JOHN HART DAM - BACKUP JET-GROUTED SEEPAGE CUTOFF WALL CONSTRUCTION

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ABSTRACT

The John Hart Dam is located 9 km west of the town of Campbell River on Vancouver Island, BC, Canada. BC Hydro selected the construction of a backup seepage cutoff wall with jet grouting that can act as additional protection in case of a seismic event. This challenging dam safety project was required to construct the seepage cutoff in the 64 year old earthfill dam without reservoir drawdown. An Early Contractor Involvement (ECI) process was chosen by BC Hydro to develop, jointly with the Contractor, a jet grouting methodology that minimized the risk of hydraulic fracturing or hydraulic jacking of the dam fills. The Contractor was required to demonstrate the effectiveness of the methodology in a Field Trial, and upon acceptance of the methodology by BC Hydro, execute the Production Works at the North Earthfill Dam. This paper describes the ECI process, the adopted jet grouting methodologies, the results obtained and the safety precaution measures implemented on site to manage the dam safety and environmental risks during the jet grouting execution.

INTRODUCTION

The John Hart Dam was constructed between 1946 and 1947 on the Campbell River. Campbell River is located in an area of high seismicity, where two earthquakes of M7 or greater have been recorded within this century. One of the earthquakes occurred in 1946, within 30 km of the John Hart Dam, which was under construction at that time.

The main components of the John Hart Development consist of a 250 m long and 30 m high concrete Gravity Main Dam with a three bay gated spillway, the North, Middle and South Earthfill Dams, a 10 m high Concrete Intake Gravity Structure with six gated bays, and three 3.66 m diameter and 1.8 km long wood stave/steel penstock connecting to the downstream powerhouse.

A major seismic rehabilitation was completed in 1988 including a plastic concrete slurry wall in the Middle and South Earthfill Dams. Jet grouting was also used to construct a flexible cutoff wall beneath the concrete Intake Gravity Structure. The site layout is shown on Figure 1.

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DESCRIPTION OF THE WORKS AND CONTRACTUAL APPROACH

In order to provide a backup seepage cutoff to interact with the existing cutoff in case of a seismic event, BC Hydro required the construction of a jet grouted cutoff wall in the right abutment of the North Earthfill Dam. The proposed cutoff wall is approximately 20 m long. It connects to the concrete main dam at the south end and to the original dam sheet pile wall at the north end. The wall penetrates approximately 17 m of sand overlying a low plastic clayey silt layer of variable thickness above basalt bedrock.

Considering the apparent good experience with jet grouting used beneath the Concrete Intake Gravity Structure in the 1987/88 seismic rehabilitation, BC Hydro selected jet grouting as the construction technique for the proposed cutoff wall in the North Earthfill Dam. Jet grouting is a well-known soil improvement technology that uses high speed jet(s) of grout mix, usually between 700 to 900 km/hr, to mix and create in situ geometrical elements (usually columns) composed of existing soil and grout mix. To create these speeds, the grout mix pressure used is in the order of 300 to 500 bars. Using high pressures, high flows and high volumes of grout mix to create the necessary energy to construct the jet grouted element, the process produces high volumes of reflow composed of soil in situ and grout mix at the ground surface.
Reflow is created considering that the soil is not able to receive the excess volume of grout necessary to create the geometrical elements designed. Reflow is a “must” in the jet grouting process, with exceptions in some special cases and applications. Without a continuous return of the reflow to the ground surface, significant grout pressure can build up in the ground with consequent hydro-fracturing or hydro-jacking of the soil. Another aspect of reflow management is to prevent highly negative environmental impact on the job.

In the case of John Hart Dam, un-obstructed return of reflow to the ground surface during jet grouting is absolutely critical. Clogging of reflow could hydro-fracture the dam fills with detrimental consequences to the stability and safety of the dam. Stringent reflow management is also essential in preserving water quality in the John Hart reservoir that supplies drinking water to the City of Campbell River. To manage the aforementioned dam safety and environmental risks, BC Hydro elected to adopt a two staged Early Contractor Involvement (ECI) contracting process. Matcon Excavation and Shoring Ltd. of Coquitlam, B.C. was subsequently awarded the contract to undertake the following tasks:

- Stage 1 - Participate as part of the BCH Design Team to provide constructability review and to develop a methodology that will minimize the risk of hydraulic fracturing in the dam fills during jet grouting.
- Stage 2 - Conduct a Field Trial to demonstrate the proposed equipment and jet grouting methodology can be safely used in a dam. Upon a successful completion of the Field Trial and acceptance of the methodology by BC Hydro, execute the Production Works by constructing the proposed seepage cutoff wall at the North Earthfill Dam.

The backup seepage cutoff wall specified in the contract consisted of overlapping jet-grouted columns in a single row with the following characteristics:

- Minimum wall thickness above El. 130 m shall be 800 mm.
- Minimum wall thickness below El. 130 m shall be 500 mm.
- Maximum vertical deviation from top to bottom of each column shall be within 1 %.
- Maximum vertical and horizontal tolerances at centre of each column shall be 50 mm.
- The unconfined compressive strength of the cement bentonite grout sample at the mixer shall be 200 kPa at 28 days.

Due to schedule constraints, BC Hydro Engineering retained Pascal Garand, P.Eng. of SNC Lavalin to conduct a laboratory test program and develop a cement bentonite grout mix. To avoid any potential confusion, responsibilities for each party were clearly defined at the onset of the ECI process.
Matcon proposed several options, including methodology, equipment, drilling systems, etc. for discussion with BC Hydro during Stage 1 of the ECI process. The final proposed methodology/design accepted by BC Hydro, to be verified in the field trial, was:

- Pre-drilling of each single hole with sonic drilling and PVC installation with 0.35 m embedment in the bedrock. No air was permitted in the dam embankment, and a minimum amount of water was allowed for drilling.
- Execution, inside the PVC pipe previously installed, of a single row of jet-grouted columns of 20 to 25 m deep, using a mono-fluid (jetting only with grout mix without air) jet-grouting system.
- Column diameter target was 1.4 to 1.6 m.
- Strict control of verticality of the jet grouted columns.
- Prepare, verification and acceptance of grout mix design provided by BC Hydro.
- Continuous real-time monitoring and recording of all the jet-grouting parameters and piezometer readings.
- Detailed environmental protection plan to properly manage the reflow/spoil to avoid contamination of the reservoir.

FIELD TRIAL

The Field Trial was completed between July and August 2012. The selected Field Trial site is shown on Figure 1. A total of three single columns and two pairs of overlapped columns, all 20 m deep, were constructed. Selected jet grouting parameters for each column are summarized in Figure 2. The sequence of installation closely emulated the construction sequence for the Production Works. During the Field Trial, no major problems were encountered except for some initial modifications to the sonic drilling procedures.

Figure 2: Jet Grout Parameters and Exposed Test Columns during Verification

In addition to demonstrating the proposed equipment and jet grouting methodology, the Field Trial also provided an excellent opportunity to gain understanding on how the adjacent ground and pore water pressure reacted to the high grout pressure jetting. Significant increase in dynamic and residual pore water pressure could lead to embankment instability. Prior to the commencement of the Field Trial, two piezometers were installed to supplement the existing piezometers on the site. This allowed pore water pressure data to be collected at different distances and depths from the various test columns during installation.
The recorded pore pressure data during the installation of a typical test column are shown on Figure 3. These data suggest that as jet grouting approached about 2 to 3 m in elevation above and below the deep and shallow piezometers, excess pore water pressure was generated in the adjacent ground. However, the excess pore water pressure started to dissipate as soon as jet grouting was halted and the residual pore pressure was minimal.

![Figure 3. Typical Pore Water Resources During Jet Grouting](image)

The collected data from all the test columns were summarized by plotting the maximum excess pore water pressure vs distances from the jet grouted columns, as shown in Figure 4. The observed trends provided a means for predicting jet grouting induced excess pore water pressure and setting alarm levels for the Production Work.

![Figure 4. Summary of Collected Pore Water Pressure Data](image)

Jet grout column diameter, especially at depth, and in-place grout consistency in the column are typical questions of controversy. In this Field Trial, column diameter was verified by three independent methods, including direct measurement with a mechanical caliper immediately after each column was jetted, exposing the upper 3 m of the test columns in an excavation, and coring with a sonic drill rig. The mechanical caliper was
only marginally effective in the upper 10 m of the columns. Significant resistances prevented the caliper be advanced below about 10 m depth. Five test columns were exposed to the top of the groundwater table in an excavation, as shown in Figure 5. Measured diameter of the exposed columns ranged from 1.5 to 1.7 m. Four vertical and inclined sonic holes (see IC4, IC5, C6 and C7 on Figure 2) were cored in two pairs of overlapped columns. All retrieved cores showed good continuity of grout in the columns.

To investigate whether hydro-fracturing or hydro-jacking had occurred during installation of the test columns, three vertical sonic holes (S1, S2 and S3 on Figure 2) were drilled approximately 2 m from test columns P1, T5 and T6. The retrieved sonic cores were carefully examined. No signs of hydro-fracturing, as indicated by the presence of grout layers, were observed.

With the measuring of verticality with TIGOR (a special jet-grouting verticality measuring tool) it was possible to determine the exact position of the center of the column along the 20 meters that were jet grouted. Maximum deviation of the test columns was 1.51%, with an average of 0.73 %.

**PRODUCTION WORKS**

Based on the promising results achieved in the field test, BC Hydro provided authorization for the Contractor to proceed with the Production Works at the North Earthfill Dam. The design of the jet-grouted cutoff was finalized as shown on Figure 6. A spacing of 0.7 m was chosen by the Contractor for the primary, secondary and tertiary columns. Spacing and diameters were compatible (with a possible 1% deviation of the hole) with the achievement of the specified wall thickness.
The Production Works (34 columns) started on September 10th and completed on October 4th, 2011. The work site for the installation equipment was a small area along the embankment. This made the logistics of installing the sonic and jet grouting drill rig, grout pump and plant for jet-grouting, grout plant and tanks for the bentonite extremely difficult as shown in Figure 7. The reflow was managed by collecting the reflow in a trench, parallel to the cutoff wall, and pumping it into several storage tanks that were emptied regularly, as shown in Figure 8.
QUALITY ASSURANCE/QUALITY CONTROL

An extensive Quality Assurance (QA)/Quality Control (QC) program was carried out during construction. The primary focus is on the consistency of the grout mix produced at the batching plant. A site laboratory was assembled to frequently test, and as required by the contract specifications, Marsh Funnel viscosity and density of the grout mix produced for jet-grouting. The grout mix provided by BC Hydro and SNC, which has a cement:water ratio of 33.5% and a bentonite:water ratio of 3.4%, was optimized to be pumpable with a Marsh Funnel viscosity less than 50 s and a density of 1225 kg/m³. For QA/QC testing, grout samples were collected from the batching plant and the reflow for each constructed column. In addition, the Contractor utilized a bailer to obtain “wet grab” samples at about 12 m depth from seven columns selected by BC Hydro. All collected samples were labelled as they were collected in the field before being shipped on the following day to the QA and QC laboratories for testing. In total, 92 unconfined compression strength (UCS) tests and six consolidated undrained triaxial tests and permeability tests were completed. All samples met the specified minimum 200 kPa of UCS at 28 days. Average measured permeability was 2x10⁻⁶ cm/s. Three sonic cored holes were also conducted to verify the continuity of the constructed cutoff wall.

Based on the pore water pressure data from the Field Trial, high and low warning levels and high alarm levels were established for 10 piezometers in the North Earthfill Dam prior to the commencement of jet grouting. Triggering of any warning levels required the jet grouting operation be halted immediately. High warning levels were triggered three times during the Production Works. Jet grouting resumed after several hours in each incident, following BC Hydro engineer’s confirmation that there was no dam safety concern. High alarm level was not triggered, which would require the execution of an established project emergency response plan, including immediate reservoir drawdown and 24 hour surveillance.
Continuous monitoring of the jet grout parameters and piezometers was carried out from a construction site office adjacent to the work site. All jet grout parameters and piezometer data were displayed in real-time on two laptop computers during jet grouting, as shown on Figure 9. The computer operator communicated with the field inspectors by radio. Jet grouting could be stopped within seconds in the event of an alarm exceedance or unusual jet grout parameter settings.

Figure 9. Real Time Display of Jet Grout Parameters

RESULTS AND CONCLUSIONS

The ECI process promoted early involvement with the specialist contractor and this procurement strategy allowed the contractor to provide their input on constructability during design with the Project Team. This process has proven to be both successful and effective for a difficult and risky job such as the backup seepage cutoff construction at the John Hart North Earthfill Dam.

The Field Trial provided invaluable information for refinements to the construction methodologies and allowed efficient implementation of the Production Works. The Field Trial allowed both the Project Team and the Contractor to investigate, discuss and resolve these unforeseen issues at early stage prior to implementation of the Production Works.

The proposed jet grouting methodology appeared to be effective in preventing hydro-fracturing in the dam fills. Clogging of the reflow could create excessive pressure and consequent hydro-fracturing or hydro-jacking of the surrounding ground.

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