SIMPLY BRILLIANT!
New Approach for Isolating Spillway Gates

Frederick Lux III, PE\textsuperscript{1}, Michael Dix\textsuperscript{2}, Dustin Hale, P.Eng\textsuperscript{3}, and Robert T. Indri\textsuperscript{4}

Abstract

The eight spillway gates at Brilliant Dam had never been dewatered since the dam’s construction during World War II and were in need of painting and maintenance. A spillway gate isolation system was not incorporated into the structure for the 34-feet-wide by 36-feet-high vertical lift roller gates when the dam was constructed. Lowering the reservoir was also not an option for this run-of-river hydro plant on the Kootenay River. As the operating agent for Brilliant Dam, FortisBC selected a design-build team of Dix Corporation, Aubian Engineering, Schnabel Engineering and Northwest Steel-Fab for provision of a means to isolate an individual spillway gate. They proposed a reverse needle cofferdam using “floating needles” – an industry first. The floating needle design utilized Aubian Engineering’s patented system for segmental floating stop logs. This spillway gate isolation system was successfully installed in an individual bay at Brilliant Dam in late March 2008, just before the spring freshet was to begin. With the spillway bay dewatered, FortisBC began rehabilitation and repainting of the now dry and accessible gate.

Introduction

Brilliant Dam and Power Plant is owned by Columbia Power Corporation and Columbia Basin Trust, and operated by FortisBC, Inc. The project is located just outside of Castlegar, British Columbia, on the Kootenay River just upstream of the confluence of the Kootenay and Columbia Rivers. Brilliant Dam is the last in a series of eight hydropower projects along 13 miles of the Kootenay River that takes advantage of the river’s 384 foot drop. The 140 foot high concrete gravity dam has four generators with a total capacity of 149 MW. This project was a top priority during World War II to provide power for a smelter located about 20 miles south at Trail, British Columbia. Brilliant Dam was constructed over two years, completed in 1944, and extensively upgraded between 2001 and 2003. A downstream view of the dam and power plant is shown in Figure 1.

The spillway consists of eight bays, each bay containing a steel 34-foot-wide by 36-foot-high roller gate. A steel superstructure supports two travelling hoists above the spillway deck. A travelling hoist lifts the roller gates by means of dual threaded stems. Each stem is fixed to an upper corner of each roller gate leaf and is located within the gate block out. With two travelling hoists, two gates can be operated at the same time or one hoist can act as a backup if the other one is out of service or not available.

\textsuperscript{1} President, Aubian Engineering, Inc., Greensboro, NC
\textsuperscript{2} Operations Manager, Dix Corporation, Spokane, WA
\textsuperscript{3} Mechanical Engineer, FortisBC, Inc., South Slocan, BC
\textsuperscript{4} Project Engineer, Schnabel Engineering, Inc, Greensboro, NC
The spillway roller gates at Brilliant Dam were in need of repair, maintenance and painting after being in service for over 60 years. Exposed steel portions of the gates exhibited some bent bracing members and a thin to non-existent paint coating. The design of the spillway structure did not incorporate a gate isolation system, such as stop log slots, when constructed limiting access to the gate leaf and its component parts. Lowering the reservoir was not an option either on this run-of-river hydro plant. Consequently, the vertical lift roller gates had never been dewatered since the dam’s construction. Further, submerged portions of the gate, seals and embedded guides had never been thoroughly inspected. FortisBC desired a spillway gate isolation system to be able to work on these gates in the “dry” so that the gates could be repaired and painted to extend their useful service life.

**Gate Isolation Approach**

What makes spillway gate isolation at Brilliant Dam so difficult is the configuration of the spillway piers and crest. The pier noses extend 10 feet upstream of the crest. This is a common design feature on many concrete spillways but one that makes it difficult to isolate the spillway gates if no provisions are made during design and construction of the dam.

**Horizontally Spanning Gate Isolation Systems**

The conventional approach for gate isolation is to provide a bearing surface at the pier noses or vertical slots in the piers upstream of the gate. When the gate needs to be
dewatered, gate isolation systems, such as stop logs, bulkheads or floating bulkheads that span across the spillway bay, are placed against the pier noses and crest face or installed in the slots under balanced head conditions. The horizontal framing members of these gate isolation systems typically bear on the pier noses or the downstream vertical faces of the slot. Seals are placed along the vertical sides and bottom of the gate isolation system so that reservoir water cannot flow into the intervening space between the gate isolation system and the gate once the space is dewatered.

Unfortunately at the Brilliant Dam, the pier noses extend 10 feet upstream of the crest as shown in Figure 2. To provide an effective bearing and seal surface requires a vertical U-shaped sealing plane to install the horizontally spanning gate isolation systems. Two locations are possible for the sealing plane: 1) At the pier noses, which would require construction of a concrete block on the foundation or extend the crest upstream to provide the bottom of the "U" and to mitigate uplift pressures when the space is dewatered or 2) Between piers on the overflow spillway crest upstream of the gate. The location at the pier noses was dropped from consideration as the pier noses came to a point requiring modification to provide a bearing surface; the foundation was covered with silt and debris and was of unknown condition; the horizontally spanning gate isolation system would need to extend near the full height of the reservoir; and all of this work would need to be done underwater.

![Figure 2. Upstream face of spillway during construction in 1944. Note spillway piers extend from top of dam to foundation 10-feet upstream of vertical face of concrete overflow section.](image)

That left a sealing plane between the piers as the only viable option for horizontally spanning gate isolation systems. This required provision of a bearing means along the side of each pier face within the spillway bay to incorporate any of the horizontally spanning gate isolation systems. Two approaches have been used to provide the bearing surface: 1) Cut a
permanent vertical notch in the concrete pier face or 2) Anchor a fabricated steel “beam seat” vertically to the pier face to support the horizontal members. These bearing supports extend from the overflow crest surface to the top of pier creating in combination with the overflow crest a vertical U-shaped sealing plane. The crest supports the weight of the horizontally spanning gate isolation systems.

Construction of an individual slot or beam seat requires significant underwater work. The slot or beam needs to be surveyed and correctly located underwater to achieve a vertical uniform sealing plane without twist. Divers are used to install a temporary cofferdam at each pier face so that the slot can be cut or the beam seat anchored in a dry environment or are used to assist with underwater cutting of the concrete or installation of anchors for the beam seat. Because there is significant underwater work, the cost to provide an acceptable slot or beam seat at each pier face can far exceed the cost to fabricate and install a horizontally spanning gate isolation system, particularly if there are a significant number of piers to be modified. This horizontal spanning gate isolation system was eliminated from consideration due to the extensive underwater pier modifications and the proximity of post-tensioned steel tendons to the pier faces.

Vertically Spanning Gate Isolation Systems (Needle Cofferdam)

Rather than using horizontal spanning gate isolation systems, another approach is to provide a needle cofferdam. A needle cofferdam consists of a sill, piers, a horizontal support girder that spans between piers, and a series of beams placed vertically between the sill and horizontal support girder. The vertical beams are referred to as needles and can consist of timbers, sheet-piles or a panelized system. These are placed adjacent to each other to provide the damming surface as shown in Figure 3. Typically, the support beam is a fabricated plate girder, truss or a hollow structural section (HSS) tube (Lux, 1997; Morgan, 2006).

![Figure 3. Simple Needle Dams (USACE, 1995).](image)

Typically, needle cofferdams are used to isolate intake openings that have a relatively long span and low head, such as crest gates. This arrangement allows two-thirds of the water load to be carried by the sill and only one third by the support beam. The primary limiting factor for use of needle cofferdams is the height of the needles; the needle structural capacity is exceeded quickly as the water depth increases. As a general rule, needle cofferdams have been limited to a depth of approximately 27 feet – the maximum depth at which steel sheet piles can be used without bracing.
Usually horizontal spanning gate isolation systems are more economical to fabricate and install than a needle cofferdam if the structure is capable of supporting the gate isolation system with minimal structure modifications. However, the cost for underwater pier face modifications needed at each of Brilliant’s eight piers to use a horizontal spanning gate isolation system more than offset the initial cost of the needle cofferdam.

In a normal needle cofferdam, the needles bear against the support beam. For a “reverse” needle cofferdam, the vertical needles pull against the support beam rather than bear against it (Boyd, 2005). A reverse needle cofferdam is used typically where the spillway vertical crest face is recessed back from the pier noses, such as at Brilliant Dam. While this arrangement complicates the needle connection to the support beam, it minimizes pier modifications for installation of the support beam. A reverse needle cofferdam was selected for use at the Brilliant Project because of its low fabrication cost; minimal need for pier modifications; no underwater structure modifications required; and its ease of installation, removal and translation from bay to bay. However, to use a reverse needle cofferdam required design of needles that could be used to dewater to a depth of 42 feet – well beyond typical needle height.

**Brilliant Reverse Needle Cofferdam Design**

For this project, the reverse needle cofferdam utilized the vertical upstream face of the spillway crest, the pier walls and a support beam located just above maximum pool, Elevation 1480.0 feet. The run-of-river operation at this plant allows the reservoir to vary from elevation 1473.0 feet to Elevation 1477.0 feet, a reservoir variation of 4 feet. Typically, the reservoir is maintained just below Elevation 1477.0 feet. The transition from the vertical crest face to an ogee shape occurs at Elevation 1439.07 feet. Thus, the total head is 42 feet when one foot of freeboard is included. The distance between piers is 48 feet and the clear span of the spillway bay at the vertical crest face location is 36.0 feet. Refer to Figure 4.

Aubian Engineering conceived of a needle design using steel HSS tubes based on their experience with segmental floating bulkheads (Lux, 2008). The needle uses Aubian’s patented system of sandwiching steel HSS tubes between steel plates to provide the structural capacity required and at the same time create buoyancy and ballasting chambers. Schnabel Engineering provided design of the pier modifications, support beam and through Aubian Engineering’s license, the floating needles.

**Floating Needles**

The design of the needles is an iterative process between fulfilling structural requirements, buoyant height needed above the reservoir, buoyant stability in all three axes when the bulkhead is floating vertically, and horizontal stability when all ballast chambers are emptied. The cover plated HSS tubes were sized to meet “CAN/CSA S16-01 – Limit States Design of Steel Structures” standards, especially the width to thickness ratios of the steel elements. The cover plate thickness and their extent on the HSS tubes were governed by structural and buoyant stability requirements.

One of the limitations of a floating bulkhead or needle is the buoyant height needed above the reservoir water surface. For the floating needle to be stable in a vertical orientation, its center of gravity needs to be below the buoyant centroid. As more of the needle is exposed
above the reservoir by removing ballast, the buoyant centroid is lowered until it reaches the center of gravity. At this point the needle is unstable and will begin to rotate to a horizontal position. The needles were designed for an exposed height of 9 feet to reach Elevation 1482.0 feet, the height needed for the top of the needles when the reservoir is at Elevation 1473.0 feet, minimum pool.

Each floating needle consists of two or three jumbo HSS 24x19x3/8 tubes welded to a downstream flat sealing plate, and upstream cover and intermediate plates to create ballasting and buoyant chambers. Three needle configurations were used; end, intermediate and center. The two end needles have a downstream sealing plate width of 76.5 inches and use two HSS tubes. The two intermediate needles have a downstream sealing plate width of 78.5 inches and use two HSS tubes. The center needle has a downstream seal width of 118 inches and uses three HSS tubes. The HSS tube and intermediate chambers are sealed at each end. A set of valves are used to add or purge water from the ballast chambers for each needle. When the needle is completely empty it floats on the reservoir in a horizontal position. When ballasted, the needle rotates to a vertical position. The needle can be trimmed to the needed elevation by adding water to lower it or using compressed air to raise it.

Each floating needle is connected at its top to the downstream support beam using bolts. At the bottom, each needle bears against the upstream vertical face of the spillway crest. An elastomeric bearing pad runs along the bottom of each needle to make a seal between the needle bottom and the crest face. A flap seal is used between each vertical needle to prevent water from passing through the joint between needles. An adjustable flap seal is used at the joint between the end needles and the piers.

**Support Beam Assembly**

The support beam assembly consists of an upstream beam to transfer the needle loads to the piers, a downstream beam to support the individual needle top end reactions and 12 tension rods spanning between the two beams to connect them together (Figure 5).

The upstream beam consists of a jumbo HSS 42x24x3/4 tube with a length of 47 feet. The 3/4 inch thick cover plates are welded to each of the 24 inch width sides. It rests on sills cut in the nose of each concrete pier. Elastomeric bearing pads mounted to the upstream beam transfer the beam end reactions to the pier concrete. These bearing pads transfer the upstream beam’s end reactions due dewatering loads to the piers. Elastomeric bearing pads are located on the bottom of the beam to support the beams self weight and live loads. The upstream beam was placed upstream of the needles for the spillway bays because there was insufficient space on the piers between the sealing plane and the gates to transfer support beam loads. Also, the pier modifications would have interfered with the post-tensioned steel anchors previously installed in each pier.

The downstream beam supports the top reaction of the vertical needles. This horizontal load from the downstream beam is transferred to the upstream beam using 12 equally spaced high strength (150 kips per square inch) threaded rods. The needles are connected to the downstream beam using two bolts through each needle HSS. At each pier, the downstream beam rests on a flat ledge containing a sliding seat. We estimated that this beam would move downstream approximately one inch due to deflection of the upstream beam when the intervening space is dewatered.
Figure 4. Needle cofferdam section through spillway bay,
Figure 5. Needle Cofferdam Plan
The support beam assembly is transported on the reservoir using a barge and cribbing when it is desirable to move it to another spillway bay or launch/extract it from the reservoir.

**Pier Modifications**

To minimize the exposed height of the floating needles, the support beam assembly was set as low as possible at Elevation 1480 feet. This necessitated that the pier noses be lowered by 6.5 feet. In addition, a suitable location and area was needed to transfer the upstream support beam end reactions to the pier. This was accommodated by saw cutting and demolishing the upper potions of the pier nose above the reservoir to provide both a level surface to support the upstream beam and a vertical surface to transfer the upstream beam end reactions to the piers.

With this unique design, the five 44-foot-long needles can hold back 41 feet of water when the reservoir is at maximum pool. When installed, the 36-foot-wide by 44-feet-high needle cofferdam holds back a reservoir load of approximately 2 million pounds at maximum pool. The support beam ends transfer approximately 330,000 pounds to each pier when the needle cofferdam is used to isolate the spillway gate.

**CONSTRUCTION**

After award of the contract in summer 2006, Dix Corporation hired Associated Underwater Services and NUS Group to perform an underwater survey of each spillway bay. NUS performed this work in October 2006. This survey was critical to the design and sealing arrangements for the needle cofferdam. The underwater survey consisted of interval offset measurements using a vertical plumb bob to measure the pier face surface variation; interval offset measurements using horizontal wire line across the vertical crest face where the needles were to bear; and a span measurement along the vertical crest face between piers. Also, they performed a visual survey of the concrete surfaces where the needles were to seal and patched those areas as required. In addition, Kodiak Measurement Services performed a level survey of the pier surfaces for the divers use and an alignment survey to locate the bearing pads to be installed on the pier surfaces.

In general, the concrete construction of the piers and upstream crest was well done with spalled concrete mostly at the water line. Total variation in span measurements considering all spillway bays was less than 3.5 inches. The variation of the pier faces along a plumb bob was less than 2 inches. The upstream vertical crest face had a maximum difference of 1.5 inches over all eight bays with an average surface variation over one bay of 0.5 inches.

In July and August, 2007, the time window set by FortisBC, Dix Corporation demolished the pier noses in preparation for the installation of the needle cofferdam. Bluegrass Concrete Cutters used a diamond wire saw to cut suitable sized concrete blocks from the pier noses. At the same time Dix Corporation mobilized a crane on flexi-float barges. The crane lifted the concrete blocks from the pier onto the barge, moved adjacent to the shoreline, and placed the concrete blocks on shore. Dix then located and installed the pier nose bearing seats for the upstream beam on the horizontal and vertical cut concrete pier surfaces.

In late August 2007, the support beam assembly arrived at the site and was installed in Spillway Bay 2 using the flexi-float barges. Dix had hoped that they could install the floating
needles in the fall of 2007 but FortisBC had scheduled an outage to begin in September. Thus, the floating needle commissioning was to occur in March of 2008 as originally planned. Consequently, Dix had to wait until spring 2008 before proceeding with needle cofferdam commissioning. This proved to be beneficial as fabrication of the floating needles took longer than expected.

FABRICATION

Support Beam Assembly
Northwest Steel-Fab fabricated the support beam assembly in August 2007. Fabrication of the assembly was performed in about 3 weeks. Approximately 10 days of delays were incurred due to submittal drawings taking longer than expected to be approved and galvanizing delays because the upstream support beam was too big for the original galvanizer’s kettle and had to be rescheduled and transported from Seattle to Long Beach, CA.

![Figure 6. Support beam assembly installed.](image-url)
Floating Needles
The fabrication of the needles consists of welding the HSS tubes to the downstream plate, welding end plates, welding cover plates, painting the interior of the space between HSS tubes, welding a cover plate to seal the space between the HSS tubes, and welding lifting lugs and other appurtenances. The only difficulty encountered was the welding of the HSS tubes to the downstream plate. The ASTM A500 tolerances for these 44 foot long tubes, particularly for twist were quite large. Consequently, the HSS tubes would not lay flat against the plate. This twist had to be taken out of the tubes before it could be welded. Since these HSS tubes are made by welding two brake formed halves together, we would recommend that the fabricator perform the welding of the HSS halves together rather than the supplier. This allows the fabricator to correct any twist or deviation before the HSS tube is formed.

Figure 7. Needle partially fabricated.
COMMISSIONING

The fabricated needles were delivered from Northwest Steel-Fab’s shop in Cusick, WA, to Brilliant Dam near Castlegar, BC, in late March 2008. The needles were delayed at the Canadian border but not for any longer than a half day. The first two days of commissioning consisted of completing assembly of the needles such as trimming seals and installing valves. The chronology of the installation was as follows:

1. Station a crane adjacent to the needles and shoreline.

2. Close all valves on the needle, secure rigging, lift the needle using the crane and place it in the reservoir so that it floats horizontally.

3. Using a tag line, secure the needle to a boat and remove the rigging lines.

4. Tow the needle to the spillway bay to be dewatered and attach tag lines.

5. Have a diver open the ballast valve and air release valve to allow the needle to move slowly from a horizontal to a vertical position.

6. Once vertical, close the air release valve and move the needle into position between the upstream and downstream support beams using tag lines.

7. Connect an air compressor to the ballast chamber and either add air too raise the needle or release air to lower the needle so that it can be secured to the downstream support beam.

8. Remove the air compressor and have a diver close the ballast valve.

9. Continue to install needles until they are all secured to the downstream beam.

Figure 8. Launching needle.

Figure 9. Needle ballasted to vertical.

Figure 10. Needles installed.
10. Have a diver inspect the positioning of the needles against the piers and crest and adjust the seal clamping bars on the end needles that bear against the pier face.

11. Open the gate slowly to dewater the intervening space.

12. Seal leaks using conventional means.

As with any new system, we had a few glitches that needed to be corrected such as incorrect size of bolts, wrong length for the cranks for opening or closing the valves on the needle, and mismatched holes between the needles and the downstream support beam. The only unexpected item was that the end needles would not come in to bear on the vertical crest face. What we found was that the flap seals were too stiff and wouldn't allow the needle to seat. The divers were able to rig a come-a-long on the crest and pull the end needle in so that it was in its correct position.

Upon dewatering, we found that leakage was minimal with most leaks being sealed with cinders. The adjustable flap seals that were against the piers proved to be particularly tight. With this unique dewatering system in place, FortisBC could proceed with repairing gate members, replacing seals and repainting the gates for the first time in more than 60 years.

**CONCLUSIONS**

Use of floating needles overcomes two significant limitations with needle cofferdams: 1) needle structural capacity with increasing water depth and 2) elimination of a crane or hoist to lift, set and remove the needles. Needles float and can be adjusted using an air compressor eliminating the need for a crane or hoist. With these limitations removed, dam owners are no longer restricted to using needle cofferdams for dewatering a spillway bay that is less than approximately 30 feet deep. Additionally, the needle cofferdam is now competitive in cost with conventional horizontal means for spillway gates such as stop logs and floating bulkheads for use at large spillway gates. Other conclusions were:
• A reverse needle cofferdam proved to be an effective gate isolation system for use at the Brilliant Project because of its low fabrication cost; minimal need for pier modifications; and no underwater modifications required.

• The floating needles using cover plated HSS beams proved to be an effective structural element for deep water use. With this capability, the depth limit for needles has been extended significantly and its use is cost competitive with horizontal spanning gate isolation systems where the structure does not have any provision for dewatering.

• The buoyant capacity of the floating needles facilitated installation, removal and translation from bay to bay. This reduced operating costs since a barge-mounted crane was not needed to move the needles or support beam from bay to bay.

• The use of jumbo HSS structural elements is particularly applicable to hydraulic structures due to their torsional resistance; ability to resist biaxial bending due to gravity and water loads; and their buoyant capacity.

REFERENCES


United States Army Corps of Engineers (USACE). EM 1110-2-2607, “Planning and Design of Navigation Dams, Figure 6-1, pg 6-2, 31 July 1995.