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## South Channel Dam Rehabilitation Project - Successfully Addressing Dam Rehabilitation Challenges

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## South Channel Dam Rehabilitation Project: Successfully Addressing Dam Rehabilitation Challenges

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### ABSTRACT

*The Post Falls South Channel Dam is located on the Spokane River in Post Falls, Idaho. The concrete gravity dam was constructed in 1906 and was recently rehabilitated. The rehabilitation project included several design elements; the primary objectives were the replacement of the six spillway gates and hoists and significant rehabilitation of the concrete. The South Channel Dam rehabilitation encountered several challenges due to the age and condition of the existing structure, the large scale of the rehabilitation, and the location of the project. The concrete rehabilitation addressed several challenges, which are presented in detail. The existing concrete consisted of cyclopean concrete; concrete demolition and surface preparation also revealed large voids and substantial areas of low strength material. This paper presents lessons learned along with procedural methods implemented for effective change management during construction. The project was ultimately a success in a large part due to the team approach and practices implemented during construction.*

**Keywords:** Construction Management, Cyclopean Concrete, Dam Rehabilitation, Dam Safety

## 1. INTRODUCTION

South Channel Dam is one of three dams within the Post Falls Hydroelectric Development (HED) owned and operated by Avista Utilities. The dam was built in 1906 and has recently undergone extensive rehabilitation to improve its durability, safety, maintenance, and operation. Originally conceived as a gate refurbishment project, the scope evolved to include significant structural rehabilitation and ultimately included spill gate and hoist replacement, structural improvements to address deteriorated concrete, rock stabilization, and temporary works including dredging and cofferdam construction. Although a relatively small dam, the rehabilitation was a complex project that included mechanical, electrical, structural, and geotechnical design and required environmental permitting and monitoring during construction. The project is also located in a high-visibility area within a public park that remained in active use during construction.

Due to the age of the structure and the location of the project, several challenges were encountered. The challenges and solutions developed for the existing concrete are presented. Based on data collected prior to construction, the original concrete was known to consist of cyclopean concrete with voids, seams, and cold joints. The condition of the concrete, however, was worse than expected. The concrete demolition revealed that the concrete was in poor condition not only at the surface, but also at depth, with alternating layers of high and low cement content and pockets of low strength material. The observed condition of the original concrete necessitated adjustments to the design and detailing during the construction phase.

This paper presents technical and procedural methods used to resolve challenges typical in dam rehabilitation projects. This paper also presents lessons learned along with procedural methods implemented for effective change management during construction. The owner, design engineers, consultants, inspector, and contractor worked as a

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unified team to effectively adapt the design as needed, while maintaining balance between documentation needs and construction schedule, resulting in successful project execution.

## 1.1. DESCRIPTION OF THE FACILITY

Avista Utilities owns and operates the Post Falls Hydroelectric Development (HED), located on the Spokane River in Post Falls, Idaho. The Post Falls HED consists of three concrete gravity dams spanning three separate channels of the river. North Channel Dam is the primary spillway structure, Middle Channel Dam contains an integral powerhouse, and South Channel Dam is the secondary spillway structure.

South Channel Dam is a concrete gravity structure approximately 40 meters (130 feet) long and 11 meters (35 feet) high. The dam includes a 23 meter (76 foot) long gated spillway section and an overflow section. Prior to the rehabilitation, the South Channel Dam spillway gate system consisted of six vertical slide gates (each approximately 1.8 meters wide by 4.0 meters high) that were manually operated by means of a crest mounted rack and pinion type hoisting system. Significant modifications and upgrades to South Channel Dam (prior to the recent rehabilitation project) included replacement of the original wooden gate panels with steel gates in the late 1980s and installation of six post-tension anchors in 1992 to improve global stability.

## 1.2. PROJECT SCOPE

The Post Falls South Channel Dam rehabilitation project was originally expected to only include gate refurbishment (gate surface preparation and gate recoating). Prior to design, further evaluation by the owner and engineer of the existing gates and the existing concrete determined that more extensive rehabilitation was needed.

The objective of the South Channel Dam Rehabilitation Project was to replace the six spillway gates and rehabilitate the concrete dam. The project included geotechnical engineering, structural engineering, mechanical engineering, and electrical engineering. The spillway gates and associated hoist mechanism were removed and replaced with six new spillway gates; each were 2.1 meters wide by 4.2 meters high (6.8 feet wide by 13.7 feet high). The new gates are of a modern steel roller-gate design with wire rope hoists. Deteriorated concrete was removed over much of the exposed surfaces and replaced with new concrete. A consolidation grouting program was also included in the dam rehabilitation. The existing mule house was replaced with a new concrete masonry structure that houses a new motor control center and controls for the gate hoists. Figure 1 shows photographs of South Channel Dam before and after the rehabilitation project. Figure 2 shows a general rehabilitated dam section at the spillway gate.



Figure 1. South Channel Dam, Before and After Rehabilitation

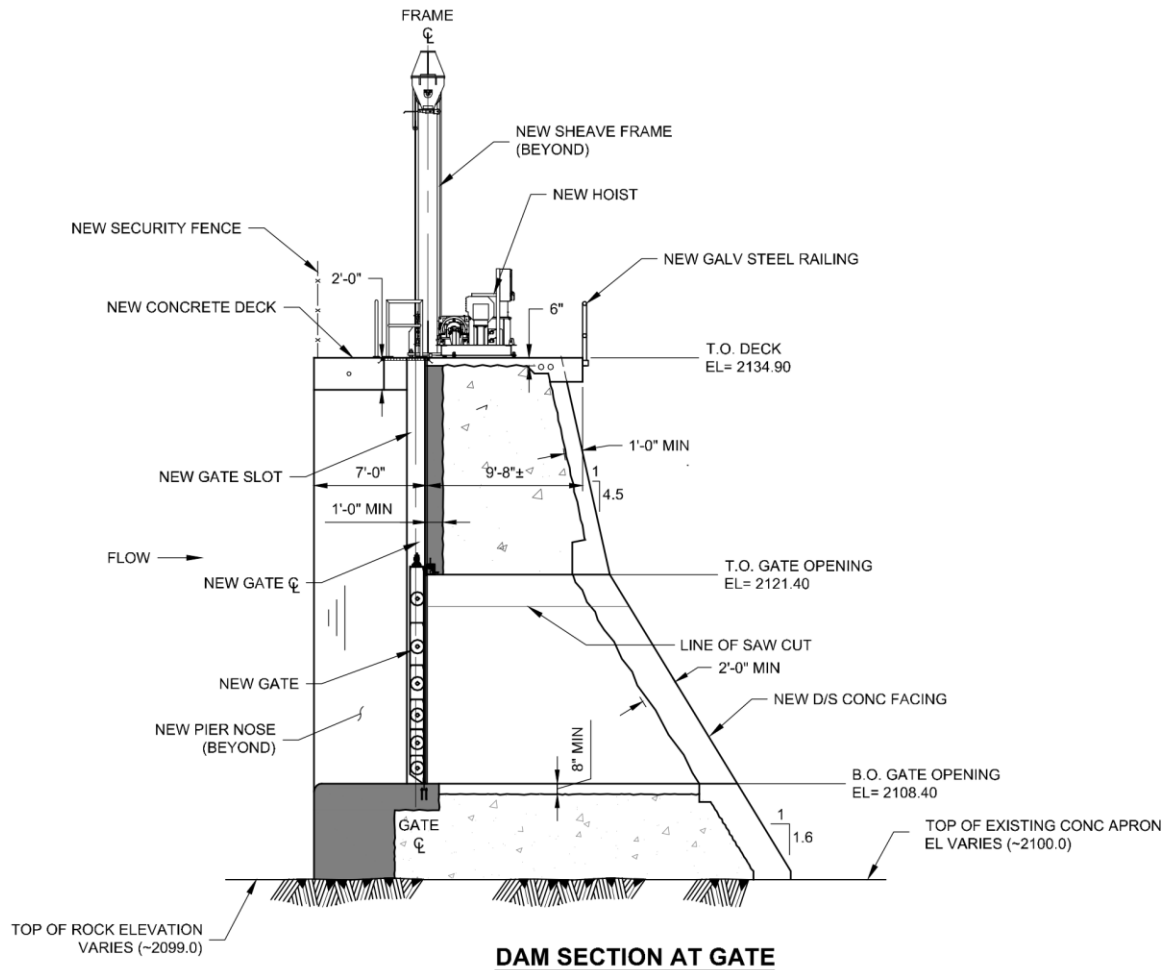


Figure 2. General Dam Rehabilitation Section at Gate

## 2. CHALLENGES

Challenges and changes were expected for the South Channel Dam rehabilitation project due to the age and condition of the existing structure and the large scale of the rehabilitation. The design addressed the challenges as much as possible and anticipated the features that were most likely to be affected by change due to conditions discovered during construction. Specific challenges encountered during the rehabilitation construction of the South Channel Dam include the following:

- Construction within the boundary of Q'emiln Park with continued public access in close proximity of the dam.
- Flooding the toe of the mechanically stabilized embankment crane pad due to unforecasted stream flows into Lake Coeur d'Alene.
- Turbidity from dredging affecting diver visibility.
- Discovery of an old grenade near the base of the cofferdam.
- North abutment rock upstream of the dam was severely undercut below the normal water level, impacting the cofferdam construction and requiring the design and construction of an additional concrete wall.

- North abutment rock stabilization required for worker safety.
- Settling of the cofferdam structural fill during the dewatering process.
- Cofferdam seepage due to bedrock fissures at the bottom and sides and interface with the cofferdam.
- Incorrect as-built drawings from the original construction.
- Poor quality of the existing concrete.
- Unexpected bedrock outcropping upstream of Spill Gate 1.
- Weak zones and heterogeneous sections of bedrock at the dam foundation.
- Electrical conduit congestion at the new concrete top deck.

This paper will present the general approach used to address the challenges and changes encountered during construction. The challenges and associated solutions developed for the rehabilitation of the existing concrete will be described in detail; other challenges identified above will not be covered.

## **2.1. GENERAL APPROACH**

By nature, rehabilitation projects are challenging and often require adjustments due to actual conditions encountered during construction. Due to the nature of the project, the team recognized from the beginning that there would be change and expected challenges during construction. As a result, a team approach was emphasized and efficient change management was implemented early in construction.

### **2.1.1. Team Approach**

The owner, design engineers, inspector, and contractor worked as a team to successfully complete the project. All members of the team had a common understanding of expectations, design intent, etc. Clearly defined roles, responsibilities, and lines of communication were also established.

The design intent was effectively communicated to all levels during construction. The design engineers placed an emphasis on explaining the design intent to the team. This helped everyone understand the important aspects of the design, and it also fostered a cooperative atmosphere. The existing post-tension anchors are an example of an item that everyone had to understand and respect; 4,180 kN (940 kips) of post-tension load is a substantial compressive force during concrete demolition.

In the spirit of this team approach, not only the inspector, but also the construction workers were looking out for the quality of the project. For example, after the structural engineer explained the importance of eliminating and avoiding feathered edges at the interface between the new facing concrete and the rock abutments to the construction team, one of the demolition subcontractor workers noticed a similar situation at a different location. The demolition worker notified the structural engineer, and the correct adjustment was made in the field.

In addition to weekly construction meetings, the project also implemented numerous onsite pre-construction meetings to discuss key construction steps well ahead of the event. This is often standard practice, but it is critical to rehabilitation projects. The pre-construction meetings ensured that everyone was prepared and knew what to expect before the busy construction activities began. The South Channel Dam rehabilitation project included pre-construction meetings regarding the access road rock blasting, cofferdam, concrete demolition, concrete placement, cold weather concrete, consolidation grouting, gate installation, and the hoisting equipment.

### **2.1.2 Efficient Change Management**

The team recognized from the beginning that there would be challenges and changes; therefore, the team developed a process for efficient change management during construction to reduce potential impacts to schedule and expense that might occur using a traditional RFI process. The Engineer Supplemental Information (ESI) process was developed. An ESI is basically a fast-track Request for Information (RFI) process. The ESIs were numbered (similar to RFIs) for

documentation. The typical RFI process is shown below in Figure 3. The implemented ESI process is shown below in Figure 4.

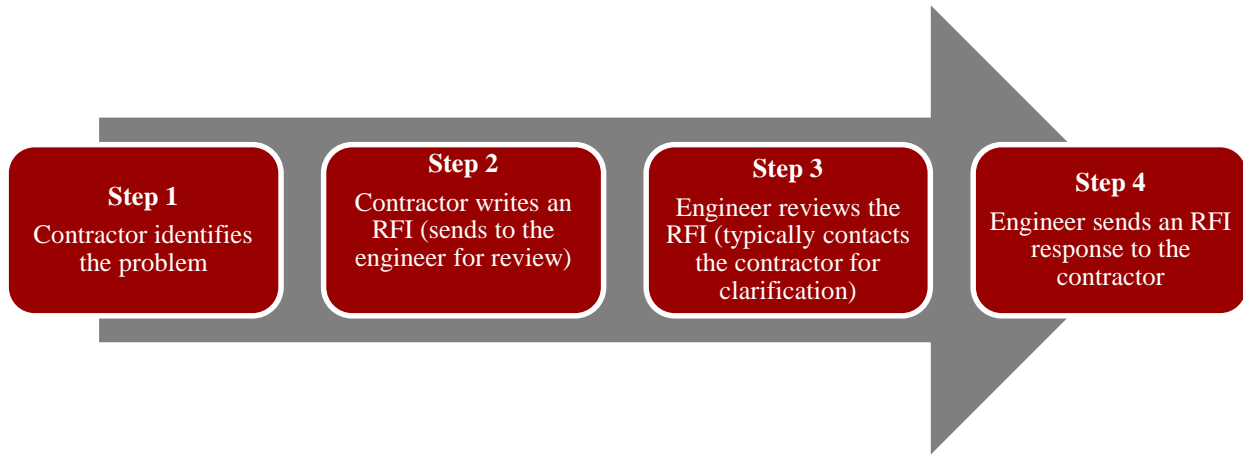


Figure 3. Typical RFI Process



Figure 4. Implemented ESI Process

The ESI process eliminates Step 2 in the typical RFI process. ESIs are also helpful when the engineer identifies the need for clarification or minor design changes prior to a question from the Contractor. An example may be a site visit where the design engineer notices a unique field condition that may warrant an additional detail for clarification. An ESI can help the design engineer get ahead of contractor questions or RFIs, therefore reducing schedule and cost impacts. The ESIs speed up the time required to determine a corrective action and implement it in the field.

The condition of the existing concrete is an application where the above general approach was implemented, as detailed in the following section.

## **2.2. EXISTING CONCRETE REHABILITATION**

### **2.2.1. Existing Concrete**

The condition/quality of the existing concrete was a driver for several proposed modifications for the project. Prior to design, investigations and condition assessments were completed for the existing concrete. The concrete data included full-depth core logs through the dam, concrete test results, and petrographic analysis. The geotechnical report (GCI 1990) for the existing post-tension anchor design provided a detailed description and evaluation of the condition of the existing concrete. The investigation included logs for three full-depth cores taken at the dam. Concrete testing revealed a surprisingly high average unconfined compressive strength of 42,600 kN/m<sup>2</sup> (6,180 psi) and a high average concrete permeability of  $1.1 \times 10^{-3}$  cm/s (GCI 1990). Petrographic analysis was performed on three existing concrete cores; the overall presence of alkali-silica reactivity (ASR) in the concrete was judged to be minor, and air content was estimated between 0 and 4% (CTL, 2013). The overall data for the existing concrete indicated cyclopean concrete with minor voids, seams, and cold joints, but with adequate compressive strength and limited chemical reaction concerns.

Prior to design, a dive inspection (AUS 2012) was performed for the upstream face of the dam, and a structural condition survey was also performed for the gate tunnels and the downstream face of the dam. The dive inspection and the structural condition survey had similar findings. The existing concrete was in poor condition with concrete spalling, cracking, and voids over a substantial area of the exterior of the dam.

### **2.2.2. Concrete Rehabilitation Design**

Due to the observed condition of the existing concrete, consolidation grouting was included in the dam rehabilitation design in order to improve the existing South Channel Dam concrete. The consolidation grouting program was designed to fill the voids in the concrete with a structural material to decrease permeability and improve the structural integrity of the existing concrete.

Based on data collected and field observations, it was determined that the upstream and downstream deteriorated concrete surfaces should be replaced with new concrete (facing concrete) rather than implementing local concrete repairs. The dam rehabilitation design included facing concrete to reduce upstream permeability and to improve freeze-thaw resistance. The new concrete was designed per the guidelines of ACI 350 (ACI 2006). The specified facing concrete included Type I/II Portland cement and a 28-day minimum design compressive strength of 31,000 kN/m<sup>2</sup> (4,500 psi). The upstream facing concrete also included a crystalline waterproofing admixture to further reduce upstream permeability. The new facing concrete was a minimum of 12 inches thick to develop the dowel reinforcement and to provide enough mass to improve the durability of the concrete repair. The new concrete facing construction included air-entrained concrete with reinforcement. The facing concrete was drilled and epoxy doweled into the existing concrete. The facing concrete dowels and concrete reinforcement consisted of #4 and #6 ASTM A615/A615M Grade 60 deformed steel bars. The condition of the existing concrete was not expected to improve significantly with depth. Therefore, the demolition was detailed to a fixed depth rather than extending the demolition down to “sound” concrete.

Due to the condition of the existing concrete and the significant lock-off loading (as high as 4,180 kN (940 kips)) for the existing multi-strand post tension anchors (Black & Veatch 1993), the minimum clearance for demolition limits and drilling locations in the proximity of the existing post-tension anchors was determined using conservative assumptions. A minimum clearance radius of 0.71 meters (2.33 feet) was specified at each existing post tension anchor location. The minimum required clearance from the existing post tension anchors was determined based on the minimum unreinforced column size needed to support the maximum anchor loading, and it accounted for the potential inclination of the existing post-tensioned anchors.

### 2.2.1. Modifications during Construction

Based on data collected prior to construction, the existing concrete in the historic dam was known to consist of cyclopean concrete with voids, seams, and cold joints. The condition of the existing concrete encountered during construction, however, was worse than expected. Concrete demolition and surface preparation revealed large voids and substantial areas of low strength material. Extending the demolition was not an option because there were no indications that the concrete would improve with depth. The observed condition of the original concrete necessitated adjustments to the design and detailing during the construction phase. The design modifications for the concrete rehabilitation included the following:

- Surface preparation and local repairs to facilitate the facing concrete
- Facing concrete drill and epoxy dowels
- Consolidation grouting

Low strength material was observed at several locations in the dam. The following questions were discussed during construction:

- How much material should be removed?
- How should the soft material be removed?
- How should the resulting voids be repaired?

Ultimately, high-pressure water was used to remove the low strength material. Test sections were performed; the team all agreed to proceed with high-pressure water to remove the areas with low strength material. The extent of low strength material removal was limited to what the high pressure water could remove. Figure 5 shows the concrete surface preparation with high pressure water and the downstream face of the dam after concrete demolition and surface preparation.



Figure 5. Concrete Demolition and Surface Preparation

High-pressure washing the concrete surfaces of the dam revealed several concrete voids. The voids ranged in size from 0.15 meters (0.5 feet) wide by 0.15 meters (0.5 feet) deep to up to 1.2 meters (4 feet) wide by 0.6 meters (2 feet) deep. The concrete voids were prepared to ensure that the voids could be filled as part of the facing concrete placement. The facing concrete was a flowable concrete mix with a water-reducing admixture and 19 mm (¾-inch)



maximum aggregate size. Each void area was inspected, and additional local demolition was performed with hand tools as needed to remove obstructions. Hard to reach deep sections were repaired with dry pack grout (Portland cement and sand) to build the void out to a depth that could be filled as part of the new facing concrete placement. The implemented void repair detail to facilitate filling with the facing concrete is shown in Figure 6.

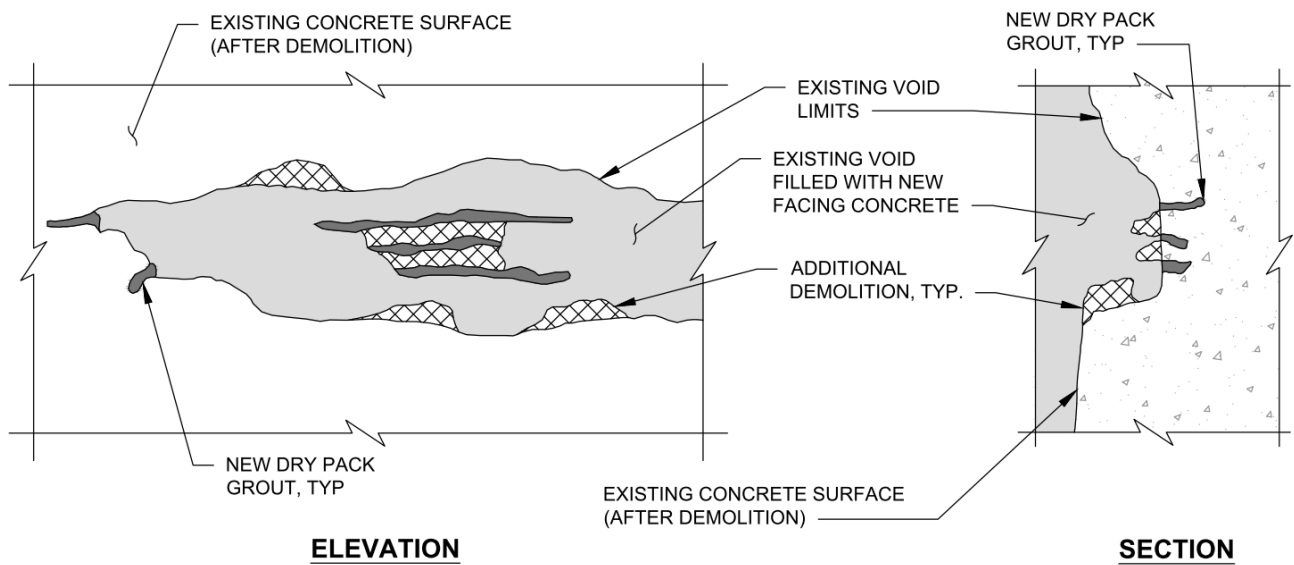


Figure 6. Concrete Void Repair Detail

Due to the extent of the concrete voids and the zones of low strength material, the reinforcement dowl design was revised. The reinforcement dowl size was increased, and the embedment into existing concrete was increased to provide more confidence in the facing concrete anchorage. The grid spacing was also increased to allow for field adjustment in order to properly locate the reinforcement dowels to anchor into the more competent concrete locations and into void areas. The existing concrete voids and the reinforcement dowl installation are shown in Figure 7 below.



Figure 7. Existing Concrete Voids, Drill and Epoxy Dowel Installation, and Facing Concrete Reinforcement

The consolidation grouting program was also adjusted after the concrete demolition was completed. Due to the condition of the existing concrete, the grouting at the upstream and downstream dam faces was moved to the gate tunnel walls. The consolidation grouting was also modified due to a change in construction sequence to expedite the schedule. The gate tunnel wall grouting was performed after the new facing concrete was installed. The primary change was a reduction in grouting pressures in order to avoid overstressing of the new facing concrete. Seventy-two locations (six per tunnel wall face) were drilled and grouted within the tunnel walls. The grout mix consisted of 1:1 water content/superfine cement ratio with 0.75% water-reducer and 0.06% diutan gum admixtures (Budinger 2015). A total of 787 liters (208 gallons) of grout was placed for tunnel grouting. Grout injection pressure ranged between 6.89 and 82.7 kN/m<sup>2</sup> (1 and 12 psi); grouting was continued on each hole until the grout injection pressure reached the design cut-off pressure of 82.7 kN/m<sup>2</sup> (12 psi) and could be maintained within 15% for two minutes.

Originally, the grouting program for the overflow section of the dam included horizontal grouting at the upstream and downstream faces of the existing overflow section. Due to the condition of the existing concrete, especially the alternating layers of low cement concrete, the grouting for the overflow section was changed to vertical grouting. The vertical grouting allowed the grouting to cross several layers of poorly consolidated concrete. The vertical grouting at the overflow section included significantly higher grout pressures due to the static head pressures (vertical column) of grout; therefore, vertical grouting was performed prior to the placement of the facing concrete in order to avoid overstressing the new facing concrete. The overflow section vertical grouting was performed on the upstream side of the overflow centerline. The grouting program featured split-spacing grouting with primary holes (3 meters on-center) and secondary holes (1.5 meters on-center) along the overflow section. The grout mix design for the overflow grouting was 1:1 water/superfine cement with superplasticizer at 2% by weight of the cement (Budinger 2015). A total of 1912 liters (505 gallons) of grout was injected in four primary holes, four secondary holes, and three tertiary holes. The maximum depth of the grout holes was 6.1 meters (20 feet), and the estimated radius of travel of grout was 0.9 to 1.5 meters (3 to 5 feet). Grout pressures ranged between 6.89 and 55.2 kN/m<sup>2</sup> (1 and 8 psi) and were based on the static head of grout due to the depth to the packer and an additional pressure not to exceed 5.64 kN/m<sup>2</sup> per meter (0.25 psi per foot) of depth below the overflow crest. Grouting was continued on each hole until the grout injection pressure reached the design cut-off pressure and could be maintained for five minutes.

## 2.3. LESSONS LEARNED

Several valuable lessons came out of all of the challenges encountered throughout the project. Notable lessons learned are as follows:

- **Verification of As-Built Drawings for the Existing Structure:** An extensive survey of the existing structure is important to verify the accuracy of the existing as-built drawings prior to construction and ideally before final design is completed. Verifying the accuracy of the as-built drawings will limit change orders, aids in accurate design drawings and specifications, and gives the team up-front knowledge of what they are dealing with.
- **Investigative Work during Construction:** Substantial data was collected during the design phase of the project to determine the quality of the existing concrete. Typically, this data is limited to visual inspection and non-destructive testing. This information is important, but additional investigative work at the beginning of construction should also be considered. Depending on the quality of the existing concrete, test areas for partial concrete demolition, evaluation, and surface prep may give valuable insight into existing conditions. Even the core logs for South Channel Dam were not representative of the actual conditions encountered after concrete demolition and surface preparation. The voids around the cyclopean concrete and the extents of the weak concrete material were substantially more than what was expected based on the core logs. If demolition

test panels are planned into the project, the contractor can schedule accordingly, and the design engineer can identify early in the construction project if design modifications are needed.

- **Design Engineer and Contractor Coordination for Ordering of Construction Materials:** The general contractor is responsible for the timing and ordering of the construction materials in order to meet the construction schedule. However, there may be materials that should be ordered in smaller batches or on an as-needed basis. The design engineer and contractor should discuss the risk and likelihood of change prior to ordering materials. Early on, it is important for the design engineer to identify materials that may be subject to change and communicate these potential issues and concerns to the contractor. An example is the drilled and epoxy reinforcement dowels for the facing concrete. The reinforcement was revised to meet the conditions encountered during construction. It may be more cost efficient to order concrete reinforcement only after enough of the demolition is completed and in small batches so that design changes can be made if needed. This may reduce the potential for change orders.

Several aspects of the project worked well and could be applied to other rehabilitation projects. These include the following:

- **Team Approach:** In the beginning of a project, it is beneficial for the design engineers to explain the basis for the design and the design intent to the design team; this fosters a cooperative construction environment. Pre-construction meetings and team workshops worked well to make sure that everyone was on the same page ahead of critical construction steps.
- **Anticipate Change:** In rehabilitation projects, even the best design may require adjustments due to actual conditions encountered. Identify areas that may change and prepare to make provisions for change. ESIs worked well for efficient change management; the process met the needs for quality and schedule.
- **Be Prepared to Adapt:** Understand the existing structure and have realistic expectations. For example, typical standard practice for concrete repair is to remove the concrete down to sound concrete. The quality of the existing concrete at South Channel Dam was questionable. As a result, the concrete demolition was adjusted to a fixed depth rather than down to “sound” concrete. High pressure washing the concrete was a project-specific solution for surface preparation of the existing concrete.

### **3. CONCLUSION**

The Post Falls South Channel Dam Rehabilitation Project consisted of multiple challenges throughout the project. Most of these challenges could not be avoided. The challenges were well understood and tools/procedures/plans were established to meet the needs of the project. This included identifying areas of uncertainty and notifying the contractor of them.

The project was ultimately a success in a large part due to the approach and practices implemented during construction. Some of these best practices include the ability to adapt the design as needed due to site conditions encountered, maintaining a proper balance between documentation needs and the construction schedule, and the importance of a unified team approach between owner, design engineers, inspector, and contractor.

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