Temperature Monitoring and Strength Testing during Construction of a Cement Bentonite Slurry Cut-off Wall

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ABSTRACT
A cement bentonite slurry cut-off wall was constructed within a subsurface alluvial channel in Northern Alberta, Canada. The wall was composed of a mixture of Portland cement, blast furnace slag and bentonite, to produce a strong but ductile, low permeability cut-off barrier. During the slurry mix design process an analysis of the effect of using cold water (10°C and less) and curing the samples at similar cold temperatures was conducted. The laboratory program found that the cold conditions decreased the rate of slurry strength increase. Therefore, detailed monitoring of the in-situ slurry temperature as it cured was undertaken and enabled slurry samples to be stored at temperatures which mimicked the slurry temperature of the wall as it cured. This temperature monitoring and controlled storage process provided lower strength results than standard ambient temperature testing and may represent more realistic slurry strength gains in the field. Although delays were encountered to allow for slurry strengths to be achieved, field based temperature and slurry strength studies successfully enabled construction to proceed in an active mine environment.

RÉSUMÉ

1 INTRODUCTION

The Base Mine Dam (BMD) at Syncrude Canada Limited's (SCL) Mildred Lake Site in Northern Alberta, Canada is an earth embankment dam with a central sand filter that was under construction at the time of this project. Along the dam alignment one area had deep fill with surrounding retaining walls for an overpass which made excavation of a trench for a deeper sand filter difficult, while a second area had a deep fluvial channel located perpendicular to the embankment axis and so both areas required the construction of low permeability cut-off walls (pile wall and slurry wall) beneath the sand filter.

The walls were located adjacent to existing engineering structures, and the proposed construction sequence for the dam influenced the wall construction method and the design of the mix for the walls. This paper describes the selection of the cut-off wall types used in the dam, the slurry mix design, strength testing and temperature monitoring during installation of the slurry wall. It draws conclusions about the usefulness of temperature monitoring and controlled temperature storage during successful construction of cementitious slurry walls in cold climate conditions.

2 BACKGROUND

2.1 Continuous Flight Auger Pile Wall

The first cut-off wall to be constructed was located along the alignment of an underpass beneath the southbound Highway 63. The overall cut-off wall was approximately 300 m in length, and approximately 12 m in depth. The construction of the BMD required the realignment of Highway 63 east of the original alignment. The cut-off wall construction was required prior to the realignment of the road, and needed to maintain continuous operation of the highway above.

Mine operations also required continuous operations of the highway underpass. The alignment of the cut-off wall was located within 5 m of the abutment of the overpass, to allow mine trucks to pass the working area. Given the proximity of the abutment foundation, and the restricted head height, the cut-off wall was constructed using overlapping continuous flight auger (CFA) piles, as shown in Figure 1. A total of 1127 piles of 760 mm diameter were installed to create the cut-off wall.

Figure 1. Flight Auger operating beneath Highway 63, Northern Alberta.

CFA grout is usually composed of a fluid mixture of sand, Portland cement, fly ash and water, producing typical Unconfined Compressive Strengths (UCS) of 24 to 30 MPa. For this project the designers required a lower strength (and higher ductility) and a lower permeability than is typical for a CFA grout. The grout was required to reach an UCS strength of between 0.5 MPa and 1.0 MPa after 28 cure days to allow construction of the BMD embankment over the CFA wall.

The CFA wall was constructed in two phases, in 2010 from October to November, and in 2011 from June to September. The installation of piles was halted for the winter and the area protected from freezing temperatures. Early construction over the CFA wall was a key requirement for the BMD construction schedule. It was recognized that cooler ground temperatures at the site would slow the strength gain within the grout mix. Field measurement of pile temperatures were therefore carried out.

Temperatures were recorded by inserting cables with thermistors at 2 m spacing into the piles. Quality control samples were cured in temperature controlled rooms at temperatures dictated by the thermistor strings measurements. The lowest temperature on the string was the chosen target temperature of the room for the curing of the samples. Based on the lowest temperature recorded, thermistor temperatures decreased from 17°C to 7°C by the completion of the project. This was recorded towards the base of the pile. Additional samples were also stored at ambient (15°C to 25°C) temperatures.

The piles cooled from the base upwards, with a temperature difference of approximately 7°C to 10°C between the base of the pile and the top monitoring point. Strength gains were monitored using a site based UCS machine. As shown in Figure 2, curing occurred more slowly in the cool stored samples than in the ambient cured samples. After 7, 14 and 28 days of curing the cool stored samples represented on average 46%, 71% and 91% of the ambient temperature UCS strengths, respectively. The results were used to enable construction works to be completed on and around the piled wall using field based results, reflecting the lower ground temperatures actually encountered.

2.2 Cement Bentonite Slurry Cut-off Wall

The second cut-off wall was constructed in September and October, 2011. An alluvial channel along the old Beaver Creek alignment was identified beneath the foundation of the dam, approximately 3 km to the west of the cut-off wall under Highway 63.

A Cement Bentonite (CB) slurry trench wall was selected to provide a strong but ductile, low permeability cut-off barrier beneath the dam. CB slurry cut-off walls were developed in Europe in the late 1960’s and have been used in the USA since the 1970’s to control the flow of subsurface groundwater and other fluids (Ryan and Day, 1986). As the BMD design required that the cut-off wall gain a higher strength (2 MPa) than standard CB slurry walls (around 0.5 MPa), blast furnace slag was added to the slurry mix.

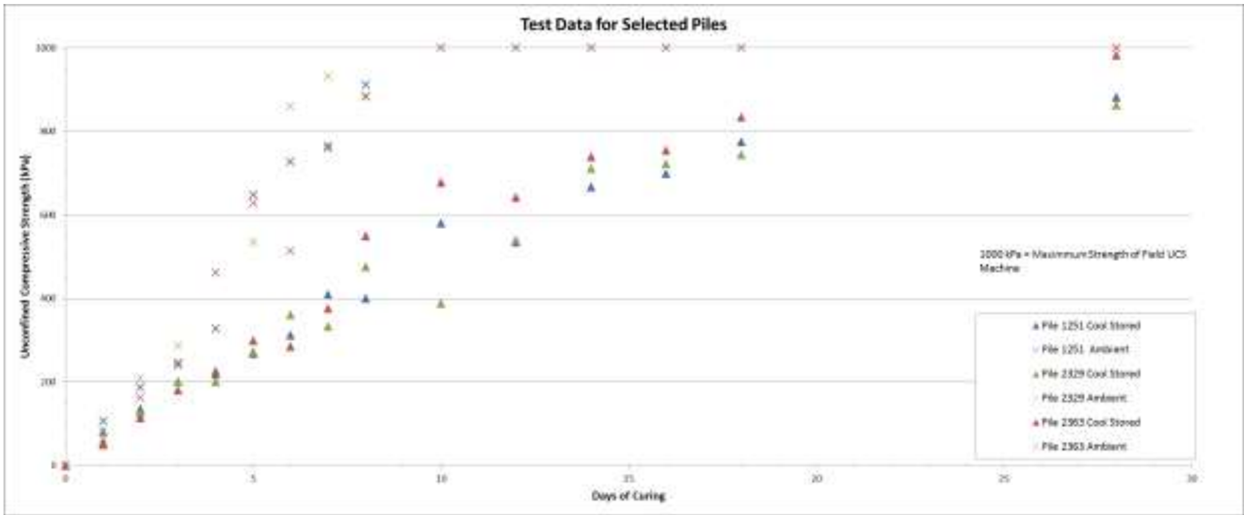

Figure 2. Increase in Strength for grout cured at different temperatures for the Continuous Flight Auger Cut-off Wall.

The CB cut-off wall was 202 m long and 0.9 m wide, with excavation carried out by a longstick excavator that was able to reach the maximum depth of 21 m required to key into relatively impermeable insitu oil sand material. As shown in Figure 3, slurry was continuously pumped from an onsite batch plant to the trench during excavation. There was a 40 m high dam upstream of the wall, upon which were constructed an active mine road, power lines and tailings pipeline infrastructure. Therefore, considering the 61 m total height from the top of upstream dam to bottom of cut-off wall trench, the wall was required to be built as a series of discrete and alternating panels to maintain an adequate three dimensional factor of safety. Although this increased the length of the construction phase the upstream infrastructure was not disturbed and no slope movements were detected as a result.

Figure 3. Longstick excavator and slurry being pumped to the Cement Bentonite slurry cut-off wall at Syncrude's Base Mine Dam.

It was also recognized for this wall that the temperature of the water used in the mix and the ground into which the slurry was placed, would affect the properties of the CB slurry as it cured. The slurry mix design process therefore included an assessment of the effect of cold (10°C and less) soil and water conditions and showed that this decreased the rate of strength increase. As a result it was decided to undertake detailed monitoring of the in-situ slurry as it cured, similar to that undertaken for the contiguous bored pile wall. This was accomplished by installing strings of thermistors in the overlapping sections of the panels and enabled samples collected from the trench to be stored at temperatures that mimicked the in-situ conditions.

3 SLURRY MIX DESIGN

3.1 Initial Laboratory Design

An initial laboratory design mix program was undertaken by Pennsylvannia Geo-Solutions Inc and focused on achieving the desired strength required for the design of the CB wall. Bentonite slurry testing indicted that water from an onsite lake was suitable but that recycled water was unusable as it caused foam to develop. A total of 16 different CB mixtures were created and strength tested. The first 13 CB mixtures consisted of gradually increasing the proportion of the blast furnace slag. The final 3 CB mixtures included sand and thinners to better represent the slurry produced onsite and placed in the excavated trench. All mixtures were made, cured and tested for strength to ASTM D2850 and D2166 standards, with laboratory temperatures of between 16°C and 27°C. The results suggested that a maximum strength of 2.5 MPa could be produced from a slurry composed of 21% blast furnace slag, 2.2% Portland cement, 4.5% bentonite and using water sourced from a lake onsite. The slurry also met all other criteria including workability, bleed and permeability; and the strain compatibility could be reached after 1 day of curing.

3.2 Cold Temperature Design

At this stage of the mix design, it was recognised that the temperature of the water used in the slurry and the temperature of the ground that the slurry would be emplaced within, could have a significant effect on the curing of the mixture. The temperature of the lake water source was measured in April and May and a temperature of 10°C was selected as representative for the water source for testing. Groundwater temperature measurements of 4 to 6°C, suggested that the ground temperature was likely to be approximately 5°C. Modelling undertaken by AMEC indicated that a 10°C slurry, emplaced in a 5°C soil would decrease to 7.5°C in 14 days.

To determine the influence of these cold temperatures on the properties of the slurry, the four best performing design mixtures were tested further using water at 4°C and 10°C and curing the samples at 4°C or 10°C, or at 10°C for 3 days then reduced to 4°C until tested, to simulate worst case conditions. The strength testing conducted on the samples showed that the colder water and curing temperatures decreased the rate of strength increase and longer cure periods were required to reach the minimum strength criteria. The samples consisting of 4°C water, and cured at 4°C, displayed the most severe reduction in strength increase, however all samples continued to harden with time. The permeability results were not affected by the colder temperatures and the results were similar to those produced with ambient temperatures. The samples with the same proportion of materials as the sample that produced the maximum strength during the initial testing, proved to be the best performing even at lower temperatures and were selected for use in the CB wall.

4 TEMPERATURE MONITORING

4.1 In-situ Slurry Temperature Monitoring

4.1.1 Thermistor Installation

Thermistor strings were used to measure the temperature of the slurry as it cured within the trench excavated for the cut-off wall. The aim was to enable the samples to be stored at similar temperatures to the in-situ slurry as it cooled and provided more representative strength results when tested. This was to confirm that the adjacent panels would reach the required strength after 7 days of construction with the potential to reduce the time gap required between panels for construction. It was also to aid long term scheduling for dam construction above the wall.

Each of the eight RST thermistor cables were 21 m long and contained ten thermometers, spaced at 2 m intervals with a weight at the base to overcome buoyancy in the fresh slurry.

Using a scaffold bridge across the constructed panel, the thermistor string was lowered into the slurry by hand within the overlapping section so that it could be excavated during construction of the adjacent panel. The installed thermistor cable was then attached to a support across the trench during the initial stages of curing.

The deepest thermistor was at approximately 16 m depth. Data was collected from the 7 thermistor strings before they were removed when the adjacent panel was excavated. The thermistor in the central section of the wall (Panel 6) was in place for 29 days because it was adjacent to the one of the last panels to be excavated. It gave an indication of long term trends, especially as it was in one of the deeper sections of the wall. The last two panels to be constructed did not have thermistors installed so that no cables remained in the completed cut-off wall.

4.1.2 Thermistor Monitoring Results

Due to unexpected delays, construction occurred in the Fall of 2011 and a decision was made to heat the raw water used in the slurry. It was also expected to increase the rate of curing in the completed panels, so that the delay between constructing panels could be reduced. This decision took the planned field temperature situation away from a cool mix/cool stored setup to a warm (ambient) mix/cool stored set up.

There was a slight heat loss in the initial slurry mix due to the open nature of the three bentonite mixing tanks but the final cement bentonite slurry was as warm or warmer than the raw water due to the mixing process and chemical reactions from the addition of the materials. Although heating of the water began the night before construction started, panels which were excavated after a break in construction had slightly cooler temperatures to start with than those which were excavated after the water had been heated for some time. The first two panels (1 and 6) had slightly lower temperatures as the heating process had only just started. Temperatures were generally warmer at the end of each day.

Temperatures of the slurry measured at the plant ranged from 16°C to 31°C and averaged 24°C. Initial temperatures measured on the thermistors immediately after installation ranged from 23°C to 27°C with an average of 25°C. Each panel was originally uniform in temperature with depth, however, as time progressed, a profile of varying temperatures developed. In general, the thermistors showed decreasing temperature with depth but not necessary in a linear trend. The shallower panels on the channel flanks showed flatter trends, which indicates that they cooled quicker than the deeper central panels which had steeper trends. This is due to the shallower panels being influenced more by the colder ground at the surface, as they have a smaller mass than the larger panels. Panels with thermistors within the top 1 m of the panel showed that the surface was significantly cooler than the next thermistor deeper into the slurry.

The thermistor that provided the lowest final temperature for each panel is presented in Figure 4. The graph shows that some panels indicated an initial increase of temperature as the slurry started to cure followed by a gradual decrease with time. The lowest temperatures at the base of the panels were 16°C to 22°C after 7 to 9 days.

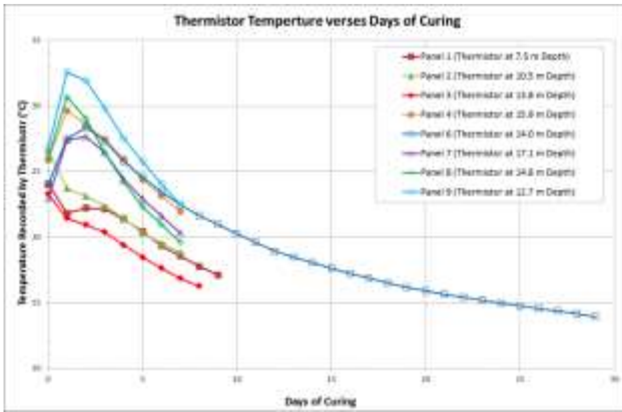

Figure 4. Graph of tempertaure trends measured by the thermistor which gave the overall lowest tempertaure in each panel.

The temperature profile with time for Panel 6 is shown in Figure 5. As it is one of the deepest panels, the trend of the lowest value was used to regulate the storage temperatures for all other panels after their thermistor was excavated or if they did not have a thermistor to start with. When the thermistor was excavated at 29 days, the lowest temperature in Panel 6 was 14°C. The cooling trend of the thermistor with the lowest temperature was extrapolated using a linear relationship to estimate that at 56 days the panels were likely to have reached the minimum ground temperature of 4°C.

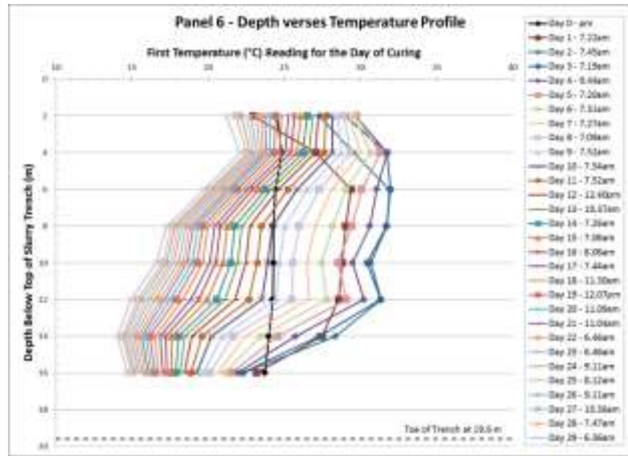

Figure 5. Temperature profile of Panel 6.

4.2 Sample Storage Temperature Monitoring

4.2.1 Aims and Method

Samples for strength testing were stored onsite during construction of the CB wall and the remaining samples were shipped to the Klohn Crippen Berger Ltd (KCB) laboratory in Calgary for further storage and testing on the predetermined cure day. Onsite, coolers were set up within a small trailer for sample storage at temperatures representative of the ground temperatures measured by the thermistors. The coolers were used as they were capable of a wider range of temperatures than conventional fridges (4°C to 18°C). A separate thermometer was placed in each cooler to provide an accurate measurement of the cooler temperature and recorded the current temperature at the time of reading as well as the maximum and minimum temperature since the last reading. A container of water was also placed in each cooler, as well as damp cloths or paper towels to increase the humidity and replicate in-situ conditions. Additional coolers were used in the Calgary laboratory at the end of the site work to create similar storage conditions as onsite for the remaining samples.

4.2.2 Onsite Issues and Results

When temperatures onsite started to drop as the Fall season progressed, it was noted that the cooler temperatures were significantly lower than the thermistor readings despite the coolers being set on their lowest settings. This was also enhanced by the heating of the water making the slurry much warmer to start with than expected. The heater in the trailer was used to raise the overall ambient temperature and then each cooler was adjusted accordingly.

The temperature of the onsite coolers were adjusted to keep them below the lowest thermistor reading, or at the Panel 6 trend line after the thermistor had been excavated. The occasional current or maximum temperature was above the Panel 6 trend line but no major temperature deviations were recorded.

4.2.3 Laboratory Issues and Results

Using the linear trend estimated from Panel 6 thermistors, the coolers in the laboratory were adjusted to match the trend until cure day 56 was reached. However, as the laboratory was considerably warmer than the onsite trailer and the samples were significantly older and therefore needed to be colder, the coolers struggled to achieve the required temperatures.

The temperatures of the laboratory coolers data generally followed the required decreasing trend suggested by the Panel 6 data, however, the temperatures were mostly above the temperature suggested from the Panel 6 trend. The values significantly above the Panel 6 trend line were mostly maximum values and may be connected with opening the door of the coolers in the warm laboratory which raised the temperature and took time to cool back down. Samples designated for standard testing at ambient temperatures were kept in plastic coolers in the laboratory at 17°C to 20°C.

5 SAMPLE COLLECTION

Standard CB molds are 50 by 250 mm, which are later trimmed to a convenient size for testing (ICE, 1999). For this project, three types of samples were collected from each panel to track the strength gain with time. All were different sizes and were stored in different ways. The slurry samples were collected in 5 gallon pails from the bucket of the excavator, after it reached to the bottom of the trench and filled on rising. This was done at the completion of the panel, before final filling, to reduce overflow of the panel with the excavator bucket in the ground. Samples were also collected by installing a 6 m long, double walled sample tube into the fresh slurry, that was extracted after 4 or 5 days and allowed for testing of the in-situ slurry without drilling. The samples sizes and storage conditions were:

- 50 mm diameter by 100 mm long plastic sample moulds – cool stored,
- 38 mm diameter by 200 mm long in-situ samples in PVC tubes – ambient stored,
- 50 mm diameter by 250 mm long PVC tubes – ambient stored.

6 STRENGTH TESTING

An extensive program of UCS testing was carried out on the samples collected from the trench, to track the strength increase of the slurry as it cured and compare with short and long term requirements. The UCS data from all of the panels, for all sample types and testing methods are presented in graphical form in Figure 6.

6.1 Onsite Strength Testing

For the first 10 cure days, the panels were tested at least once per day using a spring testing machine as a field UCS machine. After the first ten days, testing was spaced out to cover a 28 day period with days that were deemed important, based on the needs of the project. There were several limitations involved with the field testing compared to laboratory testing, including the testing method and sample size. However, the overall field trend follows that of the other sample testing methods and the expected results for the slurry mix testing during the design stage. Given the ease and low cost involved in using this equipment, it meant a large amount of data could be collected and these test results were valuable as an early indication of strength gain with time.

6.2 Laboratory Strength Testing

Laboratory UCS testing was required to obtain more accurate results that included strain measurements. The schedule of testing was based on short and long term construction decisions and as the project developed was extended through to 200 cure days. The UCS testing was undertaken at the KCB Calgary Laboratory according to ASTM D2166.

6.2.1 The 50 by 100 mm Sample Size Results

A large number of 50 by 100 mm size samples were collected. As the testing requirements changed during construction, they were used as a back-up for panels lacking larger samples to enable the testing schedule to be completed on all panels. They were also used to compare with the experimental in-situ testing results. The results provide a similar variance to the onsite testing when comparing all panels as shown in Figure 6; however the trend of each panel was relatively consistent. After 7, 14, 28, and 90 days of curing the cool stored samples represented on average approximately 78%, 75%, 81%, and 90%, respectively, of the ambient temperature UCS strengths similar to the findings in Figure 2.

6.2.2 The In-situ Sample Results

The in-situ samples flown to Calgary and tested immediately (cure day 4 or 5) showed a significant variance in strength compared to the other sample sizes that were tested. The trend was lower on the whole than other laboratory test results and there were several irregularities. The differences may be due to the difficulties in extruding the samples from the PVC tube, which involved sawing the PVC along the length of the sample and that the samples had a narrower diameter than traditional samples. Samples towards the base of the 6 m sample tube showed stronger results than those at the surface. All panels with in-situ samples were tested at 28 days for consistency, and after that used only if other sample sizes were not available.

6.2.3 The 50 by 250 mm Sample Size Results

The larger ambient cured samples are the traditional size for testing slurry wall strength and provided the most consistent results within each panel. The length of the samples allowed for adequate trimming of top and base during the sample preparation. However, when comparing the panels, there was a significant variance in strength at the same cure dates. The values are generally lower than the expected levels from the design strength testing. This may be a result of the impurities and inclusions introduced into the samples during excavation (for example sand and gravel).

Overall, the strength gain with time is clear, but the wall took longer to reach the target values than expected, and the strength for each panel was different.

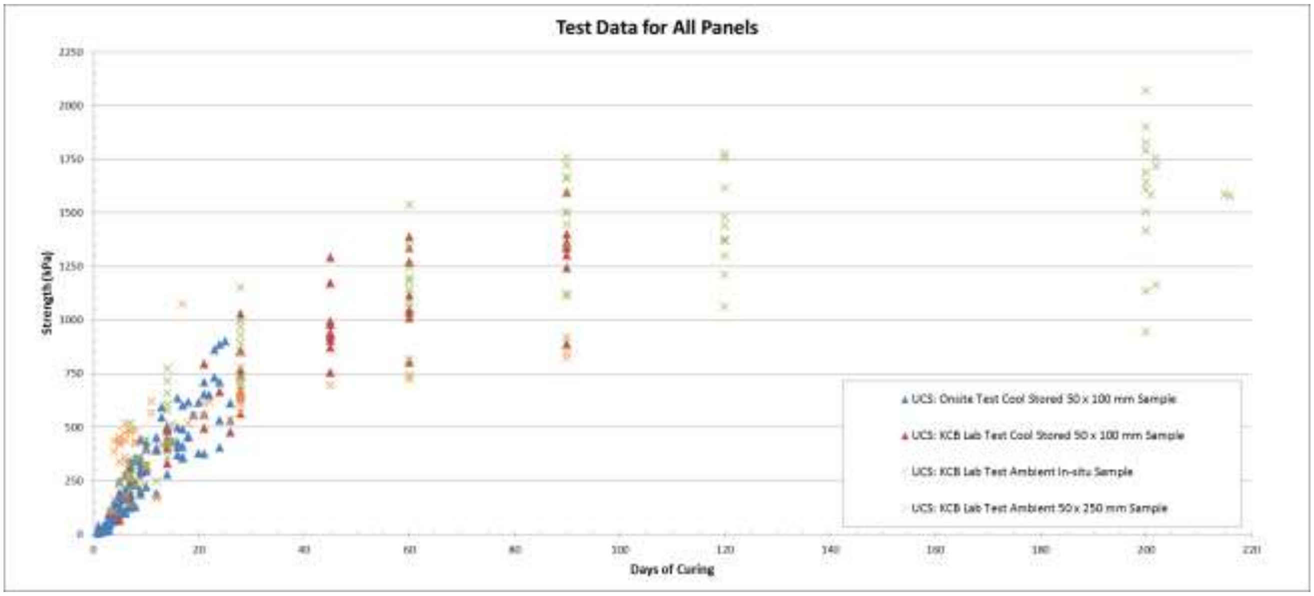

Figure 6. Graph of strength results for all panels using different sample sizes and testing methods.

6.2.4 Strain Testing Results

The strain rate required by the wall design was 1.5%. All laboratory UCS tests, irrespective of the sample type, had an associated strain at peak strength. Although the data was clustered around 1.5%, the results showed considerable variability. There appeared to be little correlation with cure date, although generally the panels appeared to show lower strain rates with increasing strength (time). The design mix testing showed a similar level of variability in strain results.

7 DISCUSSION

7.1 Variations in Results

There were considerable variations in the rates at which the panels gained strength. Variability in the strength results can be attributed to several factors, including the particular slurry mix produced for each panel. Although minimum design requirements were met for each panel, there was variance above these values. For example, Panel 7 had a higher Portland cement to water ratio and showed one of the fastest increases in strength with time. The densities of the final cement bentonite slurries for Panels 1 and 5 were lower than the rest of the panels (although still within design).

The panel samples have inclusions of foreign material as well as slurry thinner from the trench which may be the reason the values are less than the design mix strength results over time. The majority of design mix strength testing was completed using triaxial apparatus and this was shown to provide results that were approximately 10% greater than the UCS testing. Sample testing is generally undertaken within 90 cure days (ICE, 1999) but during this project samples were tested up to and above 200 days. Although every effort was made to store these at conditions similar to those at the ground, cylindrical samples within plastic casing may not be truly representative of the in-situ wall and are likely to be considerably drier than in-situ conditions.

As the objectives were to meet the short and long term goals of the project, and the project evolved as it progressed, it is recognized that there are gaps in the sampling and testing methodology in regards to having controlled/repeated testing using the same testing, sample size and storage temperature types.

7.2 Temperature Effects

Figure 7 shows a comparison between the onsite and laboratory UCS testing of 50 by 100 mm cool stored samples and the laboratory tested 50 by 250 mm ambient cured samples. In general the UCS testing of ambient cured samples suggested higher strengths than the cooled stored samples. However, the difference in sample size and testing method may account for this variance. Overall the testing results showed a very similar trend to the design mixes created with 10°C water. The heating of the water used onsite may have increased the strength, while the inclusion of foreign material in non-laboratory conditions as discussed in Section 7.1 may have counteracted the strength improvement. As expected the design mixes created with ambient water and cured at ambient temperatures displayed significantly higher strengths than the mix used in construction.

The design mixes created with 10°C water were not subjected to long term testing but can be expected to have a slower strength increase rate than those created with ambient water and cured at ambient temperatures. The data suggests that the standard ambient testing may be providing strength results which are higher than reality, assuming the samples were stored at temperatures similar to that experienced by the slurry as it cures and that the onsite UCS testing was comparable to the laboratory testing. As shown in Figure 7, at 14 cure days the ambient cured samples were reaching maximum strengths of almost 800 kPa while the cool stored samples were all below approximately 600 kPa representing approximately 75% or less of the ambient tested strength which is similar to the 71% shown in Figure 2, for the CFA at 14 cure days.

7.3 Strength Results

The purpose of the temperature monitoring and testing of samples which had been cured at temperatures similar to that experienced by the in-situ slurry, was to optimize the short term construction sequence for the CB wall and long term schedule for construction of the dam above the wall. The following sections provide the strength testing results in terms of effect on the short and long term construction scheduling.

7.3.1 Panel Sequence

The CB wall was excavated as a series of discrete panels to ensure the integrity of infrastructure and the existing dam structure on the upstream side. The short term requirement was for a UCS strength of 50 kPa (approximately 25 kPa shear strength in relation to slope stability) to be reached within 7 days, so that the adjacent panel could be constructed. The wait period between panels could be reduced if the testing indicated that 50 kPa had been reached within 7 days. The onsite UCS testing and in-situ sample results for the first two panels (Panels 1 and 6) showed strength values above 50 kPa after 4 days; however, the variability in the results were considered enough of a concern to remain on a 7.5 day schedule between panel excavation. The results were reviewed again after the second two panels had been excavated (Panels 2 and 7) and the results were considered reliable enough to reduce the schedule to 6.5 days between adjacent panels, with the 50 kPa criteria being met within this time frame. The revised schedule was used for the remaining panels.

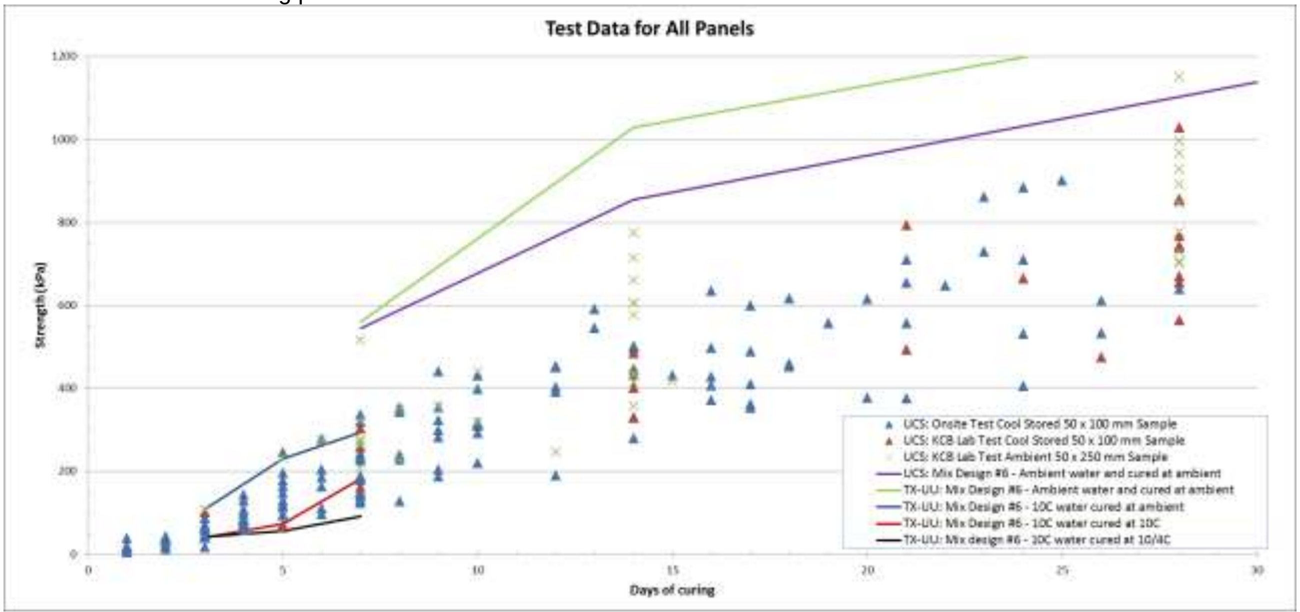

Figure 7. Graph showing comparison of strength results between cool stored and ambient stored samples, including design mix results.

7.3.2 Proximity of Heavy Equipment

Concerns were raised about heavy equipment working near the uncured wall to remove the spoil from the panels. It was stipulated that the spoil pile must be 10 m away from the wall and be less than 4 m in height. Heavy equipment (including the excavator) was required to stay 15 m away from the wall. A minimum of 28 days was initially required before any equipment could pass over the wall. This became an issue when it was realized that the area required for the rig mats, meant that the excavator would need to partially operate on top of Panel 6 to reach Panel 4 before the 28 days had elapsed. Similarly it needed to sit on Panel 6 and 7 to excavate Panel 5. An adequate factor of safety was calculated using the strength that the panels had achieved and the pressure exerted by the excavator, which therefore, allowed the excavator to operate on top of the panels prior to the 28 day period.

7.3.3 Winterization

The wall was completed by excavating the top surface so that no desiccation cracks remained, flooding the surface with fresh slurry and covering by 0.3 m of sand after curing. Insulated tarpaulins were also used to stop the top of the wall from freezing before and after the sand was placed on top of the slurry wall. In order for winterization of the wall to occur, after construction was complete, AMEC undertook further FLAC analysis using Young's modulus values from the strength testing. It was decided that for 2 m of fill above the wall, a strength of 500 kPa was required and for 4 m of fill, 700 kPa was required. After the 28 day testing was completed, all panels were above 700 kPa and the 4 m of fill was placed on top of the wall.

7.3.4 Long Term Construction Sequence

The long term goal was to reach 2 MPa at a minimum peak strain of 1.5 percent, 90 days after construction. This was designed to combat down drag load when the Base Mine Dam reached the full construction height. The strength testing and temperature monitoring during the slurry mix design and slurry wall construction, showed that cure times were slower in colder environments. Although the majority of samples did not reach the required strength within the 200 cure days, they did continue to show strength increase and were expected to reach 2 MPa when required by the BMD construction schedule.

Panel 1 showed consistently lower strength results than the other panels. This was attributed to a lower density and lower slurry temperature as it was the first panel. After analyzing the data, it was decided to leave the panel in the ground because it was still gaining strength. As it was a shallow, end panel in the pre-excavated sand chimney, a minimum of 1 MPa was required and this was reached during testing at 120 cure days.

The long term construction sequence of the Base Mine Dam above the CB cut-off wall was adjusted to account for the slow rate of strength increase. As the wall is designed to be flexible and impermeable, the rate of gain is not as important as the final strength and permeability in the overall wall design.

8 CONCLUSION

Following the successful completion of a CFA piled cut-off wall through deep fills, constructed partially with a restricted access piling rig under Highway 63, a CB slurry cut-off wall was also successfully constructed to control seepage within a subsurface alluvial channel. Installing temporary thermistors in the trench allowed the temperature of the slurry to be monitored as it cured and for samples collected for strength testing to be stored at temperatures which mimicked the ground temperatures. Although the water used in the slurry mix was heated, UCS testing indicated that the rate of strength increase was slower than expected. Variability was seen in the testing results due to different testing methods, storage temperatures, inclusion of foreign material and variations of the mix component quantities.

Despite the difficulties encountered and the delay required to reach the strength necessary for the design, the CB wall was completed within a time frame that allowed for the rest of the BMD project to proceed and no slope movements were measured by the inclinometers positioned between the crest of the embankment and the CB slurry cut-off wall. Neither were there any disruptions to upstream infrastructure.

Samples stored at temperatures which mimicked the ground conditions indicate lower strength results and may provide more realistic strength indicators than traditional testing at ambient temperatures. The field based, real time, temperature and slurry strength studies were successfully used on this construction project in an active mine environment to mitigate the risk of damage to the freshly constructed wall and dam structure.

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AMEC Earth and Environment were responsible for the design of the CB slurry cut-off wall. The project was overseen by the Syncrude Geotechnical Department which was responsible for the overall Base Mine Dam design and construction was organized by the Base Mine Dam, Major Projects Group. The contractor for construction was Graham, who subcontracted Pennsylvania Geo-Solutions Inc, both of which were crucial to the success of this project. Also Terracon Geotechnique conducted the inclinometer monitoring and CEDA International Corporation heated the water used in the slurry mix.

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