SEEPAGE MANAGEMENT CONTROL FOR A DAM REHABILITATION PROJECT USING DEEP CUT-OFF WALL CONSTRUCTION AND JET GROUTING

Michael B. Richardson, P.Eng., Klohn Crippen Berger Limited, Calgary, AB, Canada
Thomas K. Murray, P.Eng., Klohn Crippen Berger Limited, Calgary, AB, Canada
Agnel George, P.Eng., SaskPower, Regina, SK, Canada

ABSTRACT

Morrison Dam is located on the East Poplar River approximately 12 km southeast of Coronach, Saskatchewan and less than 4 km north of the US-Montana border.

The dam has experienced significant seepage throughout its history resulting in deterioration of the concrete spillway. SaskPower is undertaking a two phase rehabilitation program. Phase 1, completed in 2014, consisted of constructing a soil-cement-bentonite (SCB) and jet grout cut-off wall through the core of the dam and underlying foundation. Phase 2 is being carried out in 2015-2016 and consists of demolition and replacement of portions of the spillway structure, and improvements to the underdrainage and seepage collection system.

The SCB cut-off wall was constructed from the dam crest, through the dam core to the underlying bedrock on either side of the existing spillway structure. The SCB wall was designed to produce a low permeability cut-off barrier intercepting two pervious foundation layers (upper sand and lower gravel layers) separated by a clay zone, extending into relatively impermeable mudstone bedrock. Jet grout columns were constructed from the underside of the spillway slab to bedrock and intercepting the SCB cut-off wall, to provide a continuous cut-off wall underlying the service spillway. This paper provides a case history for the cut-off wall construction. Ongoing groundwater monitoring results have shown a reduction in groundwater levels following the construction of the cut-off wall.

RÉSUMÉ

Le barrage Morrison est situé sur la rivière Poplar Est, à environ 12 km au sud-est de Coronach, Saskatchewan et à moins de 4 km au nord de la frontière de l’état américain du Montana.

Le barrage a subi une infiltration significative depuis sa construction, menant à une détérioration du béton du déversoir. SaskPower a entrepris un programme de réhabilitation en deux phases. La première phase, complétée en 2014, comprend la construction d’une paroi étanche en mélange sol-ciment-bentonite (SCB) et de jet grout à travers le noyau et les fondations sous-jacentes. La deuxième phase (2015-2016) comprend la démolition et le remplacement de certaines portions du déversoir et des améliorations au système de drainage sous-jacent.

Une paroi étanche en mélange SCB a été construite à partir de la crête du barrage, à travers le noyau du barrage jusqu’à la roche-mère sous-jacente de part et d’autre de la structure existante du déversoir. La paroi SCB a été conçue afin de produire un écran à faible perméabilité interceptant deux lithologies perméables (sable et graviers sous-jacents) séparées par de l’argile et à même une roche-mère de mudstone relativement imperméable. Afin d’assurer une paroi étanche continue, des colonnes en jet grout ont été construites à partir de la surface de la roche mère jusqu’à la base des dalles du déversoir. Ce document présente une étude de cas pour la construction de la paroi étanche. Un suivi des données d’instrumentation sur les niveaux phréatiques a montré un rabattement de la nappe phréatique dû à la construction de la paroi étanche.
1 INTRODUCTION

1.1 General

Morrison Dam is located on the East Poplar River approximately 12 km southeast of the Town of Coronach, Saskatchewan and 4 km north of the US-Montana border. The dam is owned and operated by SaskPower and was constructed between 1975 and 1977. Morrison Dam provides a source of cooling water for the nearby coal fired Poplar River Power Station (PRPS). The primary facilities associated with the Morrison Dam include the main dam, service spillway, auxiliary spillway, and riparian low level outlet.

1.2 Background and Objectives

A major concern at the Morrison Dam service spillway since its original construction is the significant seepage that occurs in the vicinity of the service spillway structure. In addition, the overall flood handling capacity of the spillway structure together with that of the auxiliary spillway is inadequate based on 2007 Canadian Dam Association (CDA) Guidelines and therefore requires upgrades to the flow control structures. To address these concerns, SaskPower contracted Klohn Crippen Berger Ltd. (KCB) to carry out preliminary engineering studies during the period 2011-2013 to assess the seepage and underslab drainage system at the service spillway and to assess the combined flood handling capabilities of the spillways. Various options for upgrading were evaluated including rehabilitation of the existing service spillway structure as well as possible construction of a new structure at an alternative location. Based on these studies, SaskPower decided to proceed with final design and construction to rehabilitate the service spillway at its existing location, upgrade the auxiliary spillway and implement additional remedial measures including upgrades to the riparian low level outlet.

Construction was planned to occur over a two year period beginning in 2014 with completion during the winter of 2015/2016. The work carried out during the Phase 1 construction contract included the following:

- Excavation of the upper 2.0 - 2.5 m of embankment fill to lower portions of the dam crest and provide a work platform of sufficient width for the SCB slurry trench construction and subsequent backfill placement to restore the dam to the original crest elevation.
- Installation of a soil-cement-bentonite (SCB) slurry trench cut-off wall through the dam embankment to intercept and cut off seepage through two pervious foundation layers. The cut-off wall is to extend approximately 22 m vertically down to bedrock and laterally on either side of the existing service spillway (approximately 250 m total length).
- Installation of a jet grout (JG) cut-off wall to bedrock across and underlying the service spillway structure (approximately 30 m width) to tie in with the SCB slurry trench cut-off wall to provide a continuous seepage barrier combined with the SCB slurry trench cut-off wall.
- Upgrading of the auxiliary spillway including deepening of the channel, excavation of a pilot channel on the west side, construction of a two stage fuse plug (i.e. small erodible embankment), provision of riprap and a concrete slab for erosion protection, and raising of the east guide dyke.
- Excavation and re-grading of the west embankment toe ditch including an earthfill plug at the east end and a new outlet ditch at the west end to redirect drainage away from the service spillway.
- Replacement of slide gates at the riparian low level outlet and upgrades to the structure including raising the structure by 2 m to correspond with the dam crest elevation.
- Upgrading of access roads to facilitate all weather access.
The proposed work for the Phase 2 construction during 2015-2016 includes provision of temporary cofferdams; installation of local dewatering measures; demolition and replacement of portions of the spillway structure; repairs and upgrades to the remaining portions of the spillway structure; reconstruction of the underdrainage system including thicker gravel zones, new drain pipes and manholes; refurbishment of radial gates; replacement of hoists and hoist deck; and upgrading of safety and security measures.

### 1.3 Morrison Dam Key Components

Table 1 provides details of the key components at the Morrison Dam. Figure 1 provides locations for the key components.

<table>
<thead>
<tr>
<th>Key Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam Name</td>
<td>Morrison Dam</td>
</tr>
<tr>
<td>Dam Owner</td>
<td>SaskPower, Poplar River Power Station, Coronach, Saskatchewan</td>
</tr>
<tr>
<td>Reservoir</td>
<td>Cookson Reservoir – Full Supply level (FSL) at El. 753m</td>
</tr>
<tr>
<td>Reservoir Purpose</td>
<td>Supply of cooling water to the coal fired Poplar River Power Station</td>
</tr>
<tr>
<td>Construction date</td>
<td>1975-1977</td>
</tr>
<tr>
<td>Dam</td>
<td>1830 m long x 17 m high with design crest elevation of 757.0 m. Zoned earthfill embankment with upstream impervious shell and downstream semi-pervious shell, internal drains, and upstream rip-rap and bedding.</td>
</tr>
<tr>
<td>Spillways</td>
<td>Service spillway – 92.6 m long by minimum 15.4m wide concrete chute spillway equipped with two radial gates on west side of main river valley. Weir crest elevation is 750.87 m. Auxiliary spillway – approximately 120 m wide earth channel excavation on west abutment. Channel invert El. 753.8 m with fuse plug varying from elevation 754.2 m to 754.8 m.</td>
</tr>
<tr>
<td>Riparian Outlet</td>
<td>1220 mm diameter CSP with 889 mm diameter concrete liner between downstream toe of dam and 70 m upstream of gatewell. Pipe invert at El. 741.75 m.</td>
</tr>
<tr>
<td>Hazard Classification</td>
<td>Very High (in accordance with CDA 2007 Guidelines (CDA, 2013))</td>
</tr>
</tbody>
</table>

### 2 SITE DESCRIPTION

#### 2.1 Morrison Dam

The Morrison Dam is comprised of three embankment sections including the main dam across the East Poplar River valley and the east and west embankments on either side of the main valley resulting in a total dam length of about 1800 m. The dam crest is set at a minimum elevation of 757 m, varying in some places up to 757.5 m. The 17 m high earth fill dam impounds Cookson Reservoir with a storage volume of approximately 41 000 dam³ at its full supply level (FSL) of 753.0 m. The dam height decreases along the east and west embankments where it typically varies in the range of about 5 m to 7 m. Each embankment section is constructed of earthfill with an impervious fill section in the upstream shell and a random fill section and internal drains in the downstream shell.

The impervious fill is comprised of medium to low plasticity clay till and the random fill is semi-pervious silty sand and gravelly sand. An inclined chimney drain constructed of filter sand and clean pit run gravel separates the impervious and random fill zones thereby providing internal drainage. The chimney drain, which is connected to a blanket drain and rock toe drain, controls the internal drainage through the dam. Vertical sand drains were installed below the rock drain at the downstream toe of dam to a depth of 5 m. The upper dam slopes above elevation 749 m are constructed at a slope of 2.5H:1V with the lower slopes varying from 4H:1V to 7H:1V. The upstream slopes are protected against erosion with riprap and bedding gravel.
2.2 Service Spillway

The service spillway is situated on the west valley slope abutment of the East Poplar River and is a concrete chute spillway equipped with two 7.315 m wide by 2.13 m high radial gates. The gates are set on an overflow weir with a crest elevation of 750.87 m, and when closed provide containment of the reservoir up to its FSL of 753.0 m. The spillway incorporates an 11.9H:1V upper chute section and a 4H:1V lower chute section. A horizontal hydraulic jump stilling basin is provided at the toe of the structure for energy dissipation.

The spillway structure is comprised of a series of 9 monoliths with each monolith separated by a transverse joint. The crest section which includes the wing walls, bridge deck, weir and radial gates is referred to as monolith 1; the chute sections are monoliths 2 to 8; and the hydraulic jump stilling basin section is monolith 9. The proposed rehabilitation work will include removal and replacement of monoliths 3 to 7 inclusive, as well as sub cut and replacement of the underdrainage gravels, drain pipes and manholes.
2.3 Foundation Conditions

During the design phases for this project, several site investigations were carried out in the vicinity of the spillway and main dam west embankment to characterize the foundation stratigraphy and nature of the seepage affecting the structure. Boreholes within the service spillway and extending beyond the west side of the auxiliary spillway indicate that the subsurface strata in this area is comprised of a surficial sand aquifer underlain by a clay till aquitard underlain by a second aquifer consisting of a confined gravel layer. The lower gravel is a regional aquifer (Empress Formation) and overlies clay and shale bedrock. In the area of the service spillway, the shale bedrock was observed to be approximately 15 m below original ground at approximately elevation 733 m to 735 m. Alluvial deposits are present in the main river valley and as described above, sands, clay tills and gravel are the primary overburden soils on the surrounding upland (i.e. under the west embankment where the service spillway and auxiliary spillway are both located).

Boreholes were drilled along the crest of the west dam embankment to delineate the depth of pervious foundation layers. A cross section of the boreholes along the crest of the dam is provided in Figure 2. Boreholes BH01 to BH06 and BH28 are within the cut-off wall alignment.

Borehole information along the cut-off wall alignment indicate that the two permeable layers, the upper sand and lower gravel, are quite consistent in thickness and elevation until they approach the river valley where the bedrock begins to drop in elevation. The upper sand seam is generally about 3 m to 5 m thick and is located between El. 750 m and El. 745 m. The gravel seam overlies the top of the bedrock and is typically about 3 m thick in most of the area. The top of the gravel seam is consistently at about El. 737 m. The gravel layer also appeared to pinch out at BH13-01 as it approached the western valley slope of the main river valley, near the riparian outlet. The top of bedrock was typically about El. 735 m before dipping slightly on the east side of the service spillway as the boreholes approached the river valley.

3 CUT-OFF WALL DESIGN

The majority of the seepage barrier consisted of a soil-cement-bentonite (SCB) slurry trench installed through the dam embankment and the underlying pervious foundation. Due to the presence of the concrete spillway structure, an open trench excavation is not feasible across this section, and therefore an alternative seepage barrier consisting of a contiguous line of jet grout soilcrete columns was designed to cut-off the foundation underlying the spillway structure. The two seepage barrier systems were overlapped and designed to provide a continuous barrier throughout the cut-off wall length. The jet grout columns were constructed after the SCB wall to provide a suitable cut-off wall tie in between the two types of cut-off wall.

3.1 Soil Cement Bentonite Wall

3.1.1 General

The SCB cut-off wall design was carried out in two stages:
- SCB mix design
- Seepage analyses

The SCB mix design focused on the performance of the wall fabric itself. This was assessed by undertaking bench-scale tests in the laboratory to replicate the blending of materials proposed for the SCB backfill, and to replicate field conditions and mixing techniques employed in the field. By undertaking a trial of mixes in the laboratory it was possible to predict the likely performance of the mix both in terms
of design criteria and workability. It was deemed important that workability, that is, the slump of the design mix be considered to assist in construction when placing the SCB backfill into the construction trench.

Figure 2: Geological Cross Section along COW

Consequently, KCB undertook a number of trial mixes utilizing imported bentonite, water from Cookson Reservoir, locally sourced cement and excavated trench spoil return, taken as samples of the clay and gravel from the 2013 site investigation. The trial mixes provided a basis for recommended mix parameters to be specified for construction. KCB then undertook seepage modelling using FEFLOW Version 6 [computer software] to establish the length of the cut-off wall. A judgement was made between how cost effective a longer wall would be versus employing local measures, such as wellpoints or pump wells, to reduce local water levels around the spillway. This resulted in a cut-off wall length of 250 m assuming some temporary groundwater measures would still be provided during construction.

3.1.2 Trial Mix Program

For the SCB slurry, a laboratory trial mix program was carried out by KCB in advance of contract award to determine the appropriate mix proportions for each of the soil, cement and bentonite materials. It was originally intended that the soils for the SCB mix would comprise a combination of in situ soils excavated and salvaged from the trench excavation and these materials would be mixed with designated proportions of cement and bentonite. Soil materials for the trial mixes were therefore selected from test holes drilled during the 2013 investigation program along the dam centerline where the SCB slurry trench would
eventually be constructed. Since the foundation strata consisted of layers of clay as well as pervious layers of sand and gravel, soil mixes were selected based on the estimated proportions to be encountered. The water source was Cookson Reservoir. The cement used was Portland GU cement (a general-purpose cement suitable for all uses) manufactured by Lafarge. Two types of sodium bentonite were used in the laboratory testing program including Hydrogel 90 and Premium Gel.

The trial program included 4 proposed mixes for the purposes of establishing if the materials available would be workable and perform to meet the design specification, particularly concerning hydraulic conductivity. The properties of the 4 trial mixes are presented in Table 2.

<table>
<thead>
<tr>
<th>Mix</th>
<th>Fines (%)*</th>
<th>Soil Moisture Content (%)</th>
<th>Cement (% dry weight of soil)</th>
<th>Dry Bentonite in Slurry (% weight of dry soil)</th>
<th>Slump (mini-slump cone) (mm)</th>
<th>Measured Wet Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix 1</td>
<td>36.8</td>
<td>13.8</td>
<td>5</td>
<td>0.85</td>
<td>38</td>
<td>1.76</td>
</tr>
<tr>
<td>Mix 2</td>
<td>36.8</td>
<td>13.8</td>
<td>7</td>
<td>0.73</td>
<td>45</td>
<td>2.00</td>
</tr>
<tr>
<td>Mix 3</td>
<td>71.7</td>
<td>18.0</td>
<td>11</td>
<td>1.63</td>
<td>51</td>
<td>1.72</td>
</tr>
<tr>
<td>Mix 4</td>
<td>49.3</td>
<td>14.2</td>
<td>5</td>
<td>1.48</td>
<td>51</td>
<td>1.77</td>
</tr>
</tbody>
</table>

*Based on % fines in composite soil.

Figure 3 shows the results of the compressive strength with time for each of the 4 mixes. At 28 days, all mixes were greater than 200 kPa, as mixed under laboratory conditions.

Figure 4 shows the hydraulic conductivity test results for each of the 4 proposed mixes at varying consolidation pressures. All but mix 1 achieved the design max hydraulic conductivity of $5 \times 10^{-9}$ m/s.

The laboratory testing program concluded several key points:
- Water from Cookson Reservoir was suitable for producing bentonite slurry;
- The four SCB trial mix samples met the target unconfined compressive strength of 200 kPa at 28 days.
- Three of the SCB trial mix samples met the target laboratory permeability of $5 \times 10^{-9}$ m/s at 28 days (SCB Mixes 2, 3 and 4). Mix SCB 1 did not meet the target laboratory permeability.

3.2 Jet Grout Design

The design for the jet grout cut-off wall was based on field trials conducted at the beginning of the construction program. Contractor pricing for the jet grouting was based on pricing a vertical surface area of cut-off wall, based on a performance criteria for the wall. The number of columns required, and the layout of the columns was not pre-defined in the bid documents. The column configuration was to be determined by the Contractor based on the required wall design thickness of 900 mm using two rows of columns, minimum unconfined compressive strength of 500 kPa at 28 days, and minimum hydraulic permeability of $5 \times 10^{-9}$ m/s. The contract included provisions for a trial jet grout program to determine effective column diameter and column spacing for adequate overlap of columns (refer to section 4.3.2).

4 CUT-OFF WALL CONSTRUCTION

4.1 Site Layout for Construction
The site layout required space for the jet grout column test location, pits for mixing SCB backfill, a lagoon for mixing and storing bentonite slurry and a batching area for plant and equipment used to store and mix cement powder with reservoir water to make neat grout. The site layout is shown in Figure 5.

The dam crest itself was prepared for cut-off wall construction by lowering the downstream portion of the crest by 2.0 m to an elevation of 755.0m. The upstream slope including riprap was not altered.

![Figure 3: Compressive Strength versus Curing Time per Mix](image1)

![Figure 4: Hydraulic Conductivity versus Consolidation Pressure per SCB mix](image2)
4.2  Soil Cement Bentonite Cut-off Wall Construction

Bentonite was mixed with water from Cookson Reservoir and stored in the temporary lagoon excavated as shown in Figure 6.

The bentonite slurry was quality controlled to ensure it was within specification, particularly for density to stabilize the open trench excavation to approximately 23 m depth. Figure 7 shows the trench being excavated through the core of the dam while the trench is supported by bentonite slurry. During this process, the trench is excavated through the bentonite slurry which is continually pumped to the trench whilst it is being excavated. Digging through slurry requires an experienced and skilled operator to construct the trench to ensure a good clean base to the intended wall toe depth.

Instead of using the spoil material from the cut-off trench excavation, the contractor proposed to use a clay till borrow source located about 500 m from the cut-off wall site. The clay till source was relatively consistent unlike the trench spoil material which contained variable quantities of sand, gravel and clay and was also partly mixed with bentonite slurry. The borrow source allowed better control on the mix proportions for the SCB mix, and avoided constraints associated with limited space to remix the trench spoil adjacent to the SCB trench. The SCB backfill was therefore mixed at the contractor laydown area.

At the start of construction, the contractor conducted a series of mix design trials to optimize the mix. The clay till borrow source was used to mix with cement (6%, 8% and 10%), bentonite slurry (0.5% to 1.5%) and bentonite powder (0.5%) where percentages are based on dry weight of soil. Based on early test results the mix design was selected as 8% cement however this was later modified to 6% based on longer term test results.

The bentonite slurry was maintained in a mixing pond throughout the SCB trench construction. The bentonite slurry was then mixed with cement in a venturi mixer and pumped to a series of mixing pits where the clay till soil was mixed. The mixing pits included steel plates at the base of pit to facilitate breaking down clay lumps and create uniform mixing with a backhoe.

After thorough mixing, SCB backfill was transported to the dam crest by rock trucks, tipped at the end of the trench and pushed into the bentonite slurry filled trench. Excavation and backfill were carried out coincidentally, minimizing the change in bentonite slurry volume. The aim was to create a stable angle of repose of the SCB material of about 20-30 degrees to the horizontal as it was advanced. The slurry was not allowed to drop vertically through the trench to avoid the potential for segregation of materials and possible entrapment of voids filled with bentonite slurry. The slump and workability of the SCB backfill, originally tested during the bench-scale testing and checked for each batch during construction was critical for construction. A lead in trench extending a short distance beyond the cut-off wall was used to create the intended angle for deposition of the SCB mix.
Figure 5: Site Layout

Figure 6: View from Dam Crest Looking South towards the Contractors’ Layout Area
4.2.1 QA and QC during SCB Wall Construction

Quality assurance during construction of the SCB wall is key for cut-off wall projects. A full time QC technician and an experienced QA engineer were in attendance at site during the works.

Figure 8: Graph of Daily Sounding Depths Taken Every 3 m as the Cut-off Wall Progresses West of the Spillway.

Figure 8 shows the daily sounding measurements compiled for the construction of the wall to the west of the spillway. The figure shows depths of soundings taken at 3 m intervals along the wall alignment. It records the depth to top of shale bedrock, the toe depth of the wall after keying at least 1 m into bedrock, and it shows the extent of backfill that has taken place. For this particular daily reading, the top line shows that the backfill has been completed to station 1+44 m and requires some backfill between 1+44
and 1+90 to complete this section. The daily monitoring ensured that the leading face of SCB backfill was progressing at the proper angle and that the excavation did not extend more than 45 m ahead of the backfill.

4.3 Jet Grouting

4.3.1 General

Figure 9 shows the specialist tool at the bottom of the drilling stem used in jet grouting. It consists of the soil/rock roller drilling head used to drill to the required depth, and a machine tooled 0.5 m stem with a nozzle aperture at half distance where the grout fluid is forced out of the drill stem at 400 bar when the jet grout column is being constructed. The stem is especially designed to withstand the pressures which are incorporated into the system during the construction of jet grout columns. The nozzle can be seen ready for insertion into the nozzle opening. The jet grouting process uses such large pressures that the hoses delivering the grout from the pump house to the drill rig are specially designed to withstand high pressures and the connection between hoses are secured with whip preventers in case the hose connections were to break at high pressure.

![Figure 9: Rock Roller Drilling Head and Jet Grouting Nozzle Aperture with Nozzle](image)

4.3.2 Jet Grout Trials

A jet grout test section was installed at the location shown on Figure 5 that aimed to represent the expected soil types to be encountered in the production area. Three separate panels, each consisting of three jet grout columns were installed. The panels were installed using varying parameters as shown in Table 3 in order to evaluate the jet nozzle aperture, drill lift rate and spacing between columns to ensure sufficient column overlap.

The upper 3 m of the trial columns were carefully excavated to show the effective lateral penetration of the jet grout columns and resulting overlap between adjacent columns for each of the panels. As shown in Figure 10, columns 2B and 2C on the left showed the greatest degree of overlap and continuity between columns. On this basis, the contractor adopted the same parameters for production work including 1.0 m spacing between grout columns, 400 bar injection pressure, 0.25 m/min lift rate and a jet nozzle aperture of 5 mm. The jet grout column arrangement included two lines of grout holes with each line staggered from the other to provide maximum overlapping. The intent was to ensure each line overlapped for a minimum thickness of 450 mm resulting in a total width of 900 mm for the two lines.

Attempts were made to core vertically through the center of selected grout columns and at the midpoint between columns to check the quality of the soilcrete column and the lateral penetration throughout the
full length in each of the soil strata. The encountering of several coarse layers with gravel resulted in very poor core retrieval and the results were inconclusive. In the end the parameter selection was based entirely on the observations from the excavated top few metres of the soilcrete columns.

4.3.3 Jet Grouting Production Columns

The alignment of the jet grout cut-off wall extended across the spillway structure but was offset downstream of the dam centreline and overflow weir with radial gates. This alignment avoided the need for cofferdam and dewatering if the alignment was upstream of the weir. The alignment was positioned with one grout column row upstream of the monolith 2/3 construction joint and the other on the downstream side thereby connecting with the underlying concrete cut-off wall at the joint location. The spillway slab was cored for a depth of 900 mm to 1000 mm at each hole location to provide access for the jet grout injection operation.

<table>
<thead>
<tr>
<th>Panel ID</th>
<th>Pressure (BAR)</th>
<th>Lift rate (m/min)</th>
<th>Jet Nozzle Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>400</td>
<td>0.33</td>
<td>4.5</td>
</tr>
<tr>
<td>1B</td>
<td>400</td>
<td>0.33</td>
<td>4.5</td>
</tr>
<tr>
<td>1C</td>
<td>400</td>
<td>0.33</td>
<td>4.5</td>
</tr>
<tr>
<td>2A</td>
<td>400</td>
<td>0.25</td>
<td>5.0</td>
</tr>
<tr>
<td>2B</td>
<td>400</td>
<td>0.25</td>
<td>5.0</td>
</tr>
<tr>
<td>2C</td>
<td>400</td>
<td>0.25</td>
<td>5.0</td>
</tr>
<tr>
<td>3A</td>
<td>400</td>
<td>0.25</td>
<td>4.5</td>
</tr>
<tr>
<td>3B</td>
<td>400</td>
<td>0.25</td>
<td>4.5</td>
</tr>
<tr>
<td>3C</td>
<td>400</td>
<td>0.25</td>
<td>4.5</td>
</tr>
</tbody>
</table>

* in all panels, the spacing from column A to B was 1.25m, and the spacing from B to C was 1.0m in all cases

Figure 10: Excavated Jet Grouting Trail Columns

Figure 11 shows the jet grout columns being formed under the spillway slab where tight access conditions were encountered. Access for equipment and personnel into the spillway was provided by means of an earthfill ramp immediately downstream of the cut-off wall alignment. Computer records showing the depth drilled, the grouting pressure, the lift rate and rotation rate were all stored in the rig computer, and were observed during the jet grouting procedure.
Occasionally, soil blockage hindered the return of the cement grout to the surface, which can lead to overpressuring of the foundation. The rods where raised to release the soil blockage and then re-lowered at least 0.25 m below the previous position.

Extensive live monitoring of the spillway structure and wing walls was undertaken during jet grouting to ensure high grout pressures did not adversely affect the structure. Grout pressures were decreased approximately 50% in the top 1 m of grout column below the base of the concrete cut-off wall. The survey data showed that negligible movement occurred due to the jet grouting procedure.

![Figure 11: Monolith 1 looking u/s toward the Radial Gates. Jet Grouting Operations underway in the East Gate Bay](image)

5 PERFORMANCE MONITORING

In addition to a number of pre-existing piezometers in the spillway area, sixteen additional vibrating wire piezometers were installed along the downstream side of the SCB/Jet Grout cut-off wall. Historical readings are not available for these new piezometers, however, post construction water levels in the piezometers showed a steady drop from the cut-off wall extremities to the structure location. In the upper sand layer, groundwater levels varied from 749.2 m at the west end of the SCB cut-off wall to approximately 742.7 m to 743.7 m at the spillway structure. In the lower gravel layer, groundwater levels were recorded at 743.5 m at the west end of the SCB wall and at approximately 741.0 m adjacent the spillway structure.

Since it would have been necessary to extend the cut-off wall another 400 m further west to completely cutoff the upper sand layer, it was inevitable that some seepage would continue to occur. In areas where residual groundwater is still occurring in areas of excavation during Phase 2 construction, it is controlled through a combination of sumps and pumps.

6 CONSTRUCTION CHALLENGES

Figure 12 shows the long stick excavator tracking to its initial position on the west side of the spillway structure at the crest of the dam. The long stick for the backhoe is not generally available locally and was transported from the US and attached to a locally sourced excavator base unit.

The site is remote, being 2 hours south from the nearest major Canadian airport in Regina. Certain materials and specialist geotechnical equipment were imported from the US for use in constructing the
cut-off wall. Cement was locally sourced and construction water which had been tested and deemed suitable for cut-off wall construction was taken directly from the reservoir with SaskPower’s permission.

A stable working platform was provided by lowering and widening the downstream portion of the dam crest. Lowering of the dam crest also reduced the depth of trench excavation to approximately 22 m. The maximum excavation of the long stick used was 23 m which corresponded well with the project requirements. To facilitate construction of the work platform and installation of the cut-off wall, the reservoir was lowered by 600 mm to elevation 752.4 m on a temporary basis during June 2014, and continued to drop to elevation 752.02 m by December 2014. Lowering of the reservoir was also required to avoid requirements for spillway operation while jet grouting operations were underway through the spillway slab.

![Remote Access Challenges for Long Stick Excavator](image)

Figure 12: Remote Access Challenges for Long Stick Excavator

7 SUMMARY

The rehabilitation of Morrison Dam was undertaken by SaskPower using a combination of an SCB and Jet Grout cut-off wall to reduce seepage in the spillway and adjacent dam foundation. The reduction in seepage was necessary to reduce seepage flows through the earthen dam foundation and to facilitate repair of parts of the spillway structure, subsequent excavation of the foundation and reconstruction of the underdrainage system and concrete structure. The cut-off wall in combination with additional temporary dewatering measures during Phase 2 construction appears to have been successful in reducing seepage and groundwater levels in the area of the spillway.

This case history provides some indicators of what should be considered when designing and constructing cut-off walls at a dam site as follows:

- Excavating deep trenches with vertical side slopes filled with bentonite slurry requires an experienced and skilled operator to construct the trench to ensure a good clean base through to the intended wall toe depth.
- Construction of cut-off walls should be considered as seasonal construction, and should not be carried out in the winter months.
• Cut-off wall construction requires an experienced specialist contractor, equipment and materials. Adequate lead-in time and early specialist geotechnical contractor involvement is advised for this type of work.
• SCB Wall construction should incorporate pre-mobilization bench-scale testing to confirm design parameters for the SCB mix. This is required to ensure:
  o the constituents mix together;
  o the design criteria can be met; and
  o slurry workability (slump testing) is within suitable range for placement of SCB backfill.
• If available and local to the site, consistent and appropriate borrow sources maybe considered for the project, together with the use of excavated trench spoil materials as the backfill soil.
• Trial columns for the jet grouting technique are highly recommended. Jet column trials will enable parameter selection to be undertaken for the production piles.
• The trial columns should be undertaken to full depth in the same ground conditions as those for the production piles, and should test the equipment intended to be used for the production piles.
• Quality Assurance and Quality Control are required on a daily basis for the successful construction of both SCB and jet grout walls.

ACKNOWLEDGEMENTS

The authors would like to acknowledge SaskPower for the opportunity to work on this project and the contributions of senior geotechnical engineers at Klohn Crippen Berger including Brett Stephens, P.Eng. and Alex Sy, P.Eng.

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