Unloading Pore Pressure Response of the Weak Clearwater Derived Clays Under a Tailings Dyke at the Suncor Millennium Mine

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ABSTRACT
Suncor is in the process of removing Pond 8B which provides buttressing support for the downstream slope of Dyke 11B. To maintain stability, modifications are required to Dyke 11B before and during Pond 8B drawdown. The dyke modifications also involve partial excavation of the crest and downstream slope. Dyke 11B is an ex-pit dyke constructed on Clearwater Formation clay shales and Clearwater derived till. The clays are high plastic and highly pre-sheared.

Understanding the pore pressure response of the glacially-rafted and ice-pushed weak Clearwater Formation clays to the unloading was critical for the design of the project. To confirm the design parameters and assess the potential risk of removing Pond 8B, a field program was designed and executed to determine the pore pressure response of the clays due to the unloading. It was recognized that a successful trial required relatively continuous data retrieval coupled with a high level of cooperation with Suncor Operations and their contractor.

The unloading trial consisted of an approximately 650 m x 125 m instrumented area on the dyke. The piezometers installed in the excavation area were connected to a telemetry system, and the data was monitored from remote locations in real-time. The piezometers were protected during the excavation and remained operational until the day the excavation proceeded to the instrument location. The piezometer leads were disconnected during the excavation in an area of the instrumented section immediately before the excavation and re-connected to the instrument soon after the excavation to obtain as close to a continuous pore pressure response as practical.

The project was considered a success from the perspective of obtaining data throughout the excavation process. This paper presents the details of the instrument monitoring program, the effort undertaken to maintain the instrumentation during the excavation, and the unloading pore pressure response during the excavation.

RÉSUMÉ
Suncor est en train d'enlever le bassin 8B qui fournit un support de contrefort à la pente en aval de la digue 11B. Pour maintenir la stabilité, des modifications doivent être apportées à la digue 11B avant et pendant le rabattement du bassin 8B. Les modifications de la digue impliquent également une excavation partielle du sommet et de la pente en aval. A l'origine la digue 11B était construite sur des schistes argileux de la Formation de Clearwater et du till dérivé de Clearwater. Les argiles sont haut plastique haut et fortement pré-cisaillées.

Compréhension des résultats de la pression pendant le déchargement de la formation d'argile de Clearwater formées par les glaciers et poussées par la glace a été déterminante pour la conception du projet. Pour confirmer les paramètres de conception et évaluer le risque potentiel d'enlèvement du bassin 8B, un programme en chantier a été conçu pour déterminer la réponse de pression interstitielle des argiles due au déchargement. Il a été reconnu qu'un essai réussi exigeait une extraction de données continue, associée à un niveau de coopération avec les opérateurs de Suncor et ses contracteurs.

L'essai de déchargement consistait en une zone instrumentée d'environ 650 mx 125 m sur la digue. Les piézomètres installés dans la zone d'excavation étaient connectés à un système de télémétrie, et les données étaient surveillées à distance en temps réel. Les fils du piézomètre ont été déconnectés pendant l'excavation dans une zone de la section instrumentée immédiatement avant l'excavation et reliée à l'instrument peu de temps après l'excavation pour obtenir une réponse de pression interstitielle aussi proche que possible.Le projet a été considéré comme un succès du point de vue de l'obtention de données tout au long du processus d'excavation. Cet article présente les détails du programme de surveillance des instruments, l'effort entrepris pour maintenir l'instrumentation pendant l'excavation, et la réponse de la pression interstitielle de déchargement pendant l'excavation.

1 INTRODUCTION

Suncor Millennium Mine is located approximately 30 km north of Fort McMurray Alberta. Dyke 11B is an ex-pit dyke in the Suncor Millennium Mine and is a containment dyke for Pond 8B and Pond 8A (Figure 1). Dyke 11B was originally constructed as the western containment structure of Pond 8A. It was constructed between 2001 and 2005 to approximately El. 370 m with upstream hydraulically placed sand construction. Pond 8B was filled between 2001 and

2009 with Fluid Fine Tailings (FFT) to a maximum pond elevation of El. 357 m. A small tailings sand beach was placed in the northwest corner of Pond 8B during the initial stages of filling.

Figure 1. General Site Plan

In 2003, during construction of the El. 361 m bench of Dyke 11B, movement in the foundation clay was detected in the southern portion of the dyke. An end-dumped buttress was constructed into Pond 8B over the southern half of Dyke 11B to provide toe support for Dyke 11B. A buttress was not required for the northern half of the dyke due to the presence of the tailings sand beach in that region. Figure 2 shows the extent of the existing buttress and tailings sand beach within Pond 8B. Dyke 11B was successfully constructed to its final design elevation of 370 m with the buttress and the buttressing effect of Pond 8B.

Due to the mineable oilsands within the Pond 8B footprint, Suncor is in the process of removing Pond 8B and the buttressing support for the downstream slope of Dyke 11B. The proposed removal of Pond 8B has necessitated design measures for Dyke 11B to maintain stability during and after Pond 8B drawdown.

The design measures to stabilize Dyke 11B involve a combination of excavation of the dyke crest and enlarging the existing toe buttress. The design measures for the northern part of the dyke involve only partial excavation of the crest and downstream slope. Building a buttress on the northern part as a stabilization measure was not a feasible option due to the presence of the liquefiable tailings beach in Pond 8B as shown in Figure 2.

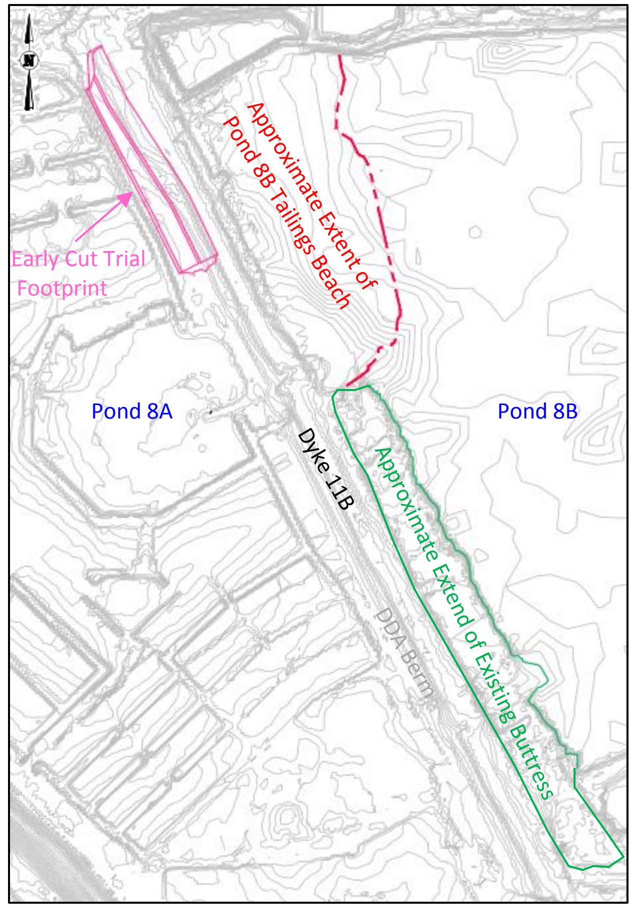

Figure 2. Dyke 11B Existing Buttress and Approximate Extent of the Pond 8B Tailings Beach

A portion of the excavation, or cut, in the northern part of the dyke was conducted prior to the overall construction to obtain information regarding the following:

- Foundation clay response to unloading; and
- Methodology for excavation of the tailings sands

The initial excavation in the northern portion of the dyke is referred to as the early cut and was carried out between May and August 2017. The intent of this paper is to discuss the pore pressure response in the foundation to the unloading. Additionally, there is some discussion provided on the construction methodology.

2 FOUNDATION GEOLOGY AND DYKE FILLS

2.1 Foundation Geology

The foundation of Dyke 11B consists of till overlying Clearwater clay shales. The Clearwater units are underlain by the McMurray Formation (oilsands). The bottom portion of the till typically consists of Clearwater Formation derived

PgKc and Kcip units and both of which are disturbed, high plastic tills that are pre-sheared and slickensided.

The PgKc and Kcip units were formed by blocks of Clearwater Formation which have been detached from the bedrock surface and transported to their current location by glacial processes. These materials generally have the same composition as in-situ Clearwater clays but, may have distorted bedding, slickensides, and occasionally contain some glacially derived sand or rounded gravel. The ice-rafted Clearwater clay (PgKc) occurs within till, and is underlain by glacial deposits typically consisting of till or glaciofluvial sediments. The ice-pushed Clearwater clay (Kcip) occurs directly above in-situ Clearwater Formation, but is out of place and generally out of stratigraphic sequence.

Laboratory test results for PgKc/Kcip indicate liquid limits greater than 120% and plasticity index greater than 100%. Residual friction angle values of approximately 7.5° were obtained from the direct shear tests results for these weak, high plastic Clearwater derived clays.

2.2 Dyke Fills

Dyke 11B consists of an overburden starter dyke with upstream hydraulically placed tailings sand construction. The tailings sand is divided into cell construction, beach above water (BAW), and beach below water (BBW) zones.

The delineation of the contractive and dilative tailings sand beach zones was carried out based on the CPT testing results using Robertson (2010 and 2016) criteria. The contractive and dilative tailings beach zones are shown on a typical cross-section of the dyke in Figure 3.

The contractive tailings beach zones are susceptible to liquefaction under static or seismic events. Detecting this event and responding accordingly is extremely challenging due to its rapid occurrence upon triggering. For this reason, where there is a material susceptible to liquefaction, it is typically assumed that it will occur and the structure is designed to handle this event. This approach was adopted in the Dyke 11B stabilization measure design as well.

3 EXISTING PORE PRESSURE CONDITIONS AND PORE PRESSURE DESIGN ASSUMPTIONS

The measured pore pressures in the dyke area showed an increase in pore pressure ratio (r_u) with increasing fill height. Figure 4 shows the r_u variation in the PgKc/Kcip material with fill height and the design pore pressure assumption for the weak foundation clays. The pore pressure assigned to the foundation clay units is based on the amount of fill loading above the original ground surface.

It was assumed that the fill height loading and r_u relationship for the weak clay foundation is valid when the fill is removed. This was one of the key assumptions that were to be confirmed from the early cut trial.

The pore pressure conditions within the Dyke 11B tailings sand fill was observed to be close to the ground surface. Two drains (as shown on the cross-section in Figure 3) were installed within the tailings sand using the one-pass trenchless technology in Fall 2016 to aid the construction activities and to increase the stability of the dyke.

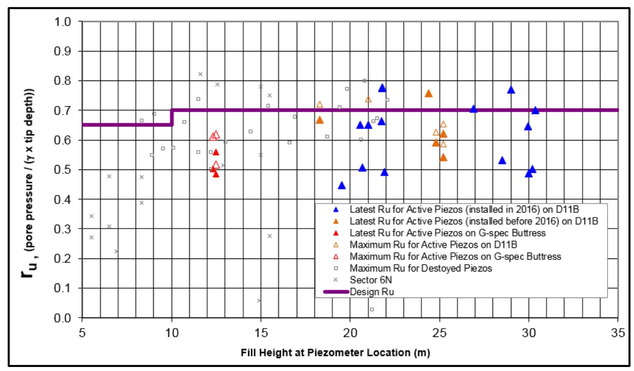

Figure 4. Pore Pressure Ratio (r_u) Vs. Fill Height Plot

The piezometer tips located in the tailings sand showed a decrease in the piezometric levels after the drain installation and pumping. For the tailings sand, pore pressure conditions prior to the drain installation were considered in the design due to the uncertainty of the drawdown in tailings sand.

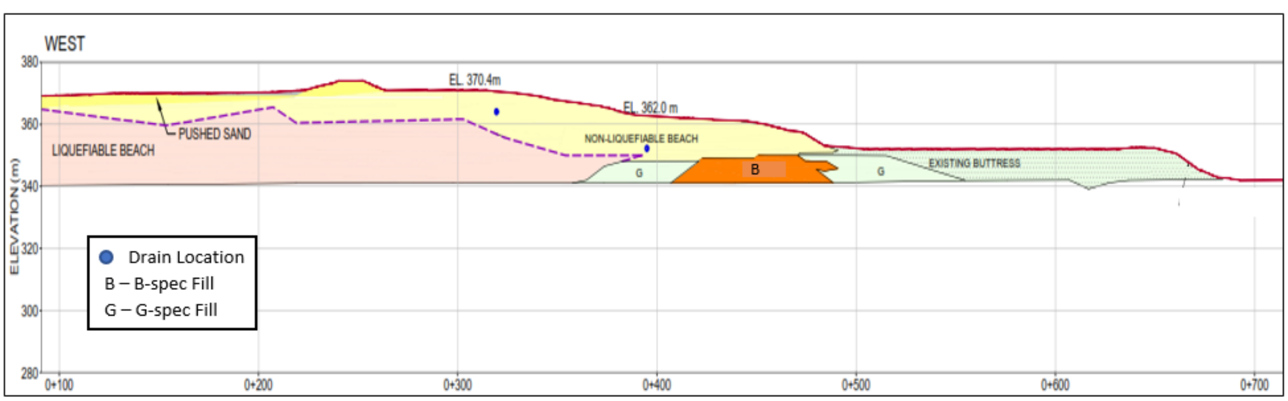

Figure 3. Dyke 11B Typical Cross-section with Liquefiable and Non-Liquefiable Tailings Beach Zones

4 EARLY CUT TRIAL

4.1 Details of the Early Cut

As the design for the Dyke 11B stabilization was developed, it was recognized that it would be beneficial to excavate a portion of the overall cut in advance of the full-scale construction to better understand potential construction issues, as well as assumptions related to foundation pore pressure response due to unloading.

The Dyke 11B early cut area is shown in plan on Figure 5. The early cut trial consisted of an approximately 650 m x 125 m instrumented area on Dyke 11B. As shown in Figure 5, the early cut is limited to the northern third of Dyke 11B where the dyke is mostly buttressed by the tailings sand beach in Pond 8B. The early cut consisted of two excavated benches (366 m and 362 m cut benches) and excavation up to 6.5 m in tailings sand.

One of the design requirements for the early cut was to maintain the Pond 8B level at elevation 353 m or higher. The pond level of El. 353 m or higher would provide adequate buttressing effect and meet the slope stability requirements for Dyke 11B early cut configuration.

As part of the design measures, additional vibrating wire piezometers and slope inclinometers were installed in the general area of the early cut to confirm the design assumptions.

The success of the early cut trial was contingent on Suncor Operations accommodating instrument protection and adjustments. After a cut was completed in the vicinity of a piezometer, the leads were reconnected as soon as feasible to obtain as continuous readings as possible. During this excavation process, before and after excavation pore pressure measurements were obtained for all the piezometers. This allowed comparison to the design assumptions and helped to assess the impact of unloading on the pore pressures in the foundation clays. A daily survey was conducted in the construction areas and this survey information was used to obtain a relationship between unloading and pore pressure response.

Visual monitoring was also carried out during the early cut trial by full-time geotechnical monitors. The geotechnical monitors observed the following during the early cut trial:

- The behavior of excavation faces in the sand
- Trafficability on the floor of the sand excavation

Wet areas and isolated sand boils were observed during the early cut trial due to the proximity of the water table to the ground surface. The construction approach (summarized in Section 4.3) adopted for this trial allowed continuous excavation within the early cut area.

Figure 5. Early Cut Footprint with Cut Bench Details

4.2 Dyke Instrumentation and Monitoring

Vibrating wire piezometers and slope inclinometers were installed in the general area of the early cut as shown on the plan in Figure 6. The piezometers were connected to a data logger, and a telemetry system was installed at each data logger to facilitate the real-time monitoring during the early cut trial. The slope inclinometers were protected during the excavation and shortened after the completion of the early cut excavation in that area.

4.3 Construction Methodology and Observations

Construction was conducted with a backhoe perched on top of the bench that was being excavated. The haul trucks were also located on top of the bench to haul the excavated material away from the cut area. This method eliminated equipment from trafficking the newly excavated bench surface, especially when wet or soft ground conditions were observed.

The surface of the newly excavated bench varied from dry and trafficable to very wet with occasional sand boils.

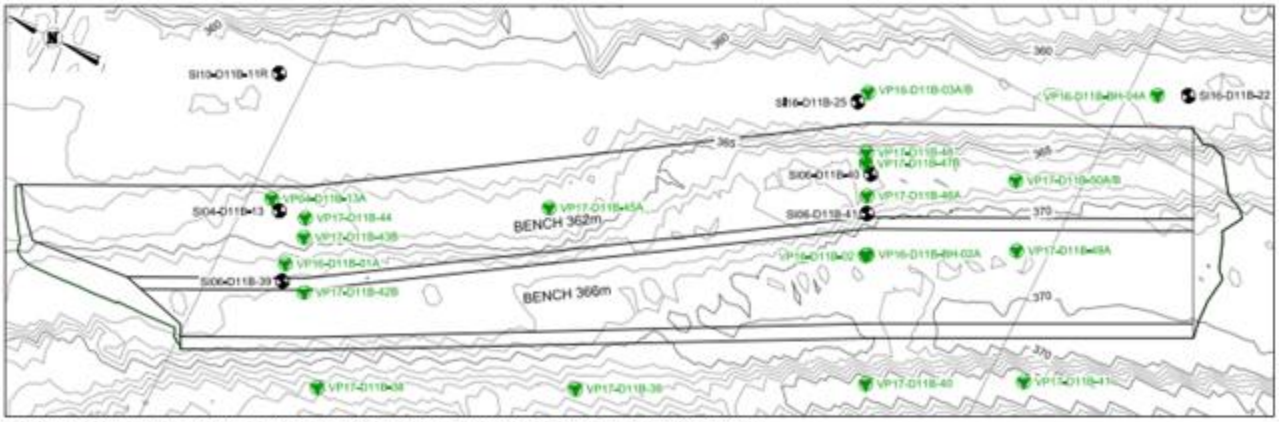

Figure 6. Instrument Locations in the General Area of the Early Cut Trial

When the surface was observed to be wet, the excavation was limited to 30 cm above the base of the design bench excavation limit. Additionally, ditches were constructed in the excavated surface to collect the seepage water and direct it away from the early cut area. The remaining 30 cm was removed in the second pass on a later day without any issues. By keeping the backhoe and trucks away from the excavated surface, the excavation progressed smoothly without any interruption even when wet conditions were encountered at the site. While the newly installed drains had only been functioning for six months prior to the excavation, it played a role in reducing the pore pressure conditions in sand within the early cut area.

The slope face of the cut was relatively dry during the operations, and no excessive slumping or seepage was observed. Continuous monitoring and additional measures were implemented to protect the instruments during the early cut excavation. Figure 7 shows the approach taken to protect the slope inclinometers and piezometers during the construction. In general, the construction proceeded without major complications, and the early cut trial was completed as planned.

Figure 7. Excavation around the Instruments

5 PORE PRESSURE RESPONSE DURING THE EARLY CUT

5.1 Pore Pressure Response in Foundation Clays

As discussed, the primary objective of the early cut trial was to observe the response of the pore pressures in the foundation clay units to the unloading of the sand.

The design of the structure was carried out based on the relationship between fill height and r_u as shown in Figure 4. This relationship is typically used for the loading scenarios. The design of the structure after unloading was based on the premise that this relationship will hold in the reverse direction as well.

Factors such as gas release upon unloading could potentially limit the amount of pore pressure that was reduced thereby resulting in a lower B-bar value and subsequently a higher r_u value. Therefore, the trial was necessary to confirm whether the pore pressure follows the r_u - height trend in the reverse direction within the excavation limits (i.e. the amount of excavation) of the trial.

Figure 8(a) shows the pore pressures in the foundation clays before (blue markers) and after (red markers) the early cut trial for all the instruments without any distinction. The same pore pressure information is presented in Figure 8(b) for the individual piezometers to show the pore pressure variation of each piezometer due to the early cut trial. The physical meaning of the variation in pore pressure ratio is shown schematically in Figure 9. In Figures 8 and 9, there are two symbols representing the “before” pore pressure ratios and two representing the “after” pore pressure ratios. The solid “before” symbol represents the pore pressure ratio prior to any excavation occurring at the site (i.e. immediately before May 2017). The hollow “before” symbol represents the pore pressure ratio immediately before excavation reaches the instrument location.

As noted in the graphs, the instrument senses the excavation prior to it reaching the actual location of the instrument. This is demonstrated by a lower r_u just before the excavation reaches the instrument (the pore pressure is decreasing due to the adjacent excavations, but the vertical load remains constant for this tip until the excavation reached the piezometer location), as discussed further in Section 5.2.

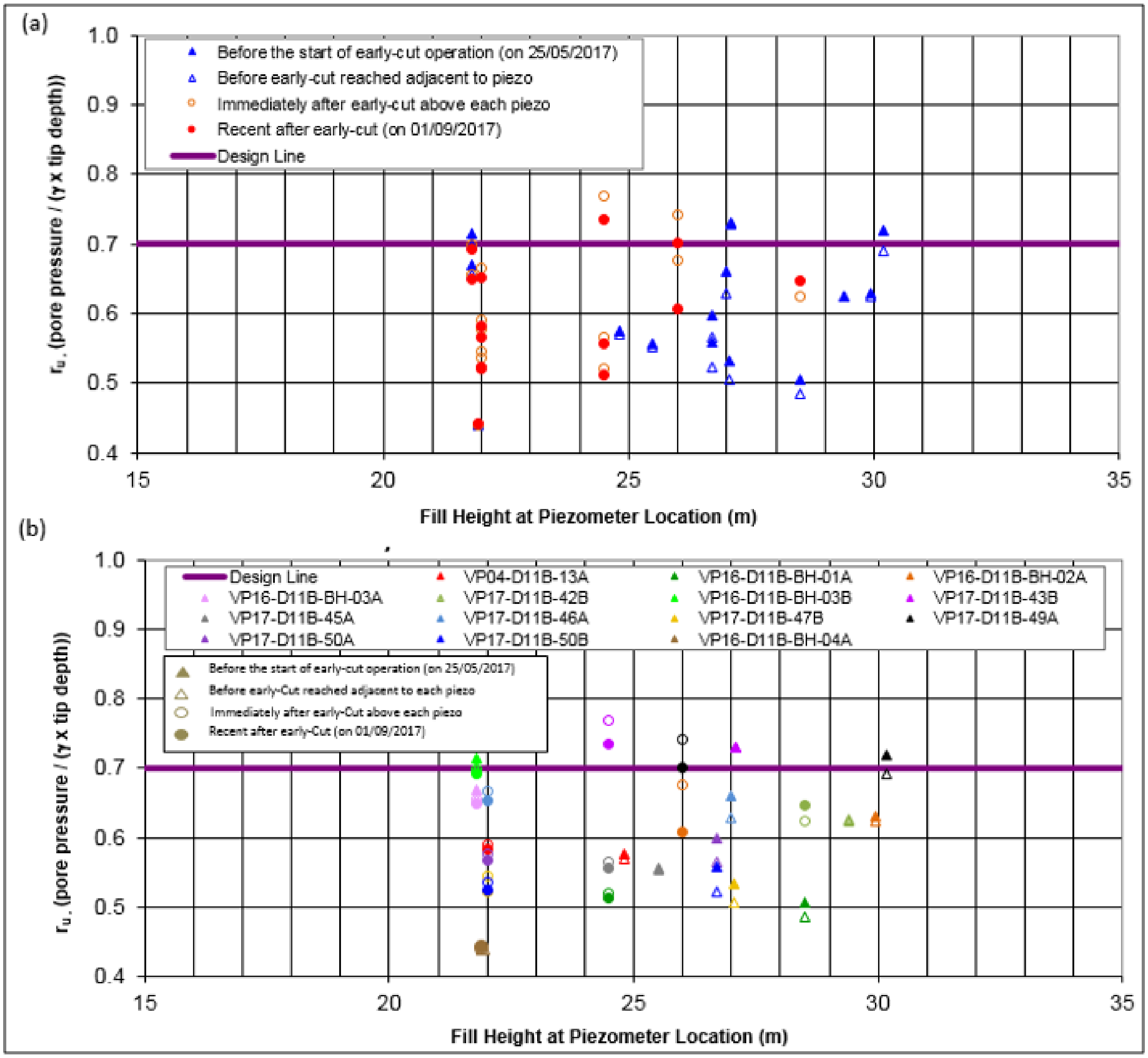

Figure 8. (a) Pore Pressure Variations for All the Piezometers at Different Stages of the Early Cut Trial (b) Pore Pressure Variations for Individual Piezometers at Different Stages of the Early Cut Trial

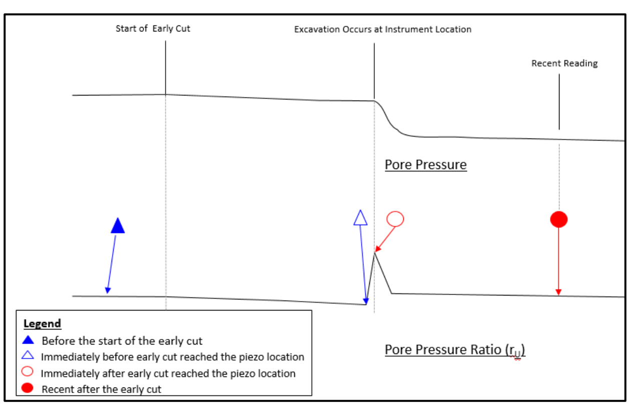

Figure 9. Typical Pore Pressure and r_u Variation Schematic

The "after" excavation is also represented by two symbols. The hollow symbol represents the r_u immediately after the excavation, and the solid symbol represents the r_u after the reading has stabilized. The r_u immediately after the excavation was typically slightly higher than the stabilized reading. This is likely due to a combination of transient effects; a lower vertical load was considered in the r_u calculation while the pore pressure is being lowered due to the excavation.

Comparing the solid symbols gives the unloading pore pressure response without the transient effects. This comparison shows that there is only a marginal change in the r_u between the before and after excavation scenarios. This is also evident in the data presented in Table 1.

Table 1. Summary of change in r_u values for the weak foundation clays

Piezometer ID	r_U Values		Change in r_U Values
	Before Early Cut	After Early Cut	$(r_U)_a$ - $(r_U)_b$
VP04-13A	0.58	0.58	0
VP16-01A	0.51	0.51	0
VP16-02A	0.63	0.61	-0.02
VP16-03A	0.67	0.65	-0.02
VP16-03B	0.72	0.69	-0.03
VP16-04A	0.44	0.44	0
VP17-42B	0.63	0.65	+0.02
VP17-43B	0.73	0.73	0
VP17-45A	0.56	0.56	0
VP17-46A	0.66	0.65	-0.01
VP17-47B	0.53	0.52	-0.01
VP17-49A	0.72	0.70	-0.02
VP17-50A	0.60	0.57	-0.03
VP17-50B	0.56	0.52	-0.04

$(r_u)_a$ – r_u value after the completion of early cut trial
$(r_u)_b$ – r_u value before any early cut excavation

The piezometric elevation vs. time and r_u vs. time plot for a typical piezometer located within the early cut area is shown in Figure10.

5.2 Influence of Excavation Immediately Outside the Piezometer Location

The tips that are located approximately 40 to 50 m below the ground surface in the weak foundation clays showed a response to the excavation adjacent to the instrument.

Pore pressure readings in the weak foundation clay showed a drop when the area adjacent to the instrument was excavated. Figure 11 shows pore pressure response of a typical piezometer in the early cut area with the excavation timelines in the general area of the piezometer. This piezometer location was excavated on June 15, 2017 and the lead was reconnected to the data logger on the day after the excavation. As shown in Figure 11, the piezometer showed distinct drops in the pore pressure readings in response to the adjacent excavation in July and August 2017.

Figure 11 also shows the B-bar vs time variation for this tip. As shown in the figure, B-bar value varied significantly compared to the variation in r_u for this time period. The piezometers located within the early cut area (where the surrounding area was excavated) typically showed B-bar values in the range of 0.9 to 1.0 at the completion of the early cut. The piezometers located close to the edge of the early cut area (where the surrounding area is only partially excavated) typically showed B-bar values in the range of 0.5 to 0.7 in this period.

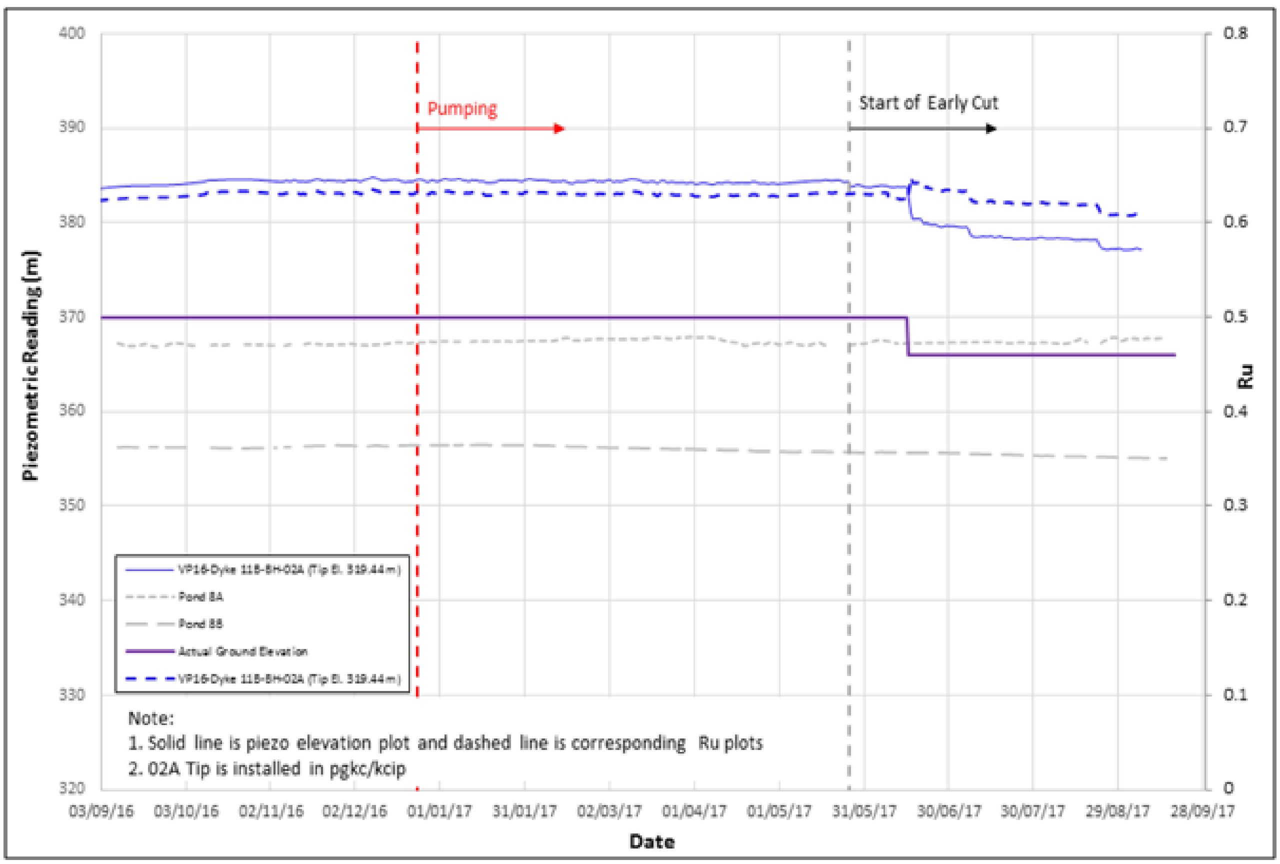

Figure 10. Typical Plot Showing the Piezometric Elevation and r_u Variation with Time

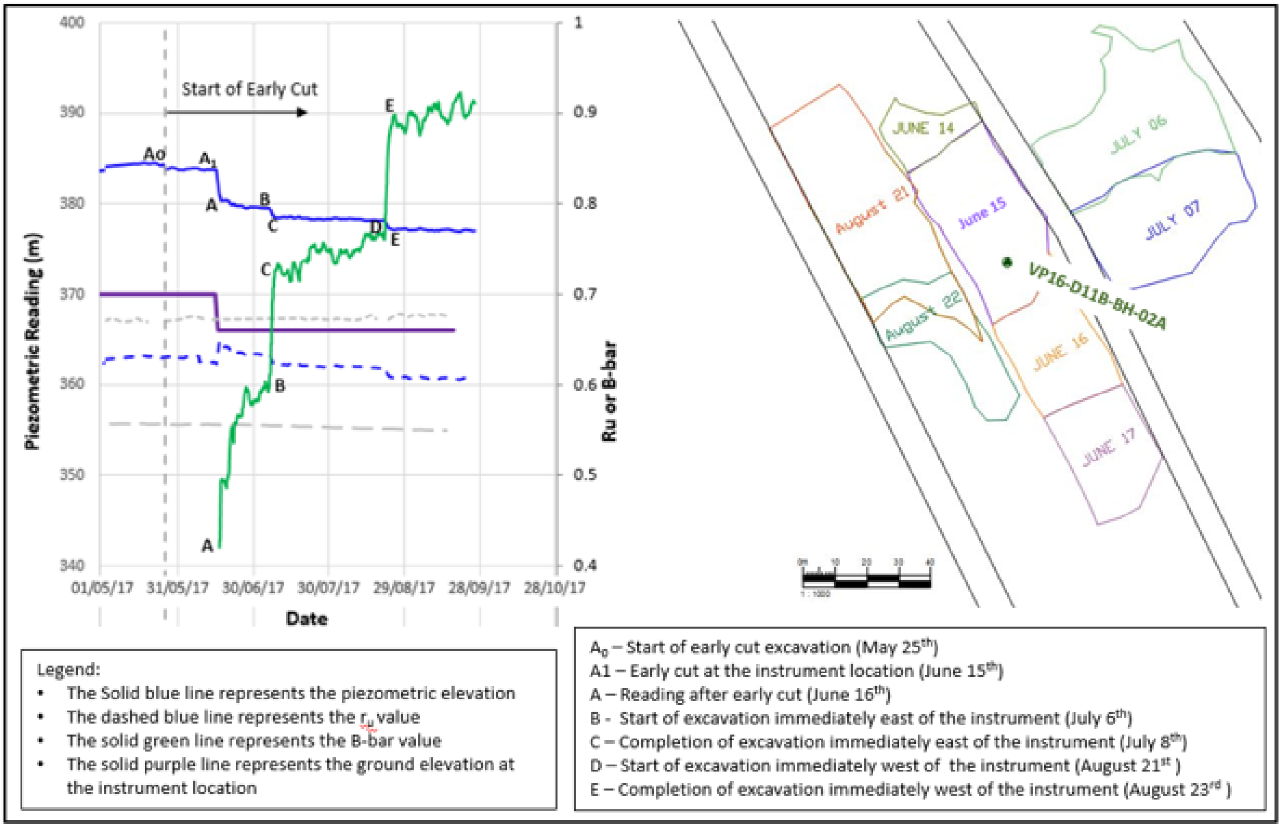

Figure 11. Pore Pressure Response Vs. Time Plot with the Excavation Timeline in the General Area of the Piezometer

5.3 Pore Pressure Response in Sand

Another design consideration for Dyke 11B is the potential for liquefaction in contractive beach sands during the construction. It is instructive to know whether a liquefaction event has occurred even when there is no evidence of excessive deformation which can potentially be done by observing the pore pressures within the sand. If contraction occurs, this should be evidenced by an upwards spike in pore pressures.

The pore pressure variations in piezometer tips in the sand were monitored to understand the impact of unloading and construction activities with heavy haulers on the contractive sand. Figure 12 shows the pore pressure variations of the tips in the sand with time. Of the seven piezometer tips that are in the sand, six tips are in the contractive tailings sand as noted in Figure 12.

The plot did not show any evidence of a spike in pore pressure conditions for the tips in tailing sand during the early cut trial.

6 CONCLUSION

The early cut trial on Dyke 11B was completed successfully. Excavation of the sand benches was achieved with no major construction difficulties.

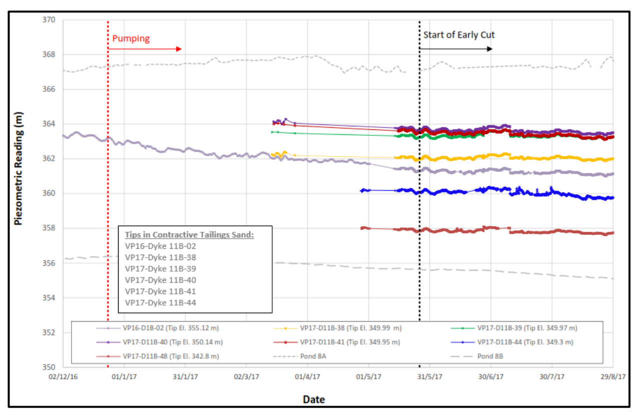

Figure 12. Pore Pressure Variation with Time for Piezometer Tips Located in Tailings Sands

Importantly, the pore pressure assumptions utilized in the design for the weak foundation clays (the unloading response of pore pressure is similar to loading) were confirmed as valid by readings from the instruments. Stability of the dyke was maintained during the pond lowering.

The major findings from this early cut trial and the instrument data are:

- The assumption of a minor change in r_u after excavation (for excavations up to 6.5 m) and the use of r_u as a design approach is valid.

- The pore pressure response for the weak foundation clays are responsive to adjacent excavation.
- The calculated B-bar values due to unloading are highly responsive to the construction activities adjacent to the instrument location.
- The construction methodology adopted for the early cut can be used for the full excavation of Dyke 11B outside the early cut footprint.

7 ACKNOWLEDGEMENT

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8 LIMITATIONS

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