GDS CASE STUDY: MOUNT POLLEY MINE TAILINGS STORAGE FACILITY EMBANKMENT BREACH

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Disclaimer: This case study has been prepared solely by GDS Instruments following our review and interpretation of a publicly available technical report. This case study has not been reviewed by third parties, and does not constitute technical advice of any sort.

GDS Instruments designs, develops and manufactures materials testing machines and software used for the computer-controlled testing of soils and rocks. This technology is used to evaluate the mechanical properties that are key in geotechnical and earthquake engineering design. Karl Snelling (Managing Director), Jerry Sutton (Technical Director) and Clayton Dodd (Sales Director) have 60 years collective experience working at GDS. This combined experience ensures customers can expect a consistency in the GDS approach of its equipment and its support.

Since being founded in 1979, it is estimated that GDS products have been used to help achieve over 1000 Phd's. As well as being the first choice for academic research, GDS products have been used in many world renowned commercial developments including the Three Gorges Dam in China, the Millau Viaduct in France, the Vasco da Gama Bridge in Portugal, Terminal Five at Heathrow and the new Crossrail links in London.

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INTRODUCTION

Early on the 4th of August 2014, an embankment breach occurred at the Mount Polley Mine Tailings Storage Facility (TSF) located in British Columbia, Canada. The cause of the breach, which released millions of cubic metres of tailings slurry and supernatant water (Brown et al., 2016) from the TSF into Polley Lake, Hazeltine Creek, and Quesnel Lake, was subsequently examined by an Independent Expert Engineering Investigation and Review Panel (the Panel). The Panel reported on its findings (Morgenstern et al., 2015) on the 30th of January 2015, concluding that the dominant reason for the breach was embankment foundation soil failing under undrained conditions due to stresses imposed by the embankment construction.

This case study briefly summarises some of the geotechnical engineering findings reported by the Panel. In particular, it focuses on the laboratory testing programme that was critical to the investigation, which utilised an advanced direct simple shear apparatus designed and manufactured by GDS Instruments (GDS). We recommend that our readers refer to the publically available Panel report, published by the Province of British Columbia, for detailed commentary relating to the Mount Polley Mine TSF embankment breach.

MOUNT POLLEY MINE TSF EMBANKMENTS AND FOUNDATION SOILS

The Mount Polley Mine TSF comprised three embankments, including a Main Embankment, a South Embankment, and a Perimeter Embankment. These embankments were designed to confine tailings generated from mining activities. It was a section of the Perimeter Embankment's northern flank (herein referred to as the Embankment) that failed without warning on 4th of August 2014.

The Embankment design consisted of an impervious core, with filter, transition, and rockfill zones on the downstream side of core. Upstream of the core, a fill zone was to consist of rockfill and/or tailings. The Embankment was also initially designed to be constructed using a modified centreline configuration however, a number of Embankment raises ultimately utilised an upstream-style construction configuration.

Figure 1: Photo of the Mount Polley Mine Tailings Storage Facility breach, looking upstream.

Source: Morgenstern et al. (2015). Used with permission from Province of British Columbia.

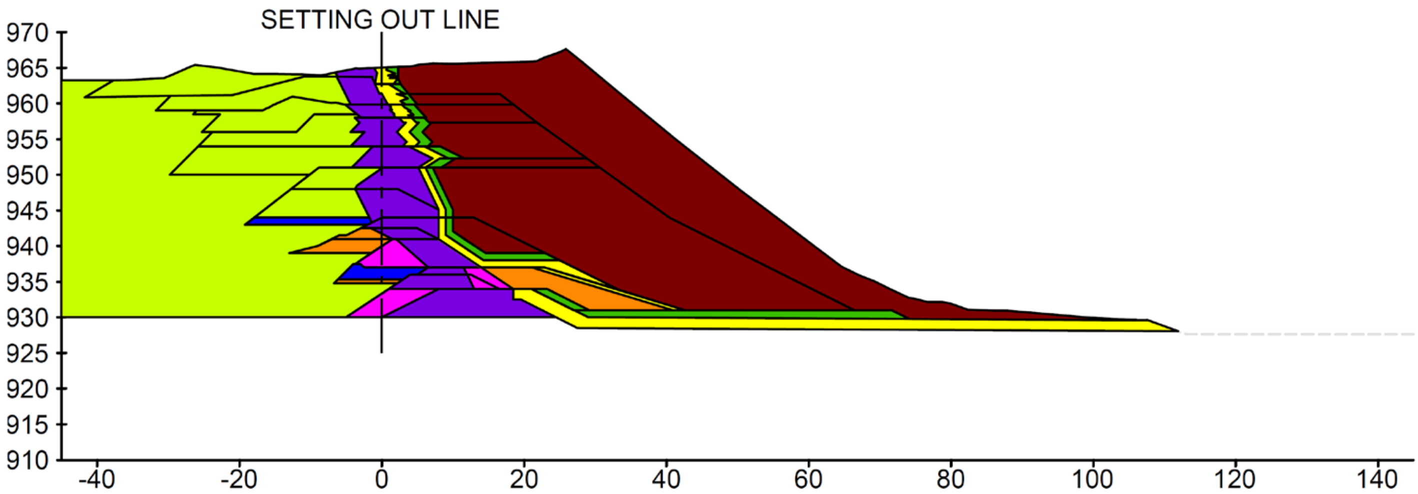

Figure 2: Schematic section of the Embankment prior to failure occurring.

Source: Morgenstern et al. (2015). Used with permission from Province of British Columbia.

In the vicinity of the Embankment breach, the generalised subsurface stratigraphy comprised glacially deposited soils. Specifically, an Upper Till stratigraphic unit was underlain by an Upper Glaciolacustrine unit (Upper GLU), with a Lower Till unit (which included a Lower Glaciolacustrine sub-unit [Lower GLU]) locating above weak bedrock. The Upper and Lower GLU materials were comprised of varved silts and clays, typically classifying as low to high plasticity clay. Variability in soil stratigraphy was however noted across the TSF footprint, suggesting the facility was constructed within a relatively complex geological environment with complex depositional history.

PANEL INVESTIGATION INTO THE EMBANKMENT BREACH

Surface investigations provided direct evidence that shear failure of foundation soil beneath the Embankment was the primary cause of the breach. Subsurface investigations then inferred the location of the shear failure zone to be within the Upper GLU unit, at an elevation approximately 10 m below the Embankment base.

Undisturbed sampling of the Upper GLU, at locations adjacent to the disturbed breach zone (i.e., where Upper GLU soils were still undisturbed), subsequently became an integral aspect of the Panel's investigation. Mud rotary drilling and a thin-walled sampler were used to obtain the undisturbed Upper GLU samples. An advanced laboratory testing programme was then specified to study the response of the Upper GLU to applied loadings, with CT (computed tomography) scanning used to select suitable samples for testing.

Figure 3: Photo of Upper GLU soil sampled from within the breach area, showing contorted and folded laminations.

Source: Morgenstern et al. (2015). Used with permission from Province of British Columbia.

ADVANCED LABORATORY TESTING PROGRAMME, INCLUDING USE OF GDS DIRECT SIMPLE SHEAR APPARATUS

A) Direct simple shear testing

Evaluating the undrained strength of the soil within the inferred shear zone of the Upper GLU deposit formed a critical component of the Panel's investigation. The strength in this zone was best assessed using the direct simple shear (DSS) test, given that it reasonably models the expected mode of deformation within the inferred shear zone.

MEG Technical Services (MTS) performed a series of monotonic constant volume direct simple shear tests as part of the Panel's investigation. This testing was predominantly undertaken using two GDS Electromechanical Dynamic Cyclic Simple Shear (EMDCSS) devices, each of which enable a constant specimen volume to be maintained during shearing (monotonic and/or cyclic) via a low compliance DSS device design, active height control, and physical lateral restraint (a wire-reinforced membrane, or, as used by MTS, a stack of low-friction retaining rings). The tests were performed as per the ASTM D 6528 test standard (ASTM, 2007).

Figure 4: GDS Instruments Electromechanical Dynamic Cyclic Simple Shear Device (EMDCSS).

MTS also have the capability of performing bender element tests on DSS specimens prepared within their GDS EMDCSS devices. Such tests are conducted by first installing end platens containing bender elements with a EMDCSS, and then using a GDS Bender Element System (BES) to generate, receive, and record S- and P-waves propagated through test specimens.

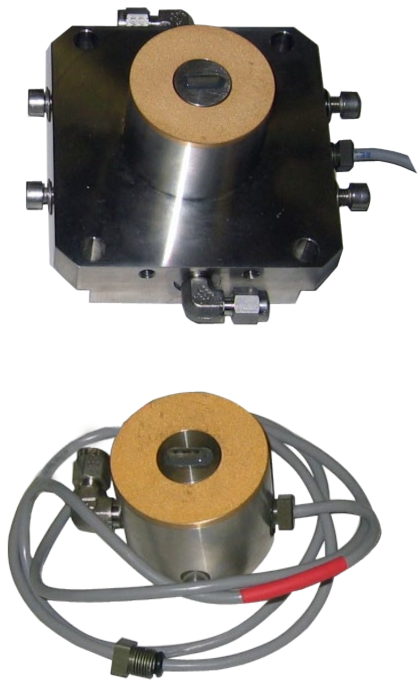

Figure: 5 Bender Element shown in pedestal and topcap.

Upper GLU test specimens sheared within the GDS EMDCSS devices were nominally 73 mm diameter. The specimens were consolidated to either 300 kPa or 600 kPa effective vertical stress, with 0 % to 20 % initial shear stress (i.e., 0 kPa to 120 kPa shear stress) applied during the consolidation stage. Such combinations of vertical and shear stresses were applied to model stress states within the Upper GLU during various stages of the Embankment construction.

Data gained from the direct simple shear tests produced estimations of peak undrained strength ratios (i.e., peak shear stress divided by vertical effective consolidation stress) in the range of 0.20 to 0.28, depending on the consolidation conditions. In addition, the test specimens generally demonstrated strain softening behaviour (i.e., a reduction in shear stress) once the soil was strained beyond the peak shear stress.

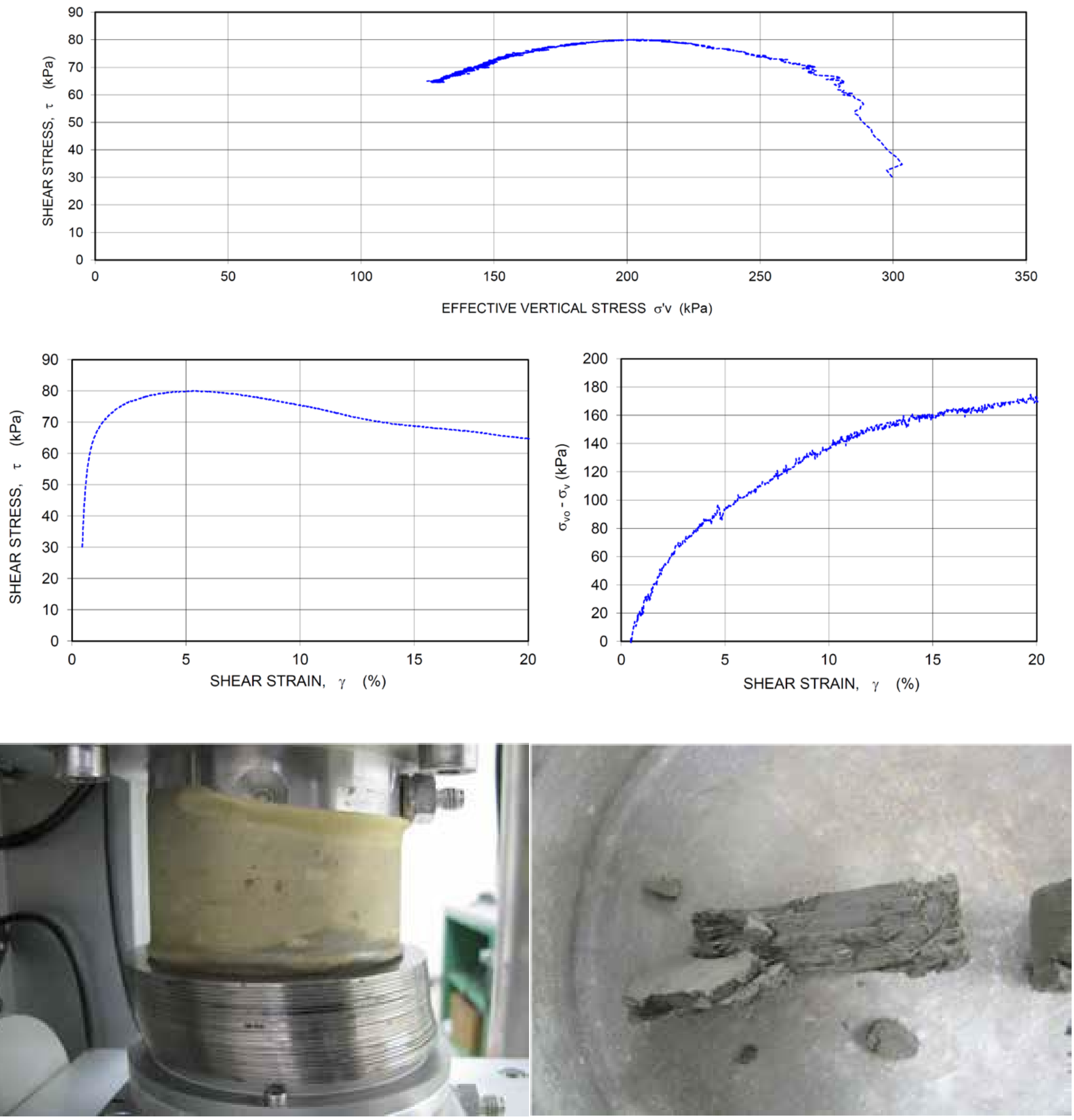

Figure 6: Direct simple shear response and photos of an Upper GLU soil specimen tested under constant volume conditions within a GDS Electromechanical Dynamic Cyclic Simple Shear (EMDCSS) device.

Source: Morgenstern et al. (2015). Appendix E: ATTACHMENTS. Used with permission from Province of British Columbia.

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B) Oedometer testing

Oedometer testing of eleven specimens obtained from the Upper GLU samples was performed to examine the volumetric response of the soil under applied load. Stress increments began at 12.5 kPa, with a maximum vertical stress of either 1600 kPa or 3200 kPa reached. These tests enabled the preconsolidation pressure of the Upper GLU deposit (within the vicinity of the breach) to be estimated, along with coefficient of consolidation values for each applied stress.

Figure 7: GDS Automatic Oedometer System (GDSAOS).

C) Triaxial testing and direct shear test

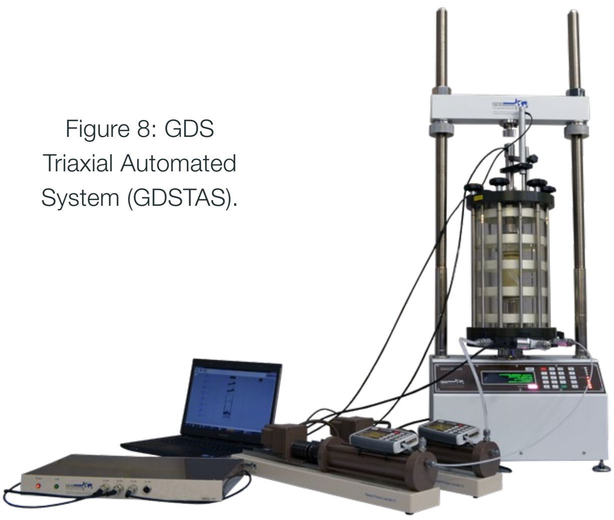

Figure 8: GDS Triaxial Automated System (GDSTAS).

A series of consolidated undrained triaxial tests, as well as a single direct shear test, were conducted as part of the advanced laboratory testing programme. The triaxial tests helped to guide strength parameter adoption for subsequent Embankment stability analyses, and enabled further estimation of coefficient of consolidation values for the Upper GLU soil confined under a range of effective stresses.

INSIGHTS FROM THE ADVANCED LABORATORY TESTING PROGRAMME

The advanced laboratory testing programme provided a number of important insights into the physical response of the Upper GLU soils to applied loadings, which in turn enabled the Panel to determine the specific mechanism of the Embankment breach.

- The direct simple shear testing provided the Panel with undrained strength parameters for the Upper GLU soils that were critical to the investigation. These parameters, subsequently adopted within limit equilibrium and deformation analyses that examined Embankment stability, helped the Panel to conclude that undrained failure of the Upper GLU deposit was the specific mechanism that caused the breach to occur.

- The direct simple shear testing also highlighted the strain softening tendency of the Upper GLU soils. This demonstrated that the resistance of the soil to applied loading would decrease as shear deformations progressed, and helped to explain why the Embankment failure occurred in a sudden manner.

- Oedometer testing showed that the Upper GLU deposit was overconsolidated prior to the construction of the Embankment, and that it became normally-consolidated during Embankment construction. This shift from an over-to normally-consolidated state resulted in the Upper GLU soils tending toward contractive behaviour under applied vertical and shear loads, and, importantly, a susceptibility to the undrained shear failure that was ultimately observed.

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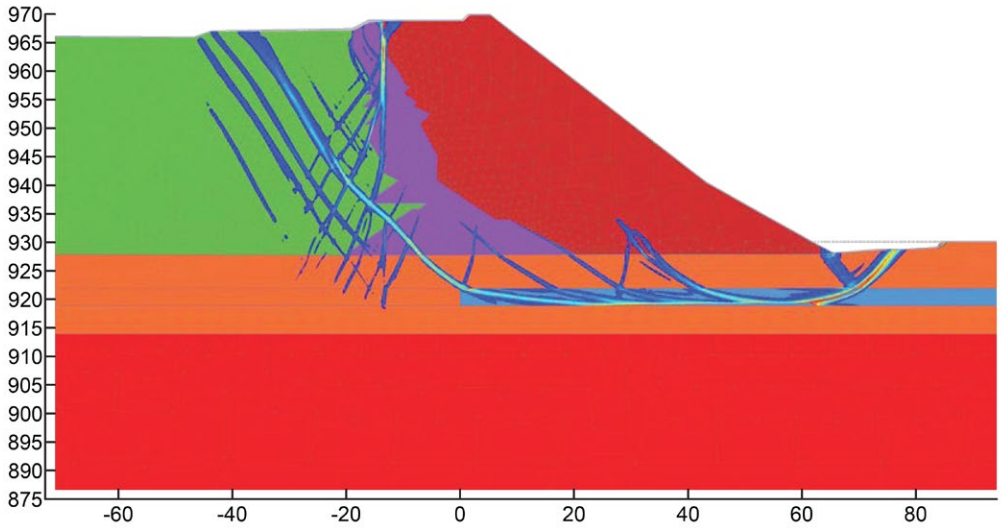

Figure 9: 2D PLAXIS analysis conducted by the Panel, showing the Embankment deformation locations estimated at failure.

Source: Morgenstern et al. (2015). Used with permission from Province of British Columbia.

SUMMARY

The Embankment breach that occurred at the Mount Polley Mine Tailings Storage Facility on the 4th of August 2014 was determined to have been caused by the undrained failure of a glaciolacustrine soil deposit located within the Embankment foundation. The deposit transitioned from an over- to normally-consolidated state as Embankment construction progressed, which in turn produced a tendency for the soil to respond to applied load in a contractive manner. This resulted in the soil demonstrating a susceptibility to undrained shear failure, which ultimately was observed.

The specific mechanism of failure described above was concluded by an Independent Expert Engineering Investigation and Review Panel tasked to examine the cause of the Embankment breach. An advanced laboratory testing programme formed an integral component of the Panel's investigation, during which the GDS Electromechanical Dynamic Cyclic Simple Shear (EMDCSS) device was utilised by MEG Technical Services to test critical soil specimens under critical loading conditions. This case study therefore demonstrates the value provided by advanced laboratory testing programmes when characterising the behaviour of foundation soils during the design, construction, and operation of tailings storage facilities.

REFERENCES

ASTM. (2007). Standard Test Method for Consolidated Undrained Direct Simple Shear Testing of Cohesive Soils. ASTM D6528-07. ASTM International.

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