Design and Construction of a Soil Bentonite Cut-off wall for Suncor's South Tailings Pond

Brett Stephens, P.Eng.
Klohn Crippen Berger Ltd., Calgary, Alberta, Canada
Mike Bowron, P.Eng
Suncor Energy Inc., Fort McMurray, Alberta, Canada

ABSTRACT
Suncor's South Tailings Pond (STP) is an external oilsands tailings storage facility with a footprint of 2300 hectares including infrastructure that was commissioned in July 2006. The Southwest Cut-off Wall forms one of four principal seepage management systems for the STP, with construction completed in 2008. The seepage cut-off comprises soil-bentonite backfill, using native materials from the wall excavation. The seepage cut-off is 900m in length and up to 34 m depth. Construction of the wall used a combination of long-stick backhoe and crane mounted clamshell to excavate the wall under bentonite slurry. This paper describes the construction of the cut-off wall including the field and laboratory testing programs to determine the soil-bentonite mix, and the QA/QC programs conducted during construction. A brief discussion of the design and construction issues specific to seepage cut-off walls in the oilsands region is also presented.

RÉSUMÉ
Le bassin de réception des résidus sud (STP) de Suncor est une installation externe de stockage des résidus de sables bitumineux avec une empreinte de 2 300 hectares, y compris une infrastructure mise en service en juillet 2006. Le mur de retenue sud-ouest constitue l'un des quatre principaux systèmes de gestion des infiltrations pour le STP, et sa construction a été achevée en 2008. La retenue d'infiltration se compose de remblayage sol-bentonite, utilisant des matériaux de l'endroit provenant de l'excavation du mur. La retenue d'infiltration a une longueur de 900 m et une profondeur allant jusqu'à 34 m. Le mur a été construit en utilisant en combinaison une chargeuse-pelleteuse à bâton long et une benne preneuse montée sur grue pour excaver le mur sous la boue de bentonite. Cet article décrit la construction du mur de retenue, y compris les programmes d'essai sur le terrain et en laboratoire afin de déterminer le mélange sol-bentonite, ainsi que les programmes AQ/CQ menés durant la construction. On présente également une brève discussion des problématiques de conception et de construction particulières aux murs de retenue d'infiltrations dans la région des sables bitumineux.

1 INTRODUCTION

The South Tailings Pond (STP) is an external oilsands tailings storage facility located on Suncor Energy Inc. (Suncor) Millennium Mine site, north of Fort McMurray, Alberta. The Southwest Cut-off wall forms one of four principal seepage management systems for the STP. This paper describes the design and construction of the southwest cut-off wall which is the first deep soil-bentonite cut-off wall to be constructed for an oil sands mine in Alberta.

2 PROJECT DESCRIPTION

2.1 General

The STP is the third external tailings pond to be constructed at Suncor's Millennium mine, and is the principal external fluid tailings storage for the operation. The STP will provide water and fine tailings storage until 2013, when in-pit storage for tailings becomes available within the Millennium mine pit. The pond will continue to store fine tailings and water from 2013 to 2035. The design dyke elevation for the STP is El. 390 m, with a maximum height of 42 m and a storage capacity of 366 Mm^3 of tailings. The design of the STP is described in Stephens et al (2006).

The STP is located immediately to the south of Ponds 8A/8B, and occupies an irregular area 4 km by 4.5 km in plan (refer Figure 1). Key features in proximity to the STP include, the Athabasca River, about 2 km west of the site at it nearest point; McLean Creek, which runs southeast-northwest through the site and eventually flows into the Athabasca River; the Steepbank Uplands which forms the eastern boundary of the STP; and Wood Creek and associated wetlands immediately to the north.

2.2 Site geology

The general stratigraphic geologic profile at the STP comprises in descending order:

- A surface layer of Holocene organic peat (muskeg);
- Pleistocene lacustrine clays and silts;
- Pleistocene glacial till;
- Cretaceous Clearwater Formation clay shales;

- Cretaceous McMurray Formation oil sands; and
- Devonian Waterways Formation limestone.

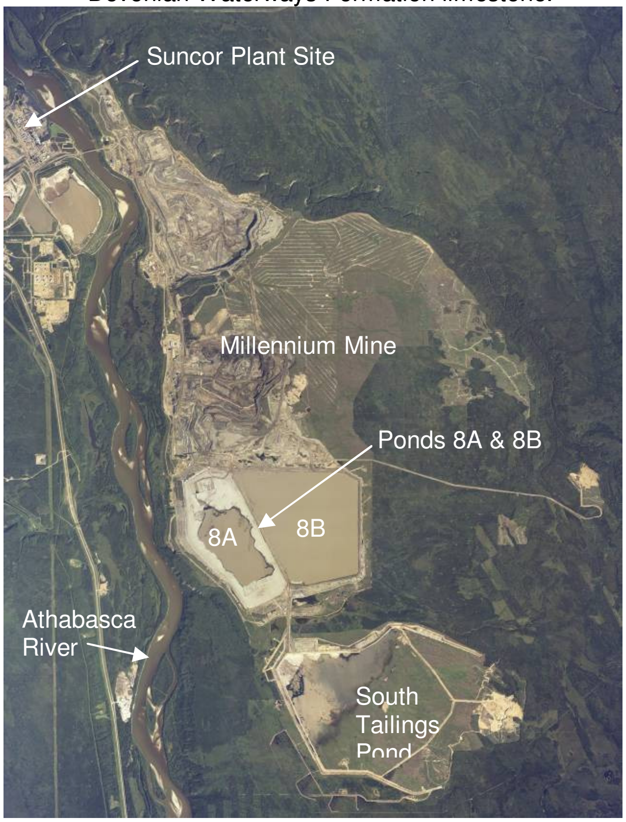

Figure 1. STP Site Location (July 2006)

A Pleistocene glacial melt-water channel, referred to as the Wood Creek Sand Channel (WCSC), has scoured through the site in a general northwest direction (refer Figure 2). The channel is typically capped with organics and glacial till, suggesting that the channel was active prior to final glacial retreat in the area, and the channel sediments are dense due to the glacial loading. The channel base typically rests unconformably on Clearwater Formation strata, but in places the channel is incised into McMurray Formation. No glacial till was encountered at the base of the WCSC.

Detailed drilling, well installation and aquifer testing programs carried out from 2004 to 2006 in the channel section northwest of the STP have shown that the channel section morphology is variable and sedimentary characteristics vary both vertically through the profile and horizontally across the channel. The channel form represents a combination of two fluvial systems. The lower channel section is interpreted as the original channel thalweg. Sediments in this section of the profile typically comprise coarse grained sands and gravels. Fines content in the units varies, and the presence of relatively high fines contents in some units suggests a proximal source for the sediment. Aquifer potential in the thalweg is typically significant, with permeabilities typically in the range 0.1 to 100 m/day. A general fining upward in the sequence is evident.

The upper channel section is significantly wider and is interpreted as a lower energy fluvial environment with both channel and overbank facies. Extensive sediment reworking is likely to have occurred in a braided and/or meandering fluvial system. Fining upward in the sequence is generally apparent, and hydraulic conductivities vary widely. The fluvial sands and gravels within the WCSC are dense to very dense. The perimeter dyke alignment of the STP was selected to maximise tailings storage by positioning the western and southern dykes on the channel.

In addition to the main WCSC, a smaller outwash channel was identified entering the channel from a southwest direction. The southwest aquifer, though smaller than the WCSC is approximately 1 km wide and up to 35 m depth in its largest section.

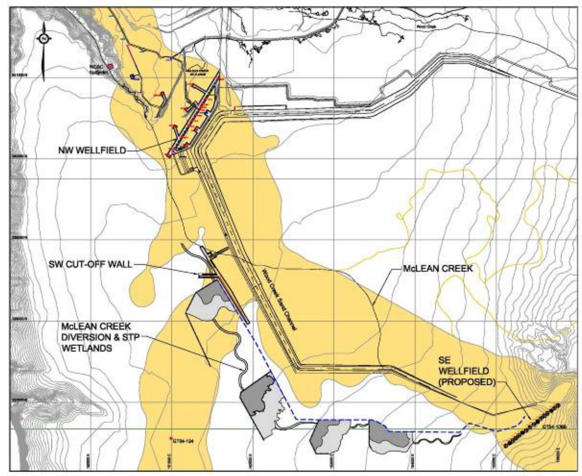

Figure 2. STP General Arrangement (1 km grid shown)

2.3 Seepage Management System

The STP has been preferentially aligned over the WCSC to take advantage of the sand and gravel foundation as a supporting medium for the pond dykes. Areas of limited glacial till cover and exposed sand present potential direct recharge pathways for the migration of process affected water from the pond into the underlying WCSC. Approximately half of the STP pond area overlies the WCSC, which presents three potential pathways for seepage from the pond to enter the environment. These are:

- Where McLean Creek has eroded and exposed the WCSC within the Athabasca river escarpment. Referred to as the McLean Creek spill point, flows from the WCSC enter the surface water within McLean Creek;
- Into the regional groundwater system to the southeast within the WCSC; and
- Into the regional groundwater system to the southwest through the SW aquifer.

The process of selection and design of the STP seepage mitigation system was an iterative, consultative process. Throughout the process, mitigation options (and combinations thereof) were raised and ranked based on factors such as risk, operational practicality and capital and operating costs.

The STP seepage management system comprises four principal elements, which are a combination of wells and a cut-off wall:

- Pumping wells to the north of the STP (NW Wellfield) to lower the water within the WCSC to below the mapped spill point in McLean Creek;
- A pumping wellfield in the southeast to intercept seepage flows to the southeast (SE Wellfield);
- Perimeter pressure relief wells at the toe of the dyke to reduce induced artesian pressures from the STP in the WCSC for dyke stability;
- A cut-off wall (SW Cut-off wall) to form a barrier to seepage flows from the STP to the southwest.

All water collected from the seepage management wells is pumped back into the closed circuit water management system of the STP.

Pumping wells were selected for the main WCSC, primarily due to the depth of the aquifer and the commitment to maintain the regional aquifer following closure and reclamation of the STP. The NW Wellfield was installed in February 2006, and has been operating continuously since. The SE Wellfield will not be installed until the rising STP pond water levels induce flows to the south within the WCSC. Monitoring of the groundwater within the WCSC is ongoing as part of management of the seepage from the STP.

Given that a deep cut-off wall had not been previously constructed in the oil sands, a number of engineering studies were completed prior to proceeding with construction. The remainder of this paper will describe the studies completed for the design and the cut-off walls eventual construction.

3 SITE INVESTIGATION AND DESIGN

3.1 Engineers Cost Estimate

Prior to proceeding with construction, an engineer's cost estimate was developed for both the cut-off wall and compared to a design and costs for a seepage interception wellfield for the same area. For the cut-off wall option, Geo-Solutions Inc., a specialist consulting firm, was engaged to prepare a cost estimate and schedule for construction. The wellfield design and costs were developed by Klohn Crippen Berger Ltd. based on experience from the design and construction of the STP NW Wellfield.

The engineers estimate identified a number of key project costs and risks for the cut-off wall construction, and allowance for these items were included in the estimate. These included:

- Construction of the working platform to support the 100 ton crane for the clamshell and the long stick backhoe during excavation of the trench;
- Logistics associated with transport of bulk bentonite from Wyoming to Fort McMurray;
- Securing suitable water supply for mixing of bentonite slurry; and
- Sourcing of suitable cranes and backhoes locally to execute the works.

Table 1. Results of Engineers Cost Estimate.

Item	Cut-off Wall	Well field
Capital Cost[1]	$5.7M	$4.4M
Operating Cost (90 year basis)	$0.7M	$24.3M
Total	**$6.4M**	**$28.7M**
Net Present Value (10% discount)	$4.8M	$6.0M
Net Present Value (20% discount)	$4.0M	$4.1M

[1]Cost in 2006 dollars.

The engineers cost estimate showed the cut-off wall to have the higher capital cost, but have the lower total cost when operating costs are considered. The lower net present value for the cut-off wall reflects the lower operational investment required for the cut-off wall. On the basis of the engineering estimate, approval for design and construction of the wall was provided in 2006.

3.2 Site Investigations

Site investigations for the SW cut-off comprised the following:

- Drilling six (6) sonic boreholes to Clearwater along the proposed alignment of the wall;
- Conduct surface geophysics, electric resistivity tomography (ERT) along the proposed alignment of the wall;
- Obtain soil samples for laboratory testing; and
- Install monitoring wells for groundwater monitoring during wall construction.

Previous site investigations for the STP proved ERT as a valuable tool in delineating the extents and base of the WCSC. Its success is due to the stratigraphy and relative resistivity contrasts between the channel sands and gravels, and the underlying clay shale Clearwater Formation.

The site investigation indicated that the depth to the Clearwater Formation varied from 12 m to as deep as 32 m (refer Figure 3). The average depth of the base of the SW aquifer was 23 m for the wall. Rafted Clearwater Formation clay shales were observed near the centre section of the wall. Given the presence of these rafted materials, a 1 m embedment for the cut-off wall was nominated. This embedment combined with full time observation by an experienced site technician/geologist, was considered sufficient to detect the presence of rafted materials in the base of the wall.

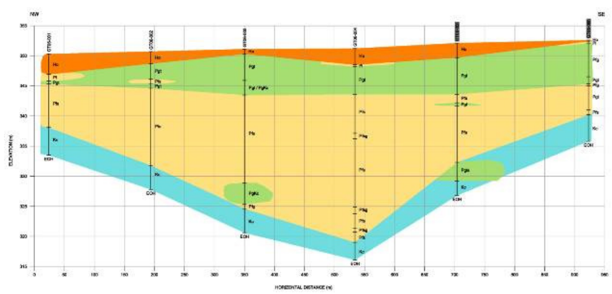

Figure 3. SW Cut-off Wall Geology

The 2004 site investigations indicated that the groundwater levels in the WCSC of the SW cut-off wall varied from elevations 349 m to 352 m. The hydraulic gradient was 1:600 toward the southwest, representing a low gradient groundwater system. The hydraulic head for the channel appeared to be maintained by the main channel of the WCSC. The groundwater levels in the SW aquifer indicated it to be a confined aquifer and partly artesian (0.6 m) for a length of the wall.

3.3 Cut-off wall design basis

The design requirements for the SW cut-off wall were as follows:

- Maximum wall depth 33 m below original ground levels. This value corresponds to the 32 m maximum depths encountered during the site investigation, and a minimum 1 m key into the Clearwater Formation shale unit. Wall excavation would comprise a long stick backhoe to depths of up to 24 m. Below this depth excavation of the wall would be carried out by a crane mounted mechanical clamshell.
- The design wall length was 1100 m. The full length of the wall was not fully determined during the site investigation, and additional drilling was planned for winter 2006/2007. The design wall area was 22,000 m^2.
- A soil-bentonite (SB) wall was selected for the project. A maximum wall permeability of 10^{-9} m/s (or 10^{-7} cm/s) was specified for the project. Experience indicated that this wall type was not adversely affected by contact with process affected water. Backfill for the wall would comprise the excavated spoil mixed with bentonite and locally sourced glacial till materials. The glacial till materials were utilized to reduce the volume of bentonite required for the project.

3.4 Soil-bentonite mix design

A laboratory testing program was completed in Q1 2007 to determine the following information for the design of the soil-bentonite mix:

- The physical properties of the bentonite products to be used for construction;
- The minimum of bentonite required for the trench slurry to satisfy the design criteria;
- The minimum amount of bentonite required for various blends of till and sand to achieve the design permeability;
- SB backfill strengths with various confining pressures;
- Laboratory permeability's for the SB backfill;
- The effects of process affected water on the SB backfill.

In brief the results of the testing program were as follows:

- An initial bentonite slurry content of 6% (6% bentonite by weight of slurry) is required to satisfy the design viscosity and filtrate loss guidelines;
- Glacial till by itself, or mixed with fluvial sand from the SW aquifer are suitable for use as low permeability backfill. These materials need to be carefully blended and mechanically broken down in the field during the SB mixing operation;
- To provide a cut-off with a laboratory design permeability of 10^{-9} m/s, the SB backfill should have the following minimum bentonite content (defined as % bentonite by weight of dry soil) as follows:
    - 2% bentonite where the fines content (<75 micron) of the backfill soils are greater than 52%;
    - 3% where the fines content of the backfill soils are greater than 31%; and
    - 4% where the fines content of the backfill soils are greater than 23%.
- The process affected water did not appear to have a detrimental effect on the permeability of the SB mixtures.

4 CUT-OFF WALL CONSTRUCTION

4.1 Site preparation

The presence of surficial muskeg required the construction of a working platform to support the long stick backhoe and crane mounted clamshell during excavation of the wall. Due to the costs associated with stripping the muskeg, and shortages of suitable borrow materials, it was decided to build the working platform over the muskeg. The work was completed in winter conditions to provide time for the muskeg to compress prior to construction.

During excavation of the trench, the layer containing the muskeg layer was excavated separately and placed as spoil. Any organic materials excavated from the trench were not used as backfill materials, and borrow materials were used to replace the materials spoiled from the excavation.

The working platform had a minimum width of 26 m, though was wider corresponding to the deeper sections of the wall. The design elevation of the working platform was 352.8 m. This elevated the platform above the artesian water levels within the SW aquifer and provided support for heavy equipment during construction of the working platform.

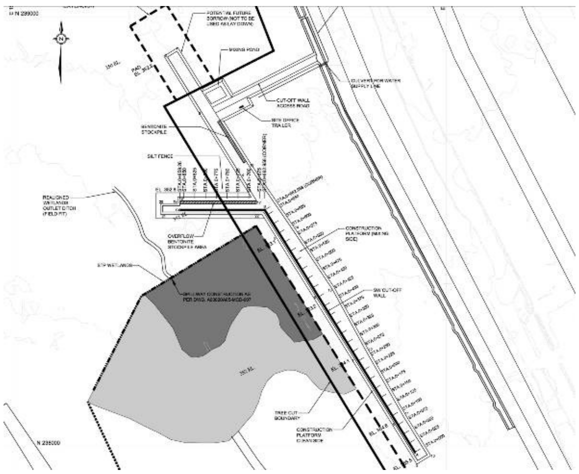

Figure 4. SW Cut-off Wall General Arrangement

The working platform serves a numbers of purposes. It provides an elevated area for construction of the cut-off wall trench, which assists in trench stability. It provides an area for blending and backfilling the SB backfill materials. It can also serve as a source of borrow materials for the trench.

Additional site investigations were completed during site development to determine the full extents of the cut-off. An alternate alignment of the wall was proposed based on this drilling to reduce the overall cut-off wall area. The alternate alignment which had a hockey stick shape, reduced the total length of the wall by approximately 200 m to a length of 860 m (refer Figure 4). Though requiring a construction joint and relocation of an outlet for the adjacent wetland, the alternate alignment was approved given the reduction in wall area. The construction of the working platform the realignment of the wall was completed in April 2007.

Site preparation also included construction of site access roads, lay-down areas and slurry mixing ponds to support construction of the wall. A water supply pipeline was installed from the NW wellfield to the cut-off wall area. The water was used to mix bentonite slurry.

The glacial till materials used to construct the working platform were assessed to be insufficient to support the excavator and cranes during excavation of the cut-off trench. Timber rig mats were used to support the heavy equipment during excavation. Though slow to move during construction, the rig mats were less expensive than importing granular materials to support the heavy equipment.

4.2 Wall excavation and construction

The SB wall is constructed by excavating a narrow trench, under bentonite slurry. The bentonite slurry acts as a stabilizing agent to keep the walls of the trench from collapsing, and also seals the trench and porous zones encountered. To maintain trench stability, the bentonite slurry is maintained at a minimum elevation within the trench during the project.

The excavation for the SW cut-off wall was predominantly carried out by a long stick backhoe. The long stick backhoe has the capacity to excavate to a depth of about 25 m. A mechanical clamshell excavator mounted on a 100 ton crane is used to excavate the sections of the cut-off wall that are deeper than the reach of the backhoe. The excavation sequence is presented in Figure 4.

Once the excavation of the trench has progressed to a point clear of the starting point, the trench is backfilled with a blended mixture of trench soils, borrow soils, bentonite slurry and dry bentonite. The bentonite in both slurry and powder form are used to reduce the permeability of the backfill. Borrow soils are used to reduce the requirements for bentonite which is a premium.

The blending of the materials is carried out with a combination of a backhoe and small dozer to achieve a homogeneous mixture to form the cut-off wall. This mixture is monitored to achieve a design slump, such that it flows and forms a gentle slope in the excavated trench when placed. Backfill rates are carried out to match excavation rates, to balance the requirements for bentonite slurry needed to stabilize the trench.

The construction of a SB cut-off wall requires coordination of the key construction activities:

- Mixing of bentonite slurry to maintain trench stability;
- Excavation of the cut-off trench;
- Blending of soil bentonite and backfilling; and
- Quality control and quality assurance of all of the construction activities.

4.3 SW Cut-off wall construction

Construction of the cut-off wall commenced in May 2007, with excavation starting in July. Poor weather conditions and site access, combined with recurring mechanical breakdown of the clamshell crane severely limited progress of the work.

In October 2007, when it was recognized that the wall would not be completed prior to the onset of winter conditions, work was shut down until the following summer. The excavated trench was backfilled with the excavated spoil, and completed areas of the cut-off wall capped prior to winter.

Work on the SW Cut-off wall recommenced in spring 2008. A heavier duty crane was secured for the clamshell, and higher rates of progress for the wall excavation were achieved. The average daily progress of excavation using the clamshell and backhoe was 72 m^2/day in 2007, and 121 m^2/day in 2008 of wall area. The higher rates in 2008 also correspond to deeper excavations within the wall, as a higher proportion of excavation used the mechanical clam shell. The construction of the SW cut-off wall was completed in August 2008.

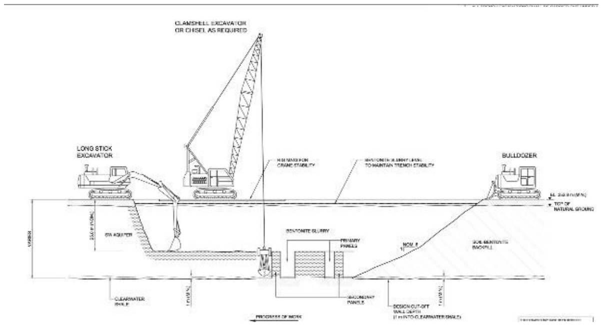

Figure 5. Excavation sequence

4.4 Site quality control

A site quality control program was implemented during construction to verify the suitability of the construction materials and their properties, that the trench was excavated to the nominated geological unit and that the soil bentonite mixtures achieve the design permeability in the field.

An experienced geologist or soils technician was present during excavation of the trench to confirm that the excavation encountered the Clearwater Formation. Observations of trench cuttings were taken at minimum 5 m intervals along the alignment of the cut-off.

Regular minimum testing of the materials used in construction were specified for the project as follows:

- Chemical analysis of water (pH, hardness, alkalinity, total dissolved solids and oil and organics) – weekly;
- Initial bentonite slurry (viscosity, specific gravity, filtrate loss) – daily;
- In-trench bentonite (specific gravity, viscosity, pH, filtrate loss, sand content) – twice per shift;
- SB backfill (slump cone, specific gravity, dry bentonite added) – each shift;
- SB backfill permeability – 1 per 100 m of wall, or 1 per week.
- Trench dimensions – minimum 5 m intervals.

Laboratory testing during and following construction confirm that the design minimum permeability for the cut-off wall was achieved for the SW cut-off wall.

5 CONCLUSION

Soil-bentonite cut-off walls can provide an alternative to pumping well fields for seepage management in oil sands projects. While generally requiring more capital to construct, the long term operating costs of the cut-off walls compared to pumping well fields are significantly less. They also have the added advantage of not adding water to the closed circuit system of a mine.

The following considerations should be made when assessing the suitability of a cut-off wall for an individual project:

- Working platform construction, and site access roads, presents a significant capital cost to the project. The platform should be constructed well in advance of cut-off wall excavation to allow preparation of the area for construction activities. Access roads need to be to a standard to allow road transport trucks to reach the project. The capital costs for access roads and working platforms need to be included in all estimates to construct these walls.
- A suitable water source needs to be identified for the project. For walls within Pleistocene melt water channels, groundwater bores located near (less than 500 m), are ideal water sources for construction. A water supply with a flow of at least 10 l/s is required for large projects.
- For walls deeper than 24 m (including platform height) a crane mounted clamshell will be required to excavate the trench. Slower rates of progress should be expected and budgeted when using a clamshell. The securing of suitably experienced clamshell operators in the oil sands is also a challenge. Designers should anticipate the presence of large boulders (>2 m) near the thalweg of any melt water channels. Slow excavation within the Clearwater and McMurray Formations should also be expected.
- While construction of a soil-bentonite wall is a simple process, a professional experienced in the construction of deep walls is essential to achieve a quality product. The construction team also needs technical site support to confirm geology, material properties and design assumptions are met during the works.
- Adequate planning and investigations are required to construct a cut-off wall. Work should commence at least 6 months prior to construction. This allows time to investigate the wall alignment in winter conditions and complete laboratory trials for mix design in advance of construction in spring conditions.
- Construction of SB walls in freezing conditions should be avoided at all costs.

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REFERENCES

Stephens, B.A., Langton, C.W., Bowron, M. (2006). “The design of tailings dams on large Pleistocene deposits. A case study – Suncor’s South Tailings Pond.” Proceedings of the Canadian Dam Association.