Executive Summary

The Ruskin Dam Right Abutment Seepage Control Upgrade was undertaken to address seepage issues and seismic performance on the dam's right abutment and comprised installation of an innovative seepage cut-off system. It was one of the most technically complex and highly constrained components of the overall Ruskin Dam and Powerhouse Upgrade Project.

Golder's construction division was the main contractor for the Right Abutment works which included:

- Installation of overlapping jet grout columns to replace existing soils, and stabilize and strengthen the abutment soils underneath the concrete dam;
- Construction of a plastic concrete cut-off wall upstream and downstream of the dam using trench-cutter (hydro fraise) technology; and
- Installation of a unique flexible membrane connecting the cut-off wall with the concrete dam.

This Cut-off Wall Tie-In to Concrete Dam was the most challenging project aspect. It involved construction of a slot connecting the newly installed seepage cut-off wall with the existing concrete dam, and development and installation of a custom designed flexible mastic asphalt membrane, combining high flexibility with low permeability.

Despite significant dam safety and schedule constraints, as well as highly variable, and in some cases unforeseen ground conditions, the work was completed within budget, achieving BC Hydro's project objectives, with no reportable health and safety or environmental incidents, and on schedule, to meet BC Hydro's milestone completion date.

This project demonstrates engineering achievement as it accomplished the successful development and application of a previously untried and untested means of flexible connectivity, the Cut-off Wall Tie-In to Concrete Dam.

Objectives, Solutions and Achievements

BC Hydro's Ruskin Dam was constructed in 1929 and 1930, with the right abutment founded on dense, highly erodible sands. Upon filling of the reservoir in 1930, the right abutment experienced seepage and piping which, over time, resulted in serious dam safety concerns related to the integrity of the abutment and concrete dam. The Right Abutment Seepage Control Upgrade was undertaken to address seepage issues and seismic performance on the dam's right abutment and comprised installation of an innovative new seepage cut-off system. It was one of the most technically complex and highly constrained components of an overall $800M Ruskin Dam and Powerhouse Upgrade Project.

Golder was the main contractor for the Right Abutment works which included:

- Installation of overlapping jet grout columns to replace existing soils, and stabilize and strengthen the abutment soils underneath the west end of concrete dam;
- Construction of a plastic concrete cut-off wall upstream and downstream of the dam using trench-cutter (hydro fraise) technology; and
- Installation of a unique flexible membrane to connect the cut-off wall with the concrete dam (Cut-off-wall Tie-in to Concrete Dam).

BC Hydro's objectives for the project included: Engaging a safe and empowered team to safely execute the works; ensuring that the unique and never before implemented technologies met all user requirements; and, ensuring that the project met its in-service date of July 17, 2013.

Acknowledging the technical constraints, and to address the unique challenges of the project, BC Hydro initiated and employed an Early Contractor Involvement (ECI) process for the Right Abutment construction contract. The ECI approach set a new precedent for BC Hydro and created significant gains and value, in particular, fostering a collaborative environment that resulted in numerous innovative ideas being exchanged between BC Hydro and Golder's construction division throughout the construction process. This collaborative approach continued through to the end of construction and resulted in the successful installation and application of a previously untried and untested means of flexible connectivity, the Cut-off-wall Tie-in to Concrete Dam.

A number of challenges and constraints had to be considered and managed during planning and execution of the project. These included: spatial limitations and access restrictions, dam safety, schedule constraints, environmental, public safety, work coordination, and variable ground conditions. Dam safety considerations presented the greatest project constraint to be overcome during construction. Given the sensitive nature of the dam and right abutment, there was the potential for a number of scenarios to be initiated that could ultimately result in failure and collapse of the right abutment if suitable construction techniques were not adopted, controlled and monitored.

Activities deemed to be high risk could only be completed during reservoir drawdown, which was scheduled annually from May 15 to August 1 (Fraser River freshet). In addition, completion of right abutment activities was governed by BC Hydro's milestone in-service date of July 17, 2013. From March to July 2013, Golder's construction division worked around the clock to meet the tight timeline. Driven by the schedule constraints, and to mitigate challenging ground conditions, Golder's construction division proposed a creative and cost-effective option to extend the plastic concrete cut-off wall through the existing drainage adit and thus closer to the dam, thereby shortening the length of the flexible Tie-in. Not only did this gain half a month of schedule, but it resulted in significant project cost savings.

Despite significant dam safety and schedule constraints, as well as highly variable, and in some cases unforeseen ground conditions, the work was completed within budget, achieving BC Hydro's project objectives, with no reportable health and safety or environmental incidents, and on schedule, to meet BC Hydro's in-service date of July 17, 2013.

Technical Excellence and Innovation

Early BC Hydro's seepage control upgrade design called for construction of a flexible seepage cut-off wall connection (i.e. Cut-off Wall Tie-in to Concrete Dam) between the newly constructed plastic concrete cut-off wall and the west end of the concrete dam where the dam soil foundation is also strengthened by overlapping jet grouting columns. This flexible Tie-in connection was undoubtedly the most technically complex and challenging aspect of the Right Abutment project. The main challenges lay with creating a perfectly straight slot 25 m deep, nominally 168 mm wide, and 7 m long through three different construction materials (plastic concrete wall, jet grout columns, and concrete dam) and keyed into bedrock, and then filling with a continuous flexible membrane free from defects.

Drilling the Slot

Given the high risk associated with drilling through the existing concrete dam and the geometric constraints from drilling through thin concrete (2.3 m for the dam and 1.0 m at the plastic concrete cut-off wall), drilling accuracy and drilling technique were deemed to represent the biggest challenges.

The chosen drilling method had to offer suitable accuracy to prevent deviation out of the concrete dam, jet grouting or plastic concrete cut-off wall; had to be of low enough impact to prevent damaging or cracking the existing materials. In particular the jet grout which was considered relatively brittle; had to be capable of advancing at acceptable rates through the various strength construction materials (jet grout, plastic concrete, and concrete), to complete within the tight schedule available for high risk activity (reservoir drawdown); and, it had to utilize equipment which could operate within the limited space constraints of the right abutment work area.

The process that Golder's construction division adopted comprised drilling a series of overlapping primary and secondary holes to achieve the slot. The method utilized an inverted pendulum technique to drill initial highly accurate narrow diameter (NQ) pilot holes for the primary holes. The inverted pendulum technique enables verticality deviation to be monitored periodically during drilling, and allows for the adoption of a correction technique to recover deviations from vertical. The accurate pilot holes were then used as guide holes for a stinger attachment on the drill used for drilling of the 300 mm diameter primary (full gauge) holes thereby ensuring verticality. Once the 300 mm primary holes were completed, the secondary holes were drilled out to create the slot using custom built guides that followed the 300 mm primary holes and prevented deviation.

Maintaining stability of the slot throughout the drilling was one of the key requirements from BC Hydro for dam safety. Analysis indicated that had the slot been completely drilled out over its 7 m length without provision of intermediate braces to ensure stability, then unacceptable stresses would have developed around the slot with a potential for collapse. Golder's construction division completed finite element analysis using PLAXIS to calculate horizontal displacement and assess slot stability. Based on the analysis, the slot was flooded to provide support prior to drill out of two final secondary drill locations which up until then had acted as temporary braces. The final two holes were then drilled using a reverse circulation method which used high volume pumps to remove drill spoil into a surface decant tank while returning water back into the slot. Constant monitoring ensured that the water level in the slot did not drop below the tolerance limit identified through the analysis.

Drilling of the slot was completed without dam safety incident, with cumulative deviations of less than 18 mm, well within the calculated alignment tolerances.

Installing the Membrane

A key project challenge lay with determining how to test and install a never before tried technology, i.e. the flexible membrane. BC Hydro's design required the Tie-in connecting the plastic concrete cut-off wall and the concrete dam to be flexible and watertight to accommodate seismic ground movements at the contact and to prevent seepage from upstream of the dam, and to have sufficient strength to prevent pinching and collapse.

Taking the key performance requirements into consideration, Golder's construction division proposed a mastic asphalt (bitumen-based) membrane. Given the unprecedented nature of the membrane a lengthy period of laboratory tests, batch scale trials, and field trials was undertaken to refine the material composition, to ensure optimum performance and to develop a methodology for installation that could be verified remotely and would work the first time. With only one attempt possible at installation it was critical that the method be successful on the first attempt.

Laboratory and field scale trials determined a relationship between mastic temperature and flow rate, whereby at temperatures above 120°C, the mastic was observed to flow freely even under water. Achieving optimal temperatures at the bottom of the slot during installation would be key to ensuring that the mastic flowed along the slot to reach the edges and fill all voids created by drilling. To confirm success, real time measurement of mastic temperatures was achieved using thermocouple strings installed along the slot. The installation approach was designed to minimize heat loss at all stages of the process from batching the membrane at the asphalt plant, through transport to site, to delivery and installation into the slot. Techniques to reduce heat loss included insulating the delivery pipes, adopting an insulated tremie method of placement, and heating the water in the slot to almost boiling (90ºC) using a steam boiler.

Approximately 47 m3 of hot mastic asphalt were successfully delivered and installed into the slot meeting all testing and verification requirements representing the first known application in North America of the mastic asphalt as a means of flexible connectivity.

Golder's construction division utilized in house global specialists from Golder Associates to support with the Tie-in Slot and flexible membrane design and construction. In addition to the strong local geotechnical expertise and testing capability, Golder Associates support was provided from individuals located as far afield as the United Kingdom and Australia.

Environmental, Economic and Social Sustainability and Aesthetics

The Right Abutment project was the first step in the Ruskin Dam and Powerhouse Upgrade Project, and was crucial for ensuring public safety for downstream residents. Once completed, the overall Ruskin Dam and Powerhouse Upgrade Project will produce enough electricity to serve more than 33,000 homes in the Lower Mainland.

The Ruskin Dam project site is located in an area of environmental sensitivity. The consequence of any uncontrolled release from construction activities had the potential to impact not only a drinking water reservoir, but also Stave River which provides a significant spawning and rearing habitat for salmon and trout. Throughout the construction project, work activities involving large quantities of deleterious materials were completed within a very close proximity of these sensitive water bodies without incident. A comprehensive Environmental Protection Plan (EPP) was prepared by Golder's construction division to assist with meeting the environmental responsibilities during construction. The EPP identified activities and equipment-specific environmental impact avoidance or mitigation measures, and outlined applicable site planning, construction practices, and environmental management. By continual adherence to these strict environmental controls, no reportable environmental incidents occurred throughout the construction program.

Reducing the impacts of the construction on the local community, as well as the many recreational users of the Stave and Ruskin area, was key throughout the project. Due to the location of the plastic concrete cut-off wall, it was necessary to reduce Wilson Street, running alongside the site, to single lane alternating traffic. Road closures were minimized and efforts to maintain local pedestrian and vehicle access, and public safety on Wilson Street adopted. In addition, and in keeping with BC Hydro's commitment to the community, where possible Golder's construction division utilized local material sources, labour, suppliers and sub-contractors during the 17 month project.

Meeting Client's Needs

BC Hydro's objectives for the Project included:

- Engaging a safe and empowered team to safely execute the works
- Ensuring the unique and never before implemented technologies met all user requirements
- Ensuring the project met its milestone completion date

A unique aspect of the project was the ability of Golder to provide the necessary in-house expertise to complete the flexible Cut-off wall Tie-in. Drawing on the collaborative environment fostered during the ECI process, and engaging subject matter technical specialists from within Canada and round the globe, a thorough planning and rigorous testing process was initiated to set the stage for the construction operations.

In-situ field trials were completed for each of the work components, giving BC Hydro confidence in the construction methods and helping to prevent unforeseen issues during construction. From March to July 2013, the construction team worked around the clock to meet the tight schedule, implementing the plans and procedures developed for each stage of the flexible Cut-off wall Tie-in connection.

Despite significant dam safety and schedule constraints, as well as highly variable, and in some cases unforeseen ground conditions, the work was completed within budget, achieving BC Hydro's project objectives, with no reportable health, safety or environmental incidents, and on schedule, to meet BC Hydro's milestone completion date. The collaborative approach initiated at contract award continued through to the end of construction and resulted in the successful installation and application of a previously untried and untested means of flexible connectivity, the Cut-off wall Tie-in to Concrete Dam.

Image 1: Location of right abutment at Ruskin

Image 2: Cores from secondary location showing inverted pendulum pilot hole

Image 3: Drill rig positioned over tie-in slot during secondary ream out

Image 4: Close up of completed overlapping drill holes

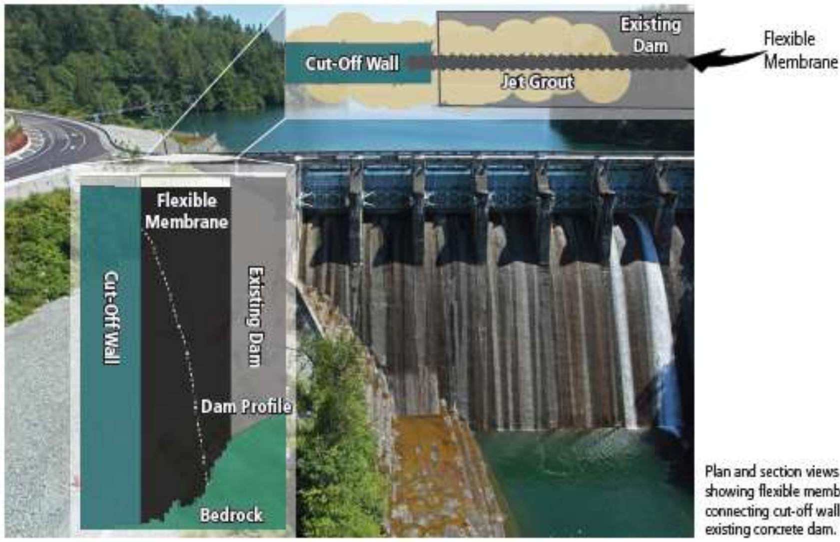
Image 5: Final preparation for mastic asphalt installation

Image 6: Delivery pipes and hopper during mastic asphalt installation

Image 7: Constrained work area showing ready-mix truck delivering mastic asphalt

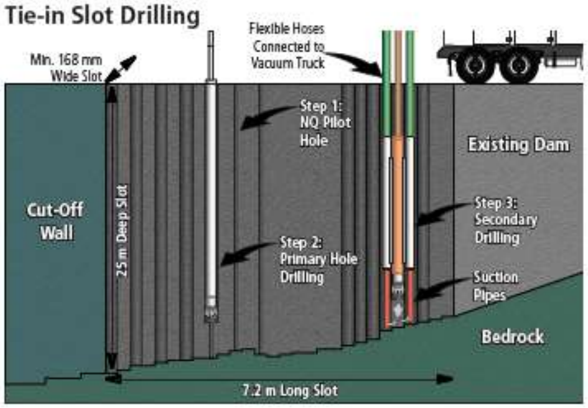
Image 8: Completed Tie-in slot showing mastic asphalt membrane

Cut-Off Wall to the Concrete Dam



Plan and section views showing flexible membrane connecting cut-off wall to existing concrete dam.

Tie-in Slot Drilling



Step 1: Inverted pendulum technique used to drill highly accurate narrow diameter (NQ) pilot holes.

Step 2: Pilot holes used as guides for drilling the 300 mm diameter primary holes thereby maintaining verticality.

Step 3: Secondary holes were drilled out to create the slot using custom built guides that followed the primary holes and prevented deviation.

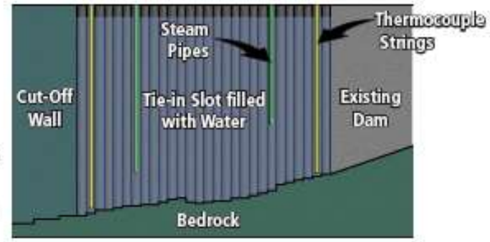
* Schematics not to scale

Mastic Asphalt Membrane Installation

Pre-Installation

Water in slot heated with steam to approximately 90°C.

Thermocouple strings installed at each end of Tie-in Slot.

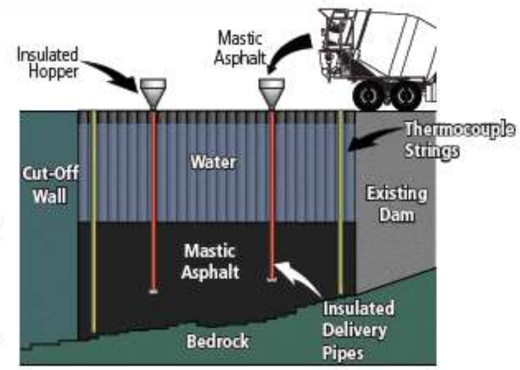


Installation

Water displaced progressively as mastic was installed.

Tremie technique adopted to install mastic.

Thermocouples monitored slot temperatures in real time.



Installation Complete

Approximately 47 m³ of hot mastic asphalt successfully installed.

All testing and verification requirements met.

First known application in North America of the mastic asphalt as a means of flexible connectivity.