near the upstream face of the dam. The leakage flow was now reported as murky from sand boiling up in the plunge pool. There was great concern that the leakage was through a joint in the bedrock beneath Block 5 at the right side of the plunge pool.



Plan – Swan Lake Dam.

Construction photo showing conduit locations.

On August 12, 1999, Mr. Bowes coordinated an underwater diver inspection of the leakage area. It was determined that the source of the leak was an 18-inch CMP conduit with a steel plate over its outlet end located in a void formed by grout-cemented construction debris at about El. 165 beneath the left side of Block 4. The diver reported the flow was emanating from a corroded hole and slot in the right upper quadrant near the top of an 18-inch-diameter CMP, and the jet of water from the leak was directed across the plunge pool from left to right where it created a boil in line with Block 5. Post-inspection preliminary review of construction documents established that the 18-inch diameter CMP was installed during construction of the foundation plug concrete in the deep, narrow stream channel beneath Block 4 of the dam.

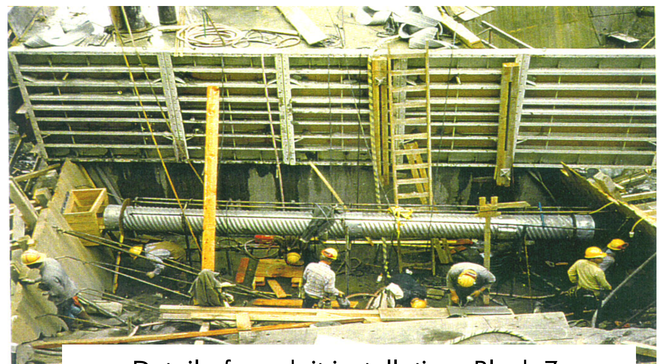
After the underwater inspection, a review of available construction records found that four 18-inch CMP conduits had been placed during construction for the temporary use of the contractor. The four conduits were to have been sealed and abandoned in place (following an approved methodology) as dam construction progressed. The four temporary conduits were located as follows:

- Block 4, El. 165; in foundation concrete reported grouted for closure. A shop drawing showed the concept and approved details for closing and grouting the CMP.

- Block 3, El. 196; in foundation concrete reported as grouted for closure. No shop drawings were available.

- Block 6, El. 226; in dam concrete. No information was available.

- Block 7, El. 231; in dam concrete. Reported as filled with concrete.



Detail of conduit installation, Block 7, elevation 231.

Review of the construction record documents determined that a procedure had been designed and submitted for abandonment of the 18-inch CMP conduits. An approved shop drawing submittal for the procedure was included in the record documents.

Action Plan

Based upon the initial underwater inspection observations of the downstream area and a review of construction records, recommendations for action were as follows:

- Repair the leaking conduit as soon as reasonably possible

- Continue to monitor leakage flow

- Inspect upstream ends of the four conduits using a remotely operated vehicle (ROV) if possible

- Select and retain a design engineer for the repairs

- Develop repair concept and review with FERC

- Prepare design and construction contract documents for the repairs to the leaking conduit and the other conduits, if required

The four conduits were assigned nomenclature based on elevation and block location (i.e., the conduit at Block 4, El. 165 is Conduit 4-165. Construction photographs indicated that the typical detail for the inlet and outlet ends of the four temporary conduits to be abandoned in place was a square block-out 18 to 24 inches deep, with the conduit end protruding about 8 inches into the block-out. The conduits were to be fitted with fabricated steel flap gates and infilled with cement grout or concrete and the block-outs concreted flush with the structure concrete surface.

At the conclusion of the initial investigation, AEA engaged Mr. Bowes to serve as Owners Representative, R&M Consultants, Inc. (R&M), with sub-consultant Acres International (Acres) to further investigate the leak, design repairs, and provide on-site construction engineering services.

Underwater Inspection

CAN-DIVE was engaged to provide underwater inspection services for the upstream end of the four 18-inch CMP conduits. Depths to the features to be inspected varied from about 70 to 170 feet, with a reservoir water surface elevation of 330 feet. CAN-DIVE deployed their Phantom HD ROV for the inspection of the upstream ends of the four conduits on September 7, 1999, and an attempt was made to inspect the downstream area from which the leakage was issuing on September 8, 1999. The upstream inspection activity was successful, but the downstream inspection was aborted because the ROV could not gain access to the leak location, as construction debris was preventing access.

ROV being deployed.

Underwater Inspection Results

The ROV inspection showed that Conduit 4-165 was not abandoned as shown on the approved shop drawing.

The upstream end of Conduit 4-165 was found to be located in a block-out in the concrete with a flat circular steel plate over the end of the CMP. The steel plate was neither galvanized nor coated to prevent corrosion. As-built documents seemed to indicate Conduit 4-165 inlet block-out had been infilled with concrete.

It was found that back-to-back steel channel walers anchored to foundation concrete with form bolts and a pipe stub held the steel plate against the CMP.

Conduit 4-165 upstream end, view from mid-height right side of block-out.

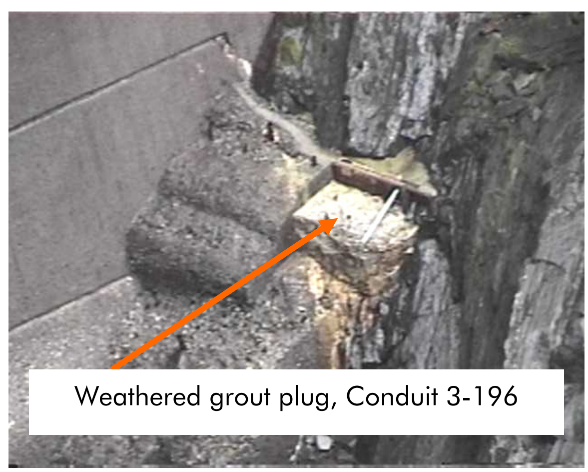
There was a corroded hole and a gap between the plate and the end of the CMP in the upper left-top quadrant into which the leakage was flowing. A significant water velocity could be seen in the video images taken via the ROV.

The upper photograph to the right shows a grout return line above the waler system. The grout line penetrates the steel end plate visible in the top half of the photograph behind the waler.

Conduit 4-165 upstream end, view from left lower side of block-out.

The photograph immediately to the right shows the end plate behind the waler system as viewed from the lower left quadrant of the block-out in the dam foundation.

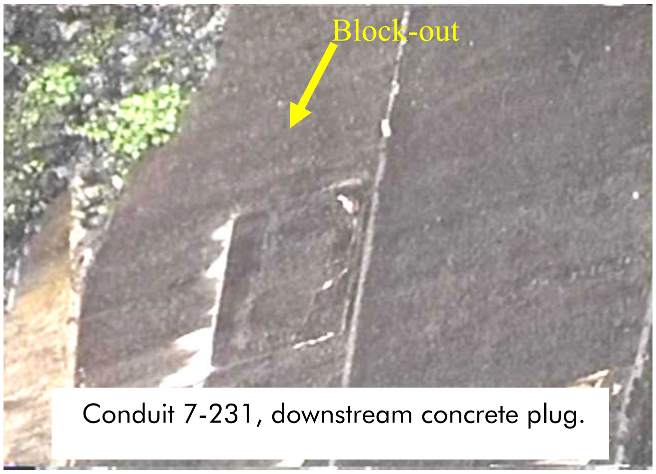
The ROV was unable to inspect the downstream end of Conduit 4-165, as construction debris prevented access. ROV inspections of the other construction conduits are summarized below:



Weathered grout plug, Conduit 3-196

Conduit 3-196: A rectilinear concrete block on the foundation extending about 4 feet out from the dam face was observed at the upstream end of the conduit. It was assumed that the conduit had been encased in this block. Remnants of grout pipes indicated it had most likely been grouted. There were no indications of structural deficiencies in the upstream concrete encasement. The downstream end of Conduit 3-196 also had about a 3-foot concrete extension, and it was assumed that the downstream end of the conduit was encased in this extension. In addition, a short cement grout plug/cap extended beyond the concrete plug approximately 3 feet and possibly encapsulated the end of the conduit. It was not known if the conduit ended within the concrete plug or the grout plug/cap. The grout plug/cap was heavily weathered.

Conduit 6-226: No evidence of the upstream end of the conduit was observed, but the ROV inspection did indicate the possible presence of a 30-inch square concrete-filled block-out with what appeared to be cut off grout pipes. The downstream end of the conduit installation is faintly visible on the surface of the dam by evidence of a concrete backfilled block-out. Neither the upstream nor downstream end areas showed evidence of leakage or structural deficiencies.



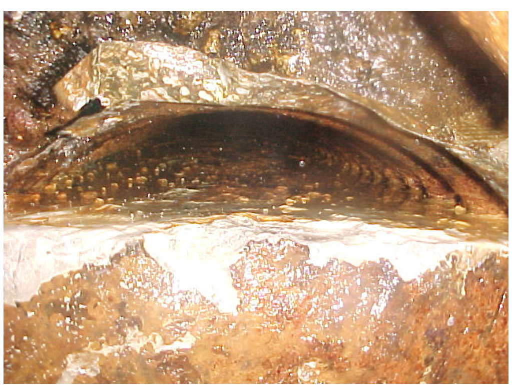
Conduit 7-231, downstream concrete plug.

Conduit 7-231: No evidence was found of a block-out at the upstream end of the conduit, but the ROV inspection showed what were believed to be remnants of cut off grout pipes.

The downstream end of the conduit is clearly visible on the surface as an intact concrete backfilled block-out. Neither end of the Conduit 7-231 block-out location showed evidence of leakage or structural deficiencies.

Conduit 4-165 Leak

The leakage from Conduit 4-165 was found to be through a void in the cement grout infill about 3 inches high at the CMP crown. The effective cross-section of the void was about that of a 4-inch pipe. Whether the grout void was washed out by the leakage or resulted from settlement of the grout infilling before it set is unknown.



Void in Conduit 4-165, looking upstream.

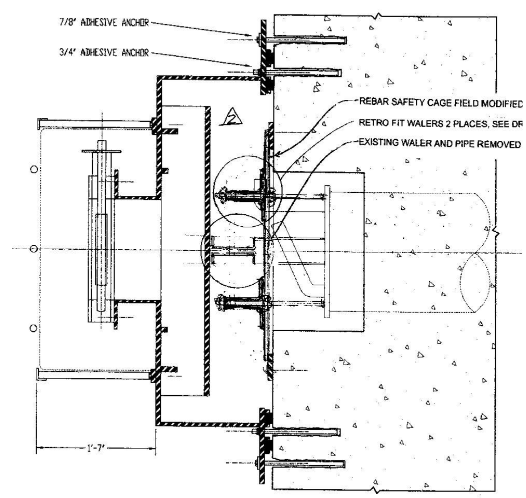
It is believed that the unprotected conduit extensions within the upstream and down-stream block-outs exposed the conduit to corrosion on the outside. The downstream block-out was only about 6 inches deep, and the conduit extended to the structure concrete surface, exposing the conduit to potential physical damage from boulders in the plunge pool. The void on the inside of the conduit also exposed the pipe wall to corrosion.

It is hypothesized that the extensive period of spill between June 15 and July 31 were of such magnitude that a turbulent flow condition was created in the plunge pool. The turbulent flow may have caused sand, gravel, cobbles, and boulders to impact the exposed downstream end of Conduit 4-165, initiating a rupture of the CMP wall. This likely resulted in loss of integrity in the upstream exposed end of the conduit. The leakage flow through the conduit could have actually initiated any time subsequent to June 15, 1999, when the reservoir began the spill period.

Concept Development and Design

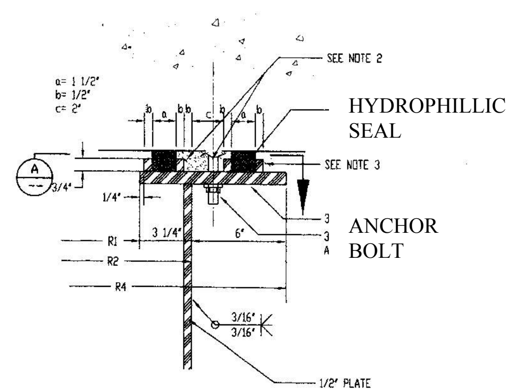
The concept for the leak repair required that divers be able to safely implement the repair and that the flow into Conduit 4-165 be stopped at the inlet with a Leak Closure Bulkhead designed to fit over the existing block-out and waler system holding the steel cover plate on the conduit.

The bulkhead base seal system was designed for high reliability, as only one opportunity was available to seal it to the dam face. Once in place, it would be impossible to remove and reset. It was assumed that the sealing surface on the concrete foundation of the dam would have to be reasonably planar and have no voids or rock pockets in the area contacted by the bulkhead seal. The Leak Closure Bulkhead was designed as a cylindrical section with a base flange containing the seal system and a flat plate top with a flow control valve. Grout valves were provided at the top and bottom of the cylinder.

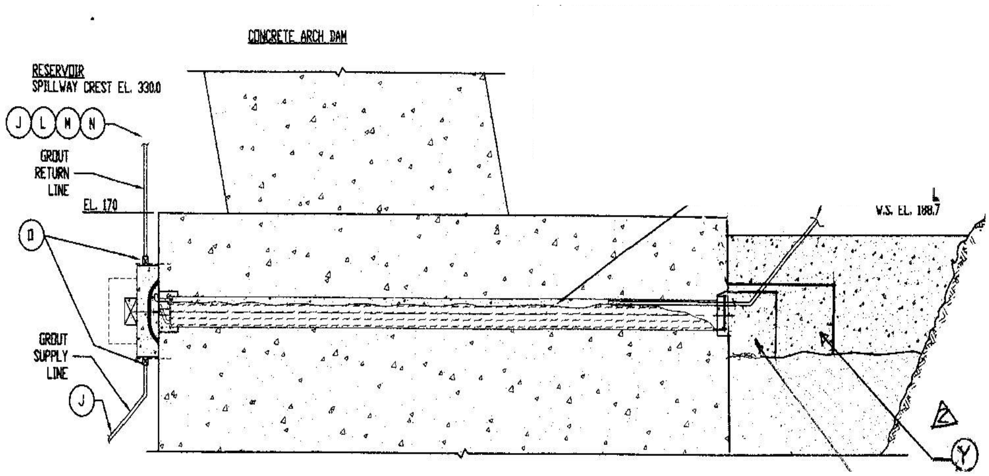


Section through bulkhead in place.

To ensure sealing of the bulkhead to the face of the concrete dam foundation plug, a seal design using two compressible hydrophilic rubber seals in channels at the outer and inner radii of the base seal with a swellable hydrophilic sealant paste between the rubber seals was used. Adeka Ultra Seal was the manufacturer of the hydrophilic seals and paste. The seals were designed to compress ½ inch total before the base seal rings contacted the concrete surface. This accommodated minor irregularities in the concrete sealing surface.



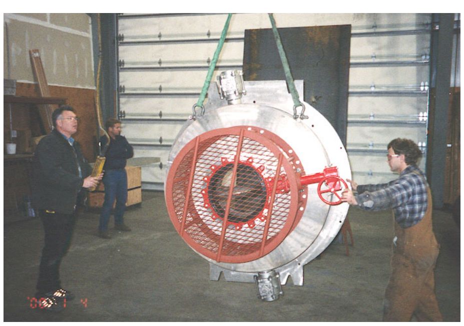
Bulkhead seal detail.



Section through Conduit 4-165 showing leak closure and grouting solution.

To safely install the bulkhead, a safety rebar cage to protect divers was provided that also served as an installation template with centering lugs to mechanically guide the bulkhead accurately into place. Removal of the outer portions of the existing walers holding the end plate on the conduit inlet was required to minimize the size of the bulkhead. Also, a 16-inch-diameter butterfly valve was provided on the face of the bulkhead for flow control and to pass the leakage flow rate while maneuvering the bulkhead into position. This would allow controlled contact with the concrete seal surface, little or no impact, and minimal danger to the divers. The valve would be left open until the hydrostatic pressure could seat and hold the bulkhead in position and until pre-installed anchor bolts could be secured. Additional control for the mating of the bulkhead with the concrete seal surface was ultimately accomplished by contractor-installed jackscrews made of 3/4-inch threaded rod.

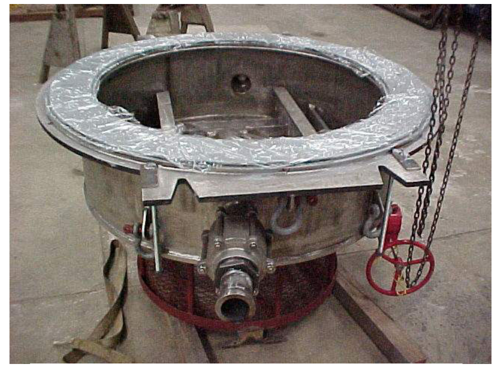
Bulkhead seal system before seals were installed.



Bulkhead top view, showing 16-inch valve, safety cage, and grout valves.

It was planned that once the bulkhead was in place the leak would stop, permitting dewatering of the plunge pool. Anchor bolting by divers of the bulkhead for grouting could then proceed while the plunge pool dewatering and downstream work proceeded. When the plunge pool dewatering was completed, a road would be constructed down through the plunge pool to allow access to the outlet of Conduit 4-165 to effect the infilling repair.

Outlet repair would comprise excavating construction debris from around the outlet then placing a grout pipe and concrete plug in the block-out on the outlet end of the conduit to assist in the grouting operation. The concrete plug and a concrete cap placed after grouting would provide protection of the Conduit 4-165 outlet from the action of future spillway discharges. Finally, all voids in the bulkhead and the crown void of Conduit 4-165 would be infilled with high-strength grout to complete the repair.



Bulkhead seal system – seals and hydrophilic paste installed.

One of the areas of great concern was the grouting operation. AEA environmental requirements allowed no wasting of grout into the reservoir. This required close attention to the grouting system alternatives and grout pressures. Prior to approval of the proposed grouting system, grouting alternatives were investigated to determine the practicable grout pressures and means of maintaining the lowest possible pressures consistent with site conditions. Alternatives considered grouting from the upstream with returns downstream and visa versa and with both barge-based grout equipment and shore-based grout equipment. The grout density and water-cement ratio were based on the specifications of the Master Builder's "Masterflow 928 Grout" selected for the project. The following criteria were used in the alternatives analyses:

- Grout density of 131 pcf
- Grout water-cement ratio of 0.57
- Laminar grout flow with a velocity of 6 fps
- Bulkhead elevation of 165 ft
- Four-inch-diameter pipe for both grout supply and return lines

The Leak Closure Bulkhead would be held in place by reservoir hydrostatic pressure until grout was introduced into the conduit void and bulkhead. Anchor bolts securing the bulkhead to the face of the dam were needed to resist the static and dynamic pressures during grouting. Grout pressure calculations showed that grout pressures would be sensitive to water-cement ratio, variation in other grout properties, velocity fluctuations, assumptions made about conduit void pressure loss, and possible transient effects arising from long pumping lines. Grout pressures could be expected in the range of 165 psi to 200 psi. The specifications required a gravity supply of the grout through a hopper located 5 feet above the reservoir level on the work barge. This approach maximized the control of the pressures within the conduit void and the bulkhead. Reservoir level was critical to grouting operations because if the reservoir level were lower than El. 270, the hydrostatic pressure resisting grout pressures would reduce the anchor bolt safety factor to an unacceptable level.