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Remediation of RCC Dam Seepage
Upper Stillwater Dam Rehabilitation – Phase 1

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REMEDIATION OF RCC DAM SEEPAGE
UPPER STILLWATER DAM REHABILITATION – PHASE I

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ABSTRACT

Since the time of initial construction a series of cracks have developed through the Upper Stillwater Dam structure extending from the upstream face to the downstream face and vertically from the crest to the underlying bedrock foundation. A remediation program was implemented consisting of chemical grouting and for certain locations installing a membrane liner across the crack plane extending from the top of the dam into the underlying bedrock. The Upper Stillwater Dam Rehabilitation Project is unique primarily in the manner employed to construct the membrane slots, each 14-ft. long with a minimum opening width of 4.5 inches to depths of 158-ft, 182-ft, and 240-ft. respectively, as well as the design and implementation of the stainless steel membrane systems. Construction of a typical slot consisted of drilling a series of overlapping drill holes using a percussion drilling system modified with a unique guide system. An initial pilot hole was core drilled to the depth of the slot followed with a percussion drilling system fitted with a special guide sleeve designed to follow the profile of each sequential slot hole to ensure a high degree of verticality and bearing alignment with adjacent slot holes. The corrugated stainless steel membrane was designed for expansion based on the total movement of the crack throughout the seasonal temperature cycles. Finally, the upstream and downstream annular spaces of the slot-membrane are back-filled with a special hot asphalt/portland cement mixture specifically designed for adhesion to stainless steel and concrete, resilience, and expansion properties.

Background

The Upper Stillwater Dam is located on Rock Creek (northeastern Utah) approximately 45 miles north of Duchesne, Utah. Construction on the roller compacted concrete (RCC) type dam started in late 1983; RCC was placed over a period of three years starting in 1985 and completing final placement in 1987. The dam has a maximum height of 292 feet (crest EL. 8,182 feet), crest length of 2,650 feet, crest width of 29 feet, and a maximum base width of 183 feet. Core tests show the RCC to have an average compressive strength of 4,600 psi after 15 years and that lift lines are well bonded. There is no reinforcement placed within the RCC except for a layer of reinforcement above the

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galleries. The upstream face of the dam is vertical, consisting of un-reinforced, slip-formed concrete facing elements with horizontal placement joints for every 2 feet of elevation. The downstream face of the dam is sloped, consisting of un-reinforced, slip-formed concrete facing elements with horizontal placement joints on 2-foot centers.

The dam has no transverse contraction joints. Since the time of initial construction, a series of full transverse cracks developed through the dam structure. The transverse cracks are continuous and irregular from the upstream face to downstream face. Crack widths on the face of the dam range from hairline to approximately 0.5-inches. Five cracks of primary concern were previously grouted with hydrophilic urethane grout above the gallery floor elevation and with cement grout below the gallery floor; the grouting program failed to effectively seal the cracks. Additionally, rope, lead caulk, oakum, and caulk had also been used in past attempts to reduce flows into the gallery. Referencing the contract specifications, Table-1 summarizes the available data on the cracks repaired. Flow measurements were taken on June 25, 2001, with the reservoir at elevation 8168.32 feet, and August 29, 2001, with the reservoir at elevation of 8152.00. Cracks indicated as being previously grouted were grouted with hydrophilic polyurethane grout above the gallery floor elevation and cement grout below the gallery floor. The downstream face elevation denotes the highest elevation of discharge from the downstream face at the time of flow measurement.

Table –1 – Recorded Crack Data

Station	Previously Grouted?	Gallery Flow (gpm)	Downstream Face Flow (gpm)	Downstream Face Elevation (feet)
24+10	No	130	< 2	Not measured.
25+20	Yes	894	2770	8114
26+50	No	< 2	10	8124
28+10	No	< 2	6	8156
28+65	Yes	5	5	7993
29+25	No	< 2	20	8129
30+95	No	10	< 2	Not measured.
32+45	No	< 2	3	8088
34+40	No	< 2	3	8082
36+00	No	< 2	5	8116
36+75*	No	< 2	5	7981
38+55	No	< 2	5	8104
40+15	Yes	2	5	8114
41+10	Yes	230	460	8092
42+85	Yes	7	330	8122

* Drill Hole between gallery and downstream face of dam.

Technical Plan for Design and Construction

The Bureau of Reclamation issued a solicitation in early 2003 for repairing the transverse cracks that developed in the dam since the time of construction. The principal components of the Bureau's remedial program included injecting chemical grout into 7 of the transverse cracks in the dam (cracks less than 20 gpm); design, manufacture and install membrane systems for 3 transverse cracks in the dam (large flows); and to drill holes from within the foundation gallery to drain 14 transverse cracks in the dam. Based on the severity of the crack, a treatment program was to be implemented involving one or more of the following scenarios; 1) drill a series of holes to drain the crack, 2) grout and drain the crack, and 3) grout and drain the crack, and install a membrane liner extending across the crack plane and from the crest of the dam to the underlying bedrock.

Concerning the membrane systems, the Government considered it extremely important that a long lasting interior water barrier system be installed at the specified cracks associated with large flows. The Bureau produced conceptual drawings that included perimeter sealing and anchorage details desired for the membrane system. The Bureau's solicitation required a Technical Plan for Design and Construction detailing construction of the membrane slot, extracting concrete, installing and sealing the membrane. Amongst other design considerations for the interior membrane system had to include life expectancy, movement capability, ability to withstand expected hydrostatic pressure and crack movement, cold temperature properties. After due consideration of various design proposals, the USBR selected the technical proposal of ASI-RCC and F.E.C., Inc. (now Nicholson Construction Company), and awarded a contract for design and construction.

Polyurethane Resin Drilling & Injection: The chemical grouting program preceded construction and installation of the proposed membrane systems. The intent of the chemical grouting program was to establish an effective water barrier for each of the crack locations, reducing seepage to less than 100 gpm (each crack) through the dam structure. The treatment zone (Illustration A) measured 20 feet thick from the upstream face of the dam and extended from the crest of the dam to the underlying bedrock, approximately 230 feet in total height.

A single-component polyurethane resin was chosen to provide a flexible water barrier in cracks subject to differential movement. The polyurethane resin system, hydrophobic in nature, possessed properties similar to hydrophilic systems. Based on the requirements of the specifications regarding grout material properties, in its cured stated the polyurethane grout had to achieve a minimum tensile strength of 110 psi bonded to wet and dry concrete as well as minimum elongation of 250 percent. The product utilized has a stated elongation of 400 percent; significantly higher than the specified elongation criteria, thus allowing the injected grout body to withstand a greater degree of movement in the dam structure.

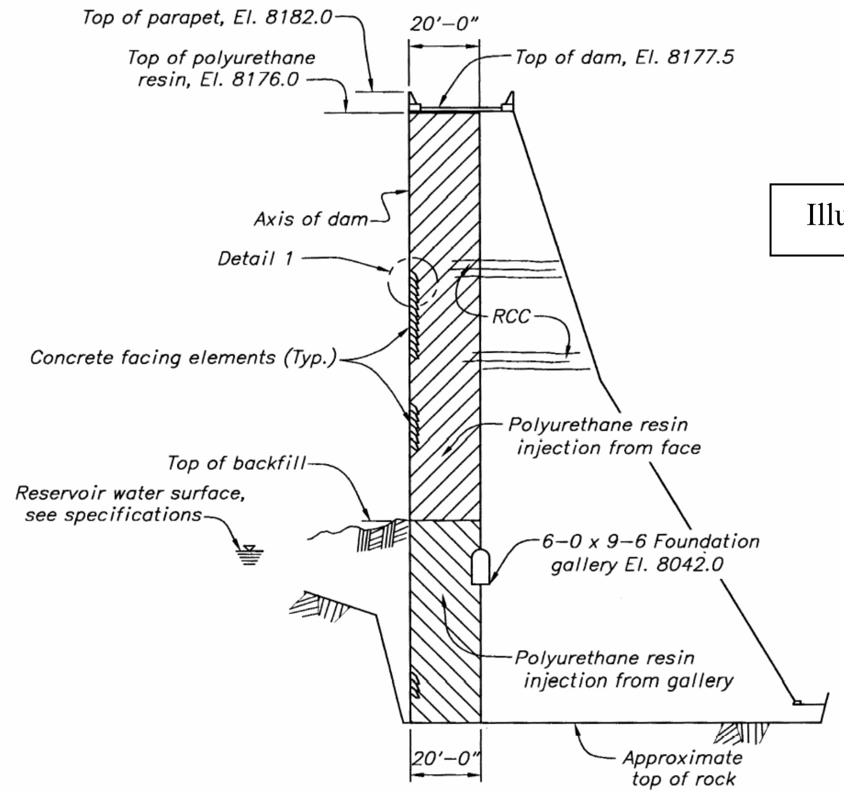


Illustration A

Ref. Contract Dwg. No. 66-D-3404

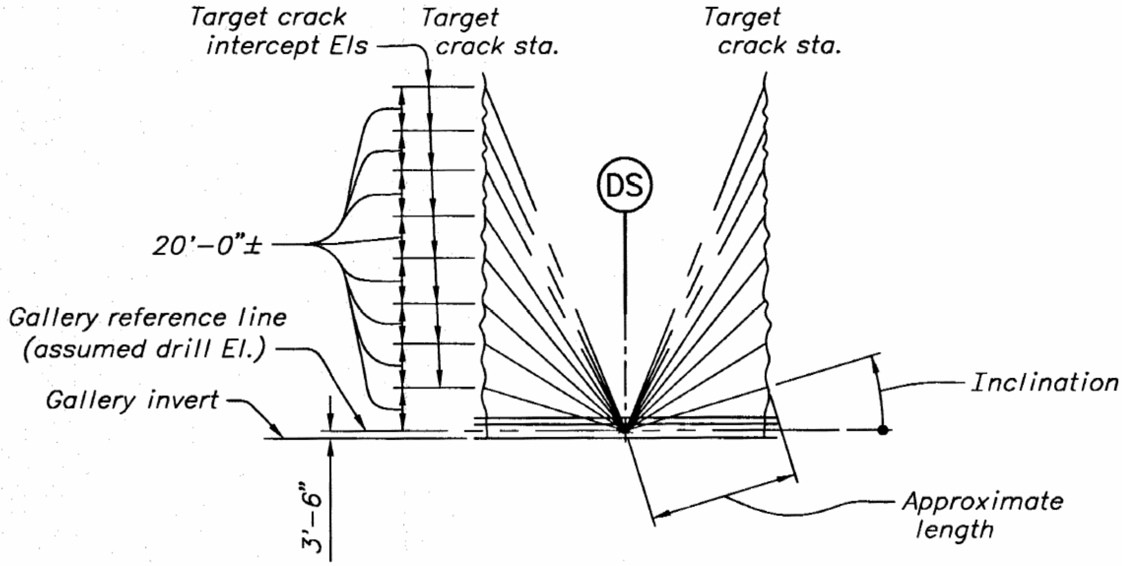
To accomplish the grouting, a series of small diameter (1-in. to 1⅞-in.) injection holes were drilled to intersect the crack plane at the midpoint of the specified treatment zone. Injection holes were drilled from either the upstream face of the dam structure or from within the foundation gallery depending upon access and elevation of the reservoir at the time the work was performed. A series of injection holes were drilled in a fan-shaped pattern so as to achieve a 7.5-ft. vertical spacing at a point where the holes intercept the crack plane. The holes were drilled at inclinations and directions (i.e., bearing) designed to intercept the crack plane approximately 10-feet distant from the upstream face of the dam. Drilling advanced the injection hole an additional two feet past the intersected crack plane. Grout injection proceeded when all holes for a particular crack plane were completed. Prior to injecting grout, holes were flushed with water to clear out residual drill cuttings and any remaining debris of the previous grouting program (hydrophilic material). Flushing also served to induce moisture into the hole to facilitate full reaction of the grout.

Considerations for the injection process included high flow conditions and low water temperatures, each with the potential to adversely affect grout set time. In such cases, an accelerator additive was used to "adjust" the reaction time as required for job conditions. Faster reaction times were achieved by the use of additional accelerator. Further adjustments were made using higher grout temperatures and by varying injection pressures and flow rates. Specific quality control measures included close monitoring of injection parameters, making appropriate and timely adjustments to the grout reaction time, visual inspections for emitted grout, and comprehensive verification checks of material properties. Grout was injected into each hole until grout material was emitted from the face of the dam (both upstream and downstream), or until backpressure on the injection pump reached 900 psi. Starting at the base of the foundation, polyurethane grout was injected into the lower holes until reaching the level of the foundation gallery. Work then proceed to the upstream face where grout was injected in ascending grout holes until reaching the top of the dam.

The chemical grouting program proved successful in achieving vertical and lateral migration of grout; grout was emitted from cracks for both upstream and downstream faces of the dam. An extensive core verification program revealed good grout penetration, grout-concrete bond strength, with no observable shrinkage in recovered samples. Crack openings varied in width, reaching 1.5 inches in recovered samples. Based on the success of the grouting program, the scope of work was expanded to include 7 additional cracks for a total of 14 cracks grouted. On concluding the grouting program, more than 21,000 gallons of polyurethane resin had been injected to seal water flows through transverse cracks.

Drain Hole Drilling: After the polyurethane grout was sufficiently cured, a series of 3-inch diameter holes were drilled at positive inclinations (upward) in a fan-shaped pattern at each crack location. Each drain hole was designed to intersect the crack plane at specified depths and inclinations as measured from a designated Drill Station. The alignment of the drain holes coincided with the apex of the foundation gallery roofline. To ensure a drain hole met the specified alignment tolerance, a series of borehole surveys were performed during the drilling at predetermined intervals. Drain holes were installed for cracks at Stations 25+20, 41+10, and 42+85 before proceeding with the installation of the interior membrane systems; drains for adjacent cracks were also installed before proceeding with drilling the membrane slot. Drilling the membrane slots commenced upon completion of the drain holes.

Slot Hole Drilling: Water stop membranes were required the full section and depth for the three most problematic cracks located at Stations 42+87, 41+06 and 25+18. Specifications required the membrane system be capable of withstanding 250-ft. of head pressure, permit a range of movement (0.4-in.) parallel to the dam axis, as well as attaining a 50-year life span. Considering the requirements for withstanding pressure,



TYPICAL DRILL SETUP STATION DETAIL
(NO SCALE)

Drain Hole Pattern

Ref. Contract Dwg. No 66-D-3410

lateral movement in either expansion or compression, and longevity resulted in a membrane design comprising corrugated annealed stainless steel grade 304L (SS304L) sheeting with rubberized asphalt grout backing placed both upstream and downstream of the membrane. The concept of using corrugated sheeting was to allow the membrane to uniformly expand or contract with dam movement while incurring minimal tensile stress to the membrane; the design also anticipates movement normal to the dam axis of 0.30 inches. The flexible rubberized asphalt material placed on either side of the stainless steel membrane helps uniformly distribute the reaction to hydrostatic load and provide backing support to the stainless steel membrane in the event movement occurs perpendicular to the corrugated pattern. In addition, the rubberized asphalt serves as a backup sealant to the membrane system.

Slot construction constituted one of the biggest challenges of the project. Each slot required an excavation 14-ft. long by 4.5-inches wide, extending from the crest of the dam to the underlying bedrock ranging from 157 feet to 228 feet in depth. Saw cutting was given due consideration at proposal time, however, this method could not guarantee the accuracy for verticality required for the proposed stainless steel membrane liner. As such, the slots would be constructed by drilling a series of overlapping holes as depicted by the diagram in Illustration B. This method of excavation posed the least risk associated with the slot excavation and also eliminated any requirement to place construction personnel within the dangerous confines of the excavated slot/side holes necessary to accomplish installation of the membrane side seals. Safety was the primary concern in the decision making process for choosing the method of excavating the slots. Illustration B diagrams the slot configuration as originally envisioned. However, a more extensive stress analysis of the stainless steel membrane when placing the hot asphalt necessitated a change in the slot design as well as the placement procedure in order to allow the membrane to fully expand and contract through the cooling cycle of the asphalt.

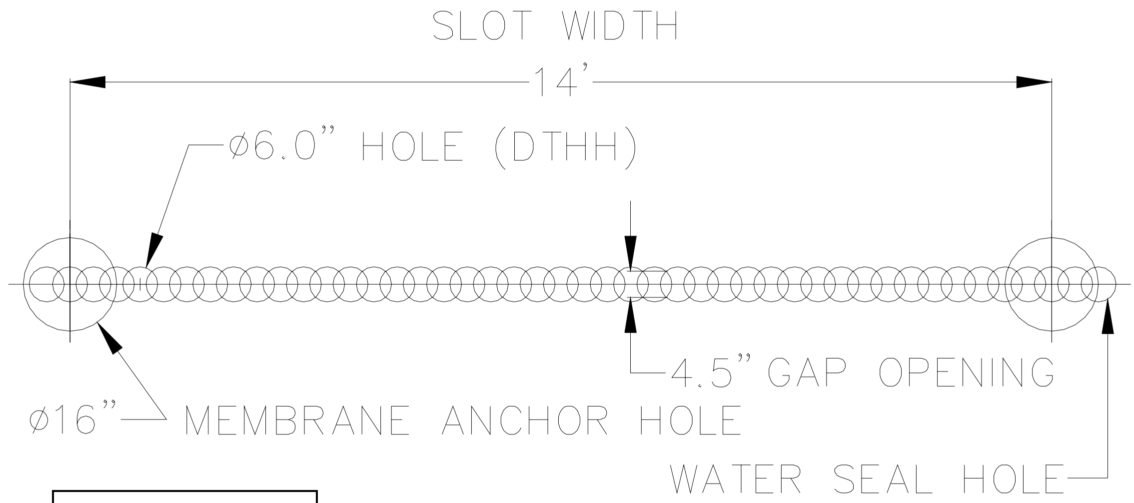


ILLUSTRATION B

The final slot configuration featured two enlarged holes on either end of the slot to accommodate the revised placement of the side seals – Illustration C.

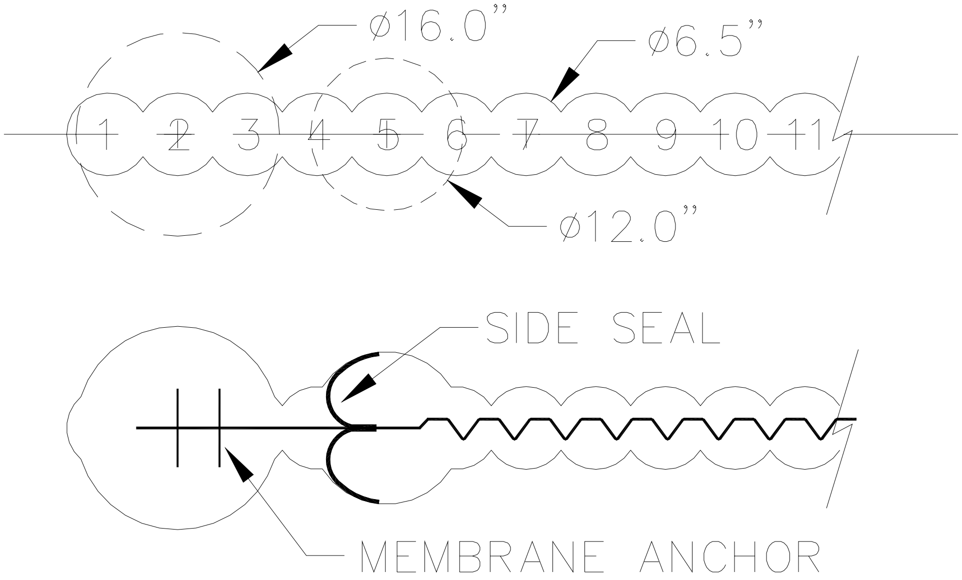


ILLUSTRATION C

Construction started with the shallowest and concluded with the deepest slot. This approach was for the most part to take advantage of opportunities to more fully develop the construction methodology and procedures prior to installation of the deeper membranes. Excavating the slots was accomplished by drilling a series of overlapping 6.5-in. diameter holes to achieve a 4.5-in. nominal slot width. Drilling was conducted using a down-the-hole-hammer (DTHH) percussive system mated with a unique offset-guide sleeve. To achieve the vertical alignment necessary for the membrane installation process, an initial pilot hole was drilled using a wireline core system; the pilot hole established the vertical alignment for the ensuing drill holes. When the pilot hole was cored to depth, the hole was reamed open using a DTHH fitted with a nose guide designed to follow the trajectory of the pilot hole. For drilling subsequent slot holes, the DTTH was refitted with a guide sleeve designed to follow the path of the adjacent borehole, thus maintaining alignment across the entire width of the slot. It should be noted that maintaining hole alignment was an evolving process in which minute adjustments were made to the drill tooling and guide-sleeve assembly as conditions dictated. When all the primary slot holes were completed, drilling proceeded to reaming two of the slot holes located on either end of the slot to accept the side seal/anchor mechanism of the membrane system. Side holes were enlarged to 12-inches or 16-inches diameter using a combination of conventional DTHH and rotary drilling methods. Also, whereas the primary slot holes extended approximately 1-ft. (±) into bedrock, the side seal/anchor holes extended an additional 5-ft. (±) into bedrock.

On completion of the slot drilling program, all cuttings and extraneous materials were removed from the slot and side holes as part of a final cleaning/bottom dredging process. The walls of the side holes were cleaned using a high-pressure water blaster to remove any drill cuttings, sludge and/or debris in preparation for installing the membrane system. One final procedure prior to installing the stainless steel membrane system was to run a test panel the full depth of the slot. The membrane test panel was full width including side anchor/seal mechanisms to verify clearance and alignment tolerances of the slot.

Installing verification “Test Panel” into slot.

Membrane Installation: Pre-fabricated components of the membrane systems were delivered to the site and field fabricated into final assembly for the individual slots. Each completed membrane comprised 1) a nose section, 2) multiple standard sections, and 3) a cap makeup section. Each of these three elements was constructed using a corrugated center component attached to a left- and right-side component. Field fabrication allowed for making minor adjustments in the standard width of the membrane to better fit the final slot configuration. To support fabrication and installation activities for each slot, two End-Support frames were positioned and anchored to the dam crest to provide a seat for temporary dogging the suspended membrane as work proceeded. A crane provided the overhead lifting capacity during fabrication activities and lowering of the assembled membranes into the slots. Winches mounted on the support frames served as a redundant safety line system for the crane throughout the installation process. After an assembled membrane was lowered into its final position the bottom seal was placed. A self-leveling cable grout was placed at bottom of the slot to secure and seal the lower portion of the membrane into place. Bagged grout was mixed on-site and pumped through a tremie pipe moved laterally along the bottom of the slot to ensure a level seal placement. The seal between the slot and the side holes as accomplished using a neoprene rubber skirting, installed onto the stainless steel membrane. The rubber skirting was attached to either edge of the SS304L sheets at the top of the dam as the membrane was being assembled. With the membrane installed into the slot excavation, the extruded rubber skirting provided a continuous friction seal thus isolating the slot cavity from the side-anchor hole cavities.

Backfilling the slot cavities entailed placing asphalt grout on the upstream and downstream sides of the stainless steel membrane in staged lifts. However, one of the concerns during placement of the asphalt was that since the unit weight of asphalt is lighter than water, if water were present in the slot it would not be possible to place the asphalt at the bottom of the slot, or the ensuing placement lifts. Through a series of trials, an asphalt grout mix was achieved consisting of a combination of Portland cement and asphalt resulting in a mixture more dense than water with adequate adhesion and elasticity properties. The asphalt batching process consisted of heating solid blocks of asphalt in a propane fueled asphalt-kettle where the temperature of the heated asphalt reached 550 (+) degrees Fahrenheit. The heated asphalt was then transferred to the batching plant consisting of two temperature controlled holding tanks. The upper tank equipped with weight scales received the hot asphalt from the asphalt-kettle. When a batch quantity was placed in the preheated tank, dry Portland cement material was added in the following ratio: 60 pounds cement to 100 pounds asphalt. Inside the tank, a hydraulic powered dual-blade mixing paddle stirred the asphalt-cement mixture to a uniform consistency. When the mix was determined to be uniformly blended, it was transferred to a second holding tank. This tank was also temperature controlled as well as equipped with a mixing paddle to continually keep the mixture agitated. From this tank, the hot-asphalt mixture was discharged into an open-throated positive displacement pump. The pump speed was controlled to achieve a placement rate of 2.7~3.2 gpm as part of the placement criteria designed to control the rate of exposure of the stainless steel membrane to hot asphalt. An insulated high-pressure hose connected the pump's discharged outlet to a dual-wall pipe manifold located at the center of the slot. The dual-wall pipe extended to near the bottom of the slot/lift elevation. Each of the aforementioned processes resulted in a temperature loss, which during the initial placement trials resulted in the hot-asphalt material congealing in the pipes as it was discharged near the bottom of the slot. It was determined that the critical temperature drop was occurring in the piping used to place the asphalt into the slot. To overcome the temperature losses, a high-pressure, high-volume boiler plant was utilized to generate steam that was circulated through the annular space of the inner-outer dual-wall pipes, thus keeping the temperature of the asphalt sufficiently high (340~360°F) to achieve a uniform flow to either end of the slot from the center where it was being injected. Once a certain quantity was placed on the downstream cavity of the membrane, the hose was reconnected to the pipe installed on the upstream cavity and the process repeated. This process was repeated until a specified lift placement was achieved. The asphalt was then allowed to cool down for a period of twenty-four hours before repeating the process again until the slot was entirely filled. The asphalt grout placement method was controlled during backfilling the up and down stream cavities of the membrane with hot asphalt by simultaneously backfilling the side anchor holes with cement grout. This was done to prevent excessive head pressure from breaching the side seal mechanisms. Lift heights were controlled so that the level of grout in the side anchor holes cavities always remained a certain elevation below that of the asphalt grout to prevent any migration of cement grout into the upstream/downstream membrane cavities. This iterative placement procedure was followed until the slot cavities and side anchor hole cavities were completely filled to near the top of the crest.

Summary

At the end of March 2005, the first slot had been completely topped off with asphalt, the second slot was fully excavated, and drilling had commenced on the last and deepest slot. The construction process continually evolved during the excavation of the slots, the installation of the membranes, and the backfilling with hot asphalt grout material. The effectiveness of the membrane systems will be more fully realized when the pool elevation reaches normal operating levels and also after the dam structure has undergone one or more seasonal expansion and contraction cycles.

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