Upgrade of a Tailings Dam using Ground Improvement

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ABSTRACT
This article represents a case-study of the upgrade of a nickel tailings dam in Thompson, Manitoba. In order to maintain the utility of the dam, and keep the tailings covered by water, a significant raise of the existing dam was required. As part of the upgrade process, two forms of ground improvement were carried out: Rapid Impact Compaction and a Cement Bentonite Wall.

The initial dam raise consisted of the placement of two waste rock berms. A slag material was advanced between the rock berms, placed by truck and bulldozer. In consideration of the loose state of the slag, Rapid Impact Compaction was used in order to densify the material in order to improve the overall stability of the dam.

In order to reduce the permeability of the dam, a cut-off wall was required. As an alternative to a traditional cut-off wall such as sheet piling, a Cement Bentonite (CB) Wall was implemented. A 1 meter wide cut-off wall with the required hydraulic conductivity properties was installed within the dam, keyed into the low permeability clay layer below.

This article further describes the particularities of the project including its geotechnical conditions, the design parameters, the ground improvement techniques implemented, as well as the testing and other quality control measures in place.

RÉSUMÉ

Cet article représente une étude de cas sur l'amélioration d'un barrage existant de résidus de nickel à Thompson, dans le Manitoba. Afin de s'assurer que le barrage demeure fonctionnel et les résidus submergés, une élévation significative du barrage existant s'avérait nécessaire. Deux techniques d'amélioration des sols ont donc été mises en œuvre: la Compaction à Impactes Rapides et une Paroi Étanche en ciment bentonite.

L'élévation initiale du niveau a été réalisée par la mise en place de deux bermes rocheuses. Un matériau scorie, mis en place entre les bermes rocheuses au moyen de camions et bulldozers, était constitué majoritairement de fines. Compte tenu de son état lâche, la Compaction à Impactes Rapides a dû être utilisée pour augmenter la densité et améliorer la stabilité globale de l'ouvrage.

Par ailleurs, une coupure étanche était nécessaire afin d'assurer l'étanchéité du barrage. Comme alternative à un rideau de palplanche traditionnel, une Paroi Étanche en ciment bentonite a été choisie. Cette paroi peut être assimilée à un mur de 1 mètre de large, exécutée au sein du barrage, et permettant d'obtenir les propriétés de conductivité hydraulique désirées.

Cet article décrit les particularités du projet, en l'occurrence ses conditions géotechniques, les paramètres de calcul, les techniques d'amélioration des sols ainsi que les tests et autres mesures de contrôle de qualité effectués.

1. INTRODUCTION

1.1 Project Description

The third phase of a dam upgrade project in Thompson, Manitoba consisted of the raising of a tailings dam, Railway Dam. The tailings, a by-product of the nickel mining operations in the area, react with the air forming an acid run-off that may result in environmental issues. As a preventative measure, the designed solution involved raising the water level within the tailings pond area, covering the tailings and isolating them from the air, essentially halting the acid generating process. In order to accommodate the increased level of water, the existing dam needed to be raised, and seepage rates need to be reduced under the design hydraulic head differential.

Two ground improvement methods were implemented in order to facilitate the raised dam's construction: Rapid Impact Compaction and a Cement Bentonite Slurry Wall.

1.2 Rapid Impact Compaction

Rapid Impact Compaction (RIC) is a fast and reliable ground improvement technique for the compaction of shallow, loose, granular soils to depths of up to 6 meters. This innovative technique, a variation on traditional Dynamic Compaction, was originally developed in the early 1990s and provides safe and controlled compaction using a 7 to 10 tonne drop hammer. Dynamic energy is transferred to the ground safely and efficiently as the hammer impacts a circular foot assembly which remains in contact with ground at all times, eliminating the risk of flying debris. The dynamic energy is transferred to the underlying soils, rearranging the soil particles into a denser configuration (Beaton et al 2011).

The treatment is usually carried out on a phased pattern, the spacing of which is determined by the soil type and the geometry and loading of structure to be supported. The soils and fills that have been treated by Rapid Impact Compaction typically have increased density, friction angle and stiffness. Increasing the bearing capacity and controlling the settlement of in-situ soils are the usual applications for RIC.

The drop hammer is supported by a track-mounted excavator base, which provides for easy mobilization and the ability to efficiently move around in narrow and limited height spaces, including within existing buildings. Given the easy mobility and small footprint of the rig, Rapid Impact Compaction is well suited for areas with limited access or locations where using a full-size crane is not feasible. The technique is also well suited where acceptable vibration levels are limited by surrounding structures (Geopac 2016).

1.3 Cement Bentonite Wall (Slurry Wall)

A Cement Bentonite Wall (CB Wall) is a form of a slurry wall. Slurry walls are sub-surface barriers designed to inhibit the flow of water and/or contaminants within soils. These walls are constructed as a trench excavation, removing the in-situ material and replacing it with relatively low permeability backfill material. The trench is excavated through a supporting material such as bentonite, or a cement-bentonite mixture, to the designed depth. In the case of a Cement Bentonite Slurry Wall, the excavation support fluid is self-hardening and is allowed to set within the trench to form the wall. The excavated material must then be disposed of or re-used elsewhere (Geopac 2016).

The excavation is typically carried out by a hydraulic long-reach excavator and can be installed to depths of up to 26 meters with specially modified equipment. The final product results in a continuous low permeability barrier that can be installed in any required shape or orientation with the hydraulic properties of the wall tuned to the project's requirements (Geopac 2016).

2. GEOTECHNICAL CONDITIONS

Clay was found to be the predominant soil type underlying the Railway Dam. The clay is generally silty with medium to high plasticity, varying from stiff to soft at depth. A layer of silt, approximately 6 meters thick, is beneath the clay. Underlying the silt is a layer of sand generally 6 to 7 meters in thickness. Finally bedrock, consisting of granite and biotitic gneiss, was encountered below this sand layer.

3. PRELIMINARY STAGES

Initial construction consisted of the installation under water of two rock berms that spanned the length of the dam upgrade area. A slag fill was then advanced between the rock berms using trucks and bulldozers, displacing water as it was placed. Figure 1 below represents a simplified general cross-section of the project.

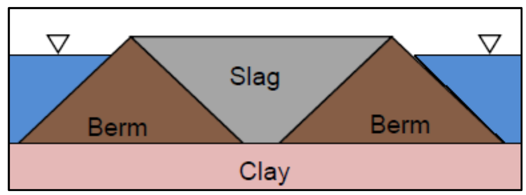

Figure 1: General cross section of dam

The slag fill was placed to a pre-determined elevation, and the surface roller-compacted in order to prepare the surface for the heavy equipment that was to be used for the ground improvement works.
The depth of the slag fill in the centre of the dam varied between depths of 3 to 6 meters. In total, a platform with an area of 9,400 square meters was prepared spanning the roughly 1.2 kilometer long stretch of dam.

4. RAPID IMPACT COMPACTION

4.1 Design

In order to facilitate and expedite the construction process, the slag was placed in one pass without compacting in lifts; consequently the slag was in a loose state at depth. In consideration of the state of the material, Rapid Impact Compaction was planned in order to compact the full thickness of the placed fill, improve the bearing capacity of the material, mitigate potential liquefaction issues and control future settlements, both total and differential.

The specification criteria set out for the RIC program was a minimum SPT N-value of 10 in the upper 6 meters of the slag.

In order to achieve the specification, Geopac designed a program consisting of five phases of compaction. These five phases were arranged in a project-specific grid that maximized the amount of energy transmitted to the loose soils to the treatment depth of 6 meters.

4.2 Site Works

Rapid Impact Compaction was carried out over the course of 2 weeks using the excavator mounted compaction rig. The works are carried out in accordance with the phased plan from the design stage. A photo of the rig in operation can be seen in Figure 2 below.

Figure 2: Photo of Rapid Impact Compaction Rig in Operation

Each compaction point is surveyed in to ensure accuracy and proper coverage of the working platform. In addition, a survey of the site elevation is taken pre- and post-construction in order to gauge the resultant settlement.

Following completion of the compaction works, Cone Penetration Tests were carried out in order to assess the effectiveness of the treatment.

4.3 Results

4.3.1 Platform Settlement Analysis

Comparing the pre- and post-Rapid Impact Compaction platform elevations, it can be estimated that the ground improvement work induced a settlement of the platform of 37 cm on average. The ground was compacted to an average depth of 5 m, thus the volume reduction ratio is described as follows:

$$\frac{37\text{cm}}{500\text{cm}} = 7.4\,\%. \tag{1}$$

This is a typical value when loose granular soils are compacted.

4.3.2 Cone Penetration Tests

9 Cone Penetration Tests (CPTs) were carried out following the Rapid Impact Compaction in order to assess the improvement of the soil characteristics. Conversion were done using Robertson and Campanella correlations. An example CPT profile can be seen in Figure 3.

As can be seen from the results, the specification criteria of N-values greater than 10 to depths of 6 meters was met, and exceeded in most locations.

These results show the typical Rapid Impact Compaction improvement curve, with the most improvement being seen around 2 to 3 meters depth, tapering off at the deeper elevations.

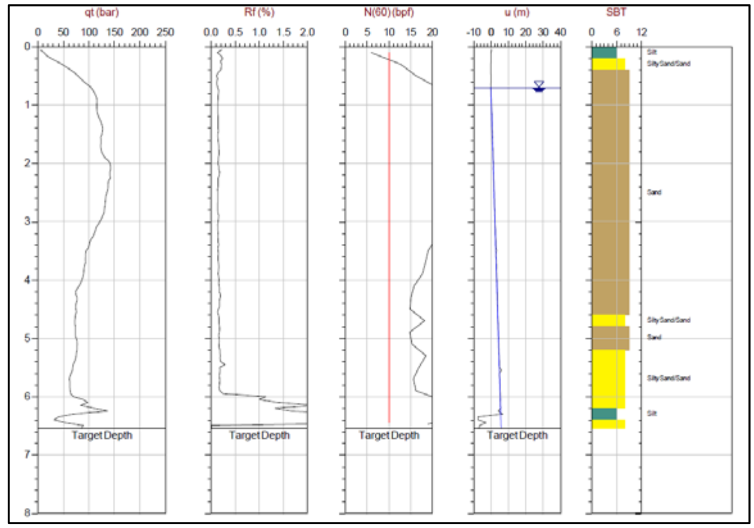

Figure 3: Typical result of CPT testing

4.4 Discussion

Geopac successfully improved the loose slag fill by Rapid Impact Compaction, meeting the specification criteria laid out by the client. Using RIC allowed for the faster placement of the slag material to full height (6 meters maximum) and compaction of the loose material in one pass. In total over 40,000 m^3 of slag material was placed and compacted using a time and cost-efficient approach.

5. CEMENT BENTONITE WALL (SLURRY WALL)

5.1 Design

As an alternative to a traditional cut off wall such as sheet piling, a cement bentonite cut off wall (CB wall) was proposed to create an low permeability barrier through the existing tailings dam, keyed 1.5 meters into the clay layer below. The objective of the treatment was to create a 1 meter wide cut off with a permeability of $8\text{x}10^{-6}$ cm/s and an Unconfined Compressive Strength of 60 kPa.

Cement Bentonite (CB) can be made with a variety of materials. CB made with Portland cement (ASTM C150 “Standard” CB) (ASTM 2016) typically has an unconfined strength of 35 to 200 kPa and a permeability of approximately $5\text{x}10^{-6}$ cm/sec. CB with Portland cement is useful on a variety of projects such as for core wall installations in earthen dams & dikes, dewatering, and groundwater control. CB can also be made with less common materials such as Blast Furnace Slag cement

(ASTM C989 – “Non-Standard” CB) (ASTM 2016) for projects with more demanding requirements. CB made exclusively with slag is approximately 10 times stronger and often an order of magnitude less permeable (1 x10^{-7} cm/s) than CB made with only Portland cement. CB made with slag cement can be used for semi-structural purposes such as earth retention as well as for contaminated groundwater control.

As part of the pre-design for the CB wall, slurry mixes with various ratios of cements and bentonite were tested to determine the ideal mix for the project requirements. The figure below provides a visual representation of the properties that can be customized based on the slurry recipe – namely permeability and unconfined compressive strength.

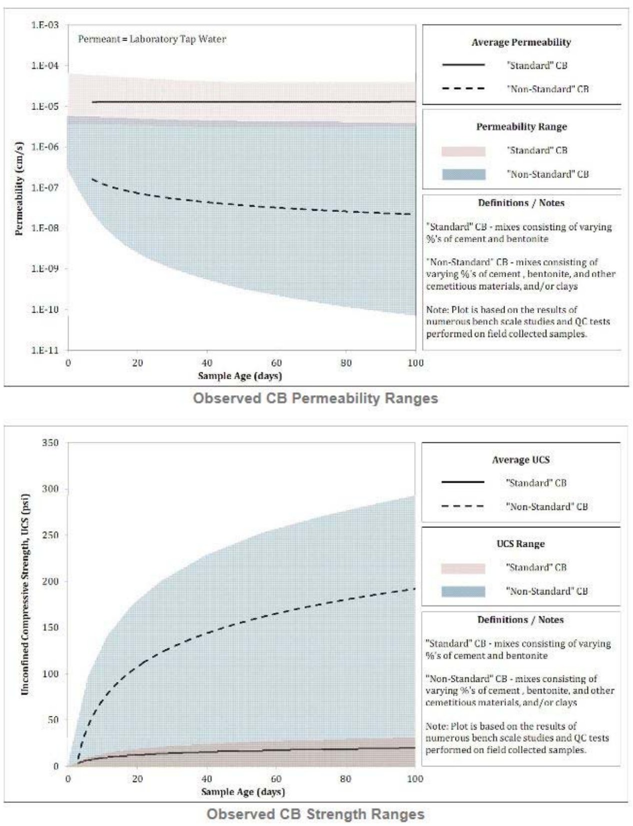

Figure 4: Strength and permeability ranges for standard and non-standard CB mixes (Geo-Solutions 2013)

Following the successful formulation of the mix design, the mix is scaled up to work on the project site level.

5.2 Site Works

The scope of work for Geopac involved the construction of the cut-off wall using the cement bentonite slurry wall technique. The CB slurry wall was excavated with a long reach excavator under cement bentonite slurry. The slurry supports the excavation without the need for conventional shoring. This allows the excavation to proceed to almost any depth, even well below the water table.

The CB slurry is mixed on the side of the excavation in a small batching plant and as the trench is excavated, the removed, in-situ material is replaced by the slurry. The slurry is placed in a fluid state, allowing it to flow into the trench. When the backfill operation is complete, the CB backfill sets and behaves like a clayey soil with the designed strength and permeability characteristics. For this project, the purpose of the cut off wall is to create a barrier through the slag dam; the bottom of the wall is anchored in the native clay. A photo of the site’s operations can be seen in Figure 5 below.

Figure 5: Photo of long reach excavator on site

Using the long reach excavator, Geopac installed the CB wall to depths of up to 32 meters, this depth varied with the natural profile of the clay. As part of the quality control measures, soundings were taken every 4 meters along the length of the wall to determine the depth of the wall and ensure proper connection with the underlying clay/bedrock. Each shift started with an overlap of the previous shift’s wall section to ensure a continuous wall surface.

Other quality control measures implemented included sampling, both before slurry is placed within the trench and in-situ tube sampling, as well as the related testing. The main test performed was a flexible wall permeability test in order to confirm the slurry wall was performing as per specification.

5.3 Results

Samples were taken regularly along the length of the wall. Cylindrical samples measuring 3” diametrically by 12” length (7.62 cm, 30.48 cm) were taken and sent to National Testing Lab in Winnipeg, Manitoba. These samples were used to perform hydraulic conductivity testing. The results of this testing are summarized in Table 1.

Table 1: Summarized results of hydraulic conductivity testing

Sample ID	Curing Time (Days)	Pressure (PSI)			Average Effective Confining Pressure (PSI)	Hydraulic Conductivity "k20" (cm/s)
		Cell	Top	Base		
Station 4+00-20' BGS	33	35	19.5	20.5	15	6.2 x 10-6
Station 6+00-20' BGS	29	35	19.5	20.5	15	7.4 x 10-6
Station 8+00-15' BGS	28	35	19.5	20.5	15	5.6 x 10-6
Station 10+00-10' BGS	28	35	19.5	20.5	15	6.7 x 10-6
Station 12+00-5' BGS	28	35	19.5	20.5	15	5.3 x 10-6

It is important that the samples be tested at a confining pressure equivalent to approximately the average pressure that the slurry experiences within the finished dam. This ensures that the permeability results are indicative of the real properties of the slurry wall. In this case, the average confining pressure was 15 PSI.

Unconfined Compressive Strength tests were also carried out. The results of which can be seen in Table 2.

Table 2: Summarized results of unconfined compressive strength testing

Sample ID	Sample Description	Unconfined Compressive Strength (kPa)			
		At 7 Days	At 14 Days	At 21 Days	At 28 Days
Station 2+10-5' BGS	Cement-Bentonite	75	86	68*	118
Station 4+00-20' BGS	Cement-Bentonite	54	NT	NT	99
Station 6+00-20' BGS	Cement-Bentonite	68	NT	NT	92
Station 8+00-10' BGS	Cement-Bentonite	82	NT	NT	101
Station 10+00-10' BGS	Cement-Bentonite	NT	NT	NT	91
Station 12+00-5' BGS	Cement-Bentonite	76	NT	NT	106

5.4 Discussion

The laboratory results show that the specification criteria were met in terms of both hydraulic conductivity and unconfined compressive strength. The slurry wall represented an effective method of creating an impermeable barrier through the slag based dam.

6. CONCLUSION

Geopac, through a combination of two ground improvement techniques, aided in the upgrading of the Railway Dam in Thompson, Manitoba.

Rapid Impact Compaction allowed for the dam to be constructed out of material available on site, namely slag, while reducing construction times. Also improved through the process was the bearing capacity of the material, and the potential for settlement or liquefaction was reduced.

Following completion of the Rapid Impact Compaction, a Cement Bentonite slurry wall was installed in order to create the impermeable core to the newly upgraded dam. A careful pre-design and precise execution on site were keys to the successful performance of this technique.

7. REFERENCES

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