26th Vancouver Geotechnical Society Symposium

Site Characterization

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ABSTRACTS

Keynote Lecture:
The Use of Cone Penetration Testing for Integrated Site Characterization

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An integrated approach to site characterization, wherein a hypothesized geologic model and governing performance mechanisms inform and direct the subsequent steps of site characterization, site idealization, and selection of representative values, is necessary to perform engineering analyses that will accurately predict performance and develop design solutions that are sufficiently robust, yet economical. Central to this process is the ability to obtain and interpret site characterization data that informs, and can be informed by, the formational geological conditions. The cone penetration test provides unique capabilities in this regard due to its high spatial data resolution, the multiple measurements obtained, and the high productivity rate.

Recent developments related to the correction, operation, and interpretation of the cone penetration test provides new opportunities that allow for better integration and accounting of the geologic depositional processes that formed the subsurface stratigraphy and the soil properties. This presentation will address the following three recent developments. First, a new inverse filtering procedure to correct cone penetration data for thin-layer and transition effects will be presented. The mechanics of this procedure will be outlined and followed by a worked example that shows how application of this correction can reduce predicted liquefaction induced 1-D settlements. Second, a framework to assess and then control the drainage conditions during cone penetration will be presented. Using pore pressure dissipation tests and normalized velocity, the framework can inform in real-time the change in penetration rate needed to achieve the desired drained or undrained penetration condition. Test results will exemplify the data generated, and its subsequent impact on empirical correlations used to estimate soil properties. Finally, the use of a geostatistical model informed by the geologic model and conditioned on cone sounding data will be used to demonstrate the level of uncertainty that can exist when spatially interpolating between cone soundings across a project site. Using a case history, the sensitivity of the geostatistical model uncertainty to the number and spacing of cone soundings as well as to the assumptions in the geologic model will be demonstrated and guidance for reducing this uncertainty presented.

The Investigation for, and Design of, Working Platforms

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With the ongoing development of urban areas, construction is expanding into areas of marginal land, often requiring more sophisticated geotechnical solutions and consequently the use of large, and in many cases, specialized equipment to install deep foundations or even temporary construction elements. Such equipment often exerts very high contact pressures on the subgrade. Safe operation of the equipment consequently requires a stable working platform that must be engineered to account for the high contact pressures. Numerous cases are reported every year of equipment toppling or sinking through working platforms, some involving serious injury or even death. The responsibility for the assessment of the ground conditions and design of the structure of the working platform rests with the Geotechnical Engineer. In investigating project sites, assessments are often focused on the key technical issue facing the foundation design of the structure itself which often implies detailed investigation of the engineering properties of the deep soils. Assessment of the surficial soils, which directly impact the design of the working platform, are often a secondary thought. This paper is intended to show the importance of that component of the site investigation and to provide insight into the design of working platforms, as well as highlight the changes in regulatory requirements in other jurisdictions. The paper will also provide information on recently published technical resources to assist Engineers with such assessments.

Comparison of iBPT Results to the Seismic CPTu

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The development of the Instrumented Becker Penetration Test (iBPT) has allowed for advancements in the characterization of potentially liquefiable gravelly soils, specifically where the use of other in-situ testing methods is not practical. The iBPT N60 correlation was developed in part by applying a rigorous SPT screening program to adjacent boreholes while also considering the effects of field variability. This paper analyzes the results from paired iBPT – Seismic CPTu (SCPTu) testholes to further explore the performance of the iBPT N60 correlation when compared to the CPTu and established interpretation methods. The effects of spatial variability are also considered by performing a statistical analysis of the CPTu profiles clustered within the testing area. The comparison of the iBPT results to the seismic shear wave velocity results from the SCPTu is also investigated.

South Taylor Hill – Investigation and site characterization for geotechnical design

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British Columbia Ministry of Transportation and Infrastructure (MOTI) is undertaking a multi-phased approach to upgrading the Alaska Highway 97 (four laning with reduced grade and improved curvature) at South Taylor Hill, northeast British Columbia, where the highway crosses the southern approach slope to the Peace River. Construction of the highway upgrade for the lowermost 2.5 km section of the hill connecting with the Peace River Bridge at Taylor was completed in 2016. The site geology comprises a surficial blanket of colluvium over a glacial overburden sequence of till, glacio-lacustrine sediments (Lake Mathews), paleo-fluvial gravels and underlying shale bedrock. The geotechnical design for the project requires slope stabilizing designs to facilitate the upgrade and mitigate the impact from the slow-moving multi-level

landslide crossed by the highway. Site characterization involved a review of published reports and prior site-specific studies as well as available aerial imagery and LiDAR survey, to interpret the geology and geomorphology of the site. This paper describes the site geology, historical stability issues, site investigations, and discusses how the geological model and lessons learned from the construction at the lower section of the hill has influenced the geometric design and slope stability analyses for subsequent phases.

Mix design process for a large soil cement hydraulic barrier wall

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Golder Construction recently completed a vertical hydraulic barrier wall surrounding contaminated soil and groundwater at a former manufactured gas plant site. The project performance specifications consisted of a barrier wall with a minimum 91 cm (36") in thickness, a maximum hydraulic conductivity of 1.0×10^{-6} cm/s, and a minimum UCS strength of 1,380 kPa (200 psi). The wall alignment was constructed through clean sand and gravel soil around the contamination zone. The base of the wall was keyed into an underlying clay aquitard with a termination depth of 25 to 27m below surface. Cutter Soil Mixing (CSM) was identified as the preferred construction method for the barrier wall construction. Golder developed the installation work plan following a detailed review of the available geotechnical information for the site. This paper presents the methodology utilized for assessing Cutter Soil Mixing (CSM) viability, identifying a suitable soil-cement mix design, and discusses unique constructability aspects associated with CSM technology. The project was subject to rigorous quality control (QC) measures, requiring strict controls on mixing energy, wall verticality/alignment, visual inspection of panel overlaps, in situ hydraulic conductivity testing and soil-cement mix sampling. This paper also details the QC verification process developed during the field mix trial required prior to full scale production.

Applied glacial geology of the Interior Plateau of BC: examples from three tailings dam foundations

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John Clague, Simon Fraser University, Burnaby, BC

This paper presents an overview of the glacial geology at three tailings dam facilities in the interior of BC, highlighting the geologic controls on thin clay layers found interbedded with glacial till and other glacial deposits. The pattern of glacial advance and retreat within the Interior Plateau of British Columbia commonly blocked drainages during both glacial advance and retreat, resulting in glaciolacustrine deposits. Previous work has identified widespread advance and retreat phase glaciolacustrine deposits within major valleys. However recent experience has demonstrated that thin glaciolacustrine deposits are interbedded within glacial deposits including glacial till, commonly with little to no surface expression, and that these layers may control the stability of tailings embankments located on these deposits. The foundation geology of three tailings embankments is summarized and compared. The depositional environments and glacial history is interpreted for each site, and the implications for stress-history, extent, and continuity are discussed.

Site investigation methodology for the Interior Plateau of BC to characterize thin clay layers within glacial deposits

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Several cases of tailings dam failures have been reported in the last few decades that were attributed to poor geological / geotechnical site characterization. Mount Polley disaster in interior BC being the most recent Canadian example. Proper site characterization in an area with complex geological history such as the interior BC, among others, require proper assessment of a site investigation methodology. The selection of appropriate site investigation method is guided by several factors such as: investigation type; risk, benefit and limitations; tolerable level of sample disturbance; logistical limitations; existing geological understanding; planned instrumentation etc. Currently there is a paucity of archival literature that provides systemic guidance in the selection of a proper site investigation method where thick glacial deposits including very dense glacial till and boulders are interstratified with thin clay layers. This paper is envisioned to fill the existing gap. This work is backed up by recent and decades of legacy experience in several explored / operating / closed mine sites located in the interior BC.

This paper provides guidance on:

- compromise between continuous recovery and disturbance;
- pros and cons of typically practiced methods in different ground conditions e.g., risks, benefits and limitations;
- cased vs uncased drilling and practical limitations; and
- challenges and risks of drilling through dam fill with a suggested method.

Applications of Mixed and Virtual Reality Techniques in Site Characterization

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During the last five years there has been a dramatic increase in the use of Mixed and Virtual Reality, MR/VR, techniques in mining engineering. The majority of these applications have focused on improving visualisation of engineering projects including open pits and surface mine reclamation. In this paper we will present the direct application of MR/VR to geotechnical site characterisation using the Microsoft HoloLens.

The potential application of MR/VR in the direct mapping of rock outcrops, holographic core logging and virtual joint roughness measurement will be demonstrated. The use of the Microsoft HoloLens in direct mapping of the lithology and structure of rock masses in surface and underground environments will be illustrated using a newly developed software. The concept of a virtual core shed and the use of virtual core logging in geotechnical, mining and petroleum sectors will also be discussed. Holographic measurement of the roughness of discontinuities has been developed using a virtual joint roughness profiler which allows interactive calculation of roughness coefficients in varied directions in addition to qualitative holographic comparison of roughness profiles with Barton's Joint Roughness profiles.

Examples of the use of multi-sensor remote sensing techniques (LiDAR, photogrammetry, thermal and hyperspectral) in site characterisation will be presented and the results portrayed and interpreted using holographic visualisation. Finally, applications of holographic techniques in landslide and rockfall hazard investigations will be highlighted with reference to case studies.

Application of ground-based interferometry for rock slope monitoring in Canadian conditions

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Ground-based, interferometric, synthetic aperture radar (GB-InSAR) has been successfully used for monitoring both natural and man-made rock slopes in recent years. However, it has seen limited use within North America and Canada outside of the mining industry. GB-InSAR has many potential advantages over traditional geotechnical monitoring techniques and other remote sensing technologies such as satellite based InSAR, LiDAR, and UAV photogrammetry. These advantages include very high accuracy down to 0.1mm, operation during all weather conditions, and high spatial and temporal coverage monitoring an area close to 5km^2 with a time of acquisition and processing of under 3 minutes resulting in near real-time monitoring of areas of known hazard and risk. Advantages such as these can result in a considerable increase in safety to workers, infrastructure, and equipment exposed to such risks if employed properly.

However, common Canadian conditions such as dense vegetation cover, limited cell phone coverage, and long winters with periods of deep snow and short daylight duration which limit solar power generation results in significant challenges for the deployment of GB-InSAR. This paper presents the installation, challenges and results of the deployment of GB-InSAR equipment, specifically an IDS Georadar IBIS-L, at two research sites located in western Canada that pose rock landslide and rockfall hazards.

The first site discussed is the Checkerboard Creek Rock Slope which is a 2 to 3 million m^3 slow-moving bedrock landslide adjacent to the Revelstoke Dam reservoir with a measured maximum rate of displacement of approximately 10 mm/year. The equipment was initially installed at this site in October 2016, however, was unable to collect continuous data due to solar power restrictions. Therefore, improvements to the system were made in 2018 to address this and other issues. The second site is a 100 m high and 300 m long natural rock slope with a history of rockfalls located along Alberta Highway 742 on the upper portion of the Canmore Creek Valley, approximately 5km west of the townsite of Canmore, AB. The small relative size and high frequency of the rockfall events at this site should test both the spatial and temporal resolution limits of the GB-InSAR system.

Detailed Site Characterizations of Karst Terrain – A Case History from the United Arab Emirates

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In 2010, the Al Ain Municipality commissioned a series of geophysical investigations and geohazard assessments on proposed residential and commercial development lands located in the south portion of the City of Al Ain, Abu Dhabi Emirate, UAE. The geological conditions of the area, along with historical and recent evidence, confirmed that the City was situated over karst terrain, with a high potential for solution cavities and collapse features to impact surface developments.

Natural hot springs are common in the plains below the steep mountain slopes, with several of these springs existing in public parks in Al Ain. The presence of hot water springs and easily dissolved carbonate rich limestone, coupled with the visual and historical evidence of subsidence due to the collapse of overlying limestone, further highlighted the risk of land development with Al Ain Municipality.

During site visits to the adjacent mountain areas, numerous examples of karsts/solution cavities throughout the limestone rock outcrops were observed. This included large sinkholes and cavities in exposed bedrock formations. Voids ranging from a few centimetres to over several metres, and larger were observed in the area.

In addition to the presence of natural solution features, an extensive Falaj system is known to exist in portions of Al Ain. A falaj is an irrigation system dating back to the Iron Age (about 3000 years ago), which consisted of hand excavated horizontal tunnels connected to the surface with vertical shafts. Falaj is the term that refers to the whole system while the tunnels are referred to as the aflaj. Tunnels vary from 3 to 30 kilometres in length. Water flows down from a "mother well" at higher elevation, and was used for irrigation and drinking water supply. Some of these ancient aflaj are still active.

Two proposed development areas were studied in 2010. The Shibat Al Watta study site covered an area of approximately 5,869,200 m^2, while the Al Daher site covered an area of approximately 8,039,492 m^2. The two sites were located about 4 km apart. The sites were investigated in series.

The investigations consisted of three main phases. Firstly, GPR (Ground Penetrating Radar), ERT (Electrical Resistivity Tomography) and Ohm-mapper scanning geophysical methods were

used to identify potential karst features and subsurface anomalies. Areas where potential subsurface voids or collapse features were suspected based on the ERT and Ohm-mapper were then further surveyed by microgravity and seismic methods. Finally, a drilling investigation was conducted which targeted suspect areas with the purpose to confirm the presence/absence of a solution cavity or collapse feature, as well as to calibrate the geophysical readings and interpretation with respect to the measured voids.

The geophysical study consisted of Electrical Resistivity Tomography surveys (ERT) at a line spacing of 50 m to a depth of approximately 30 m; Capacitively-coupled Resistivity Imaging (CCR – Ohm-mapper) of about 455 km of line length; Ground Penetrating Radar (GPR) for identification of Falaj system with about 273 km of survey; Microgravity Survey to further delineate potential voids identified by the ERT and CCR methods; Seismic Refraction to map the top of competent bedrock and groundwater with spread lengths totaling about 27 km; Three-dimensional Cross-Hole Seismic Refraction and Seismic Reflection Testing, including surface to borehole and borehole to borehole measurements in 26 locations.

A total of 50 boreholes were used to confirm the findings of the geophysical assessment. In general, very few open voids were found; however, of greater prevalence were the numerous infilled cavities identified within the conglomerate and uppermost portions of the limestone. The borehole data indicated that over 80% of the infilled voids were located in the conglomerate strata, and the upper 1 to 3 m of the underlying limestone. The presence of cavities was not limited to the near-surface, as low core recovery was experienced in the deeper marl or oolitic limestone in several boreholes.

Using the comprehensive geophysical investigation and confirmatory drilling data, it was determined that the geohazard risk ranged from “Low” to “Medium” over much of the Shibat Al Wattah site, with some areas of “high” risk. The areas with a deemed “high” potential risk were primarily due to the confirmed presence of numerous high severity voids and collapse features in the underlying bedrock within the delineated areas.

The high-risk areas covered approximately 380,000 m^2 at the Shibat Al Wattah site (about 6.5% of the development area) and about 451,000 m^2 (5.6% of the development area). The high-risk areas tended to be grouped but were not isolated to any one area.

It was concluded that without the use of all 6 different geophysical techniques, it would not have been possible to delineate the full and complete extent of the solution cavities, or the infilled status of the collapse features.