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Risk and Liability

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ABSTRACTS

Keynote Lecture presented by Charles Hunt:

The deep seated geology and geotechnical conditions of North Vancouver as revealed through the excavation of the Twin Tunnels project

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The Twin Tunnels project excavated two 3.8 m diameter bored tunnels between the Seymour filtration plant on Lillooet Road and the Cleveland Dam some 7.1 km to the west. Tetra Tech Canada (formerly EBA Engineering Consultants Ltd.) were employed as the independent mapping geologists on the project. This work involved sidewall mapping and photographing the tunnel walls, discontinuity characterization and assessment of the NGI Q and Rock Mass Rating (RMR) values. The paper overviews the geological conditions and in particular project specific alteration characteristics considered important for tunneling. The paper presents the geotechnical and discontinuity data and preliminary interpretations thereof. Average and variations in geotechnical parameters are presented. During tunneling samples of rock were cored and tested at an independent laboratory (CANMET), the results of this work and petrographic examination are presented in the paper, as well as in-situ stress testing.

A probabilistic approach to one-dimensional equivalent-linear ground response analysis for a site in British Columbia

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Estimating earthquake-induced ground motions at a specific site would ideally involve modelling the rupture mechanism of an earthquake source, the propagation of stress waves through the earth to firm ground, and the influence of overlaying soils on the characteristics of the ground motion delivered to the surface. However, the complexity of rupture mechanics, the uncertainties in energy transmission, and the computational effort involved make this approach unpractical for typical engineering applications. Current state-of-practice is to employ probabilistic seismic hazard analyses to estimate firm ground motion characteristics at the site and then use ground response analyses to determine the response of the soil deposit to the motion of the firm ground immediately beneath it. Ground response analyses play a crucial role in the estimation of seismic risk, as they account for the effect of local site conditions during an earthquake and can significantly amplify or de-amplify the intensity of predicted surface ground motions.

Probabilistic seismic hazard analyses estimate the likelihood that various levels of ground shaking will be exceeded at a given location considering the contribution from potential earthquake sources near the site. Due to their probabilistic nature, these analyses provide a rational framework for the significant uncertainties in size, location, and rate of recurrence of earthquakes to be identified, quantified, and combined into estimates of seismic risk.

In contrast, ground response analyses (whether equivalent-linear or non-linear) are primarily carried out deterministically. In the case of one-dimensional equivalent-linear ground response analyses, the amplification of ground motion at a specific site is estimated as a function of the initial shear modulus (G_{max}) or shear wave velocity (V_s), modulus reduction (G/G_{max}) and damping ratio (D) versus shear strain (γ_s) curves. Each of these input parameters carries considerable uncertainties due to the spatial variability of soil conditions and the difficulty of predicting dynamic soil behaviour. While this uncertainty may be approximately estimated using parametric studies, a probabilistic approach has the advantage of fully capturing the effects of input uncertainties on the distribution of the resulting ground motion amplifications.

This study carries out a probabilistic one-dimensional equivalent-linear ground response analysis for a site in British Columbia. First, the stochastic properties (i.e., the mean, variance, and correlation coefficient) of the soil parameters are estimated through a combination of available geotechnical data at the site (e.g., seismic cone penetration tests) and published literature. Monte-Carlo simulations are then carried out based on the estimated soil parameters, and combined with a variety of input ground motions to perform ground response analyses. The results of this paper can be used to estimate the distribution of ground motions at the surface of a soil mass.

Hazard and risk assessment of a large rock slope in the Canadian Rocky Mountains

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As part of Parks Canada Agency (PCA)'s ongoing rock slope risk management program Tetra Tech Canada Inc. (Tetra Tech) inspected four large slopes in the Rocky Mountain National Parks. The purpose of the inspection was to identify geological hazards on high priority slopes, assess the risk, and provide recommendations and cost estimates to improve safety for road users and reduce maintenance requirements.

This paper outlines findings from the inspection and risk assessment undertaken on the "Weeping Wall" on Highway 93N (H93N) in Banff National Park (BNP). The inspection addressed rock and soil slopes' geological hazards.

Highway 93N, known as Icefields Parkway (IFP), traverses the UNESCO World Heritage Sites of Banff and Jasper National Parks. The IFP connects the Trans-Canada Highway near Lake Louise in the south to the town of Jasper and Highway 16 in the north. IFP runs along the backbone of the Canadian Rocky Mountains and is approximately 228 km long, the south end is designated as Sta. 0+000 near Lake Louise, and Sta. 227+500 at the crossroads of IFP Highway 16 near Jasper. The Weeping Wall is located between km 102+170 to km 105+855 on IFP.

The Weeping Wall forms the lower sub vertical face of Cirrus Mountain, on the east side of H93N. The geology comprises limestone and dolomite. The base of the natural rock slope is set back from H93N about 225 m at the southern end and 35 m at the northern end. The height of the slope also reduces from 600 m to 100 m with increasing chainage. Due to the size of this slope traditional rock fall risk management tools of scaling, anchoring, mesh, or other techniques would have been cost exorbitant. Therefore, the rock fall risk assessment for the Weeping Wall portion of the IFP was undertaken to quantify the risk of rock fall to vehicle users. For the purposes of this paper we define risk as the sum of the consequences from an event, multiplied by the probability of that event occurring.

Hourly climatic and vehicle count data were reviewed for the Weeping Wall area to determine probability of rock fall factors and exposure risk of IFP users.

Rock fall records on a very remote rock face are particularly difficult to obtain with a high level of confidence. Due to the lack of available rock fall records for the Weeping Wall, Tetra Tech used an empirical approach to determine a representative frequency of rock falls at the Weeping Wall. Using historical data bases and comparison of digital rock slope topographic models, Hantz et al. (2016) analyzed rock fall data for six rock slopes of representative geomorphological conditions. Orders of magnitude were proposed for rock fall frequency parameters for these different conditions based on available rock fall records.

Based on field observations, historic rock fall debris mapped using point cloud data obtained using a high density mobile LiDAR surveying vehicle, estimated rock fall frequencies, rock fall runout analysis, traffic volumes, and climatic data, a PDI was developed for different seasons and sections of the Weeping Wall slope.

Sleep on it! Fatigue risk management considerations in the geotechnical engineering consulting field

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Several Engineers work in a variety of high-risk industrial and construction worksites, and workplace fatigue is a frequent contributor to near-misses and incidents that lead to injury, lost time, and potentially, fatalities. In addition to workplace incidents, fatigue may also adversely affect engineer's short and long-term health, personal relationships, and quality of technical work. Several factors are outside the engineer's control to achieve a restful night's sleep; including client work sites with prescriptive hours of operations/shift lengths and remote locations requiring extensive travel. The nature of the consulting industry also results in travel to multiple sites across a large geographic area. Developing and implementing fatigue risk management controls is the goal of this paper.

There are a number of factors that result in fatigue. This paper is focused on sleep-related fatigue and its risk factors. A sound understanding of the fatigue risk factors provides the basis upon which control measures can be developed. High-level fatigue-management controls will be discussed, which are broadly grouped in management and personal strategy controls. Company management strategies generally provide the engineer with the opportunity to rest and a safety management system adapted to manage fatigue. These strategies can include guidance on duty and rest periods and suggested processes to follow when measuring and monitoring fatigue during these periods. Personal strategies are tools that can be used by the individual to maximize sleep quantity and quality. Tools can include developing a sleep routine to implement when sleeping in an unfamiliar setting, using wrist-based activity trackers to quantify sleep and monitor fatigue risk factors, as well as planning daily tasks around naturally occurring changes in daily alertness levels. Sleep science and the research into fatigue risk management has a large body of research associated with it, and this paper is intended to provide a high-level overview of the topic, and to provide examples of practical, easy to implement tools to manage fatigue risk.

Reliability-based dynamic analyses for seismic design optimization in British Columbia

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Probabilistic based dynamic analysis of soil and concrete structures under earthquake ground motions provides an effective tool for considering uncertainties in soil parameters (Lacasse, 2019) and for dealing with hazard contributions in ground motions from crustal and subduction earthquake sources (Wu, 2015 and 2018). In this paper, seismic site response analyses are carried out using VERSAT-1D (Wu, 2001; WGI, 2020) for a soil profile located at Roberts Bank Port in Delta BC under 11 subduction Interface motions and 11 non-Interface (Intra-slab and Crustal) motions at various earthquake intensity levels. As a continuation of the probabilistic analyses presented in Wu (2017), recommendations for design of the 1/2,475-yr ground motions (NBCC, 2015) in the Lower Mainland are made for engineers to develop the Interface motions targeted to the 1/5,000-yr Interface spectra, develop the non-Interface motions targeted to the 1/5,000-yr non-Interface spectra, and then use in design whichever presents a higher seismic demand. When necessary such as for large and costly projects, analysis refinement could be carried out to further reduce the higher demand of the two types of ground motions and thus reduce cost.

In addition, to study the effect of soil parameter uncertainties on soil liquefaction potential, discretized probability density functions for the $(N_1)_{60}$ of a sandy soil layer at depths from 4 to 12 m (such as these in Figure 1) are considered for computing the reliability index (□) from its combinations with other stochastic variables (i.e., V_s values, soil damping ratio, and the □ parameter for the shape of liquefaction resistance curve). The reliability-based analyses will generate a FS_{liq}[1] probabilistic hazard curve, including variabilities in soil parameters and in input ground motions. Hopefully, the results can be used to obtain in a risk-informed manner the expected FS_{liq} (i.e., for the target reliability index) under the 1/2,475-yr ground motions per NBCC (2015).

As a supplement to the more conventional deterministic analyses, the reliability-based dynamic analyses as showcased in this paper would provide the theories and justifications, as well as the practical tools required to perform the analyses, to optimize and improve seismic design of structures in BC, and likely reduce construction cost.

[1] FS_{liq} is the factor of safety against soil liquefaction as per Seed and Harder (1990), Youd et al. (2001)

Large area flood, steep creek, and landslide-dam flood risk prioritization

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Mountainous regions are frequently subject to geohazards that cause property damage, loss of life, and the interruption of transportation arteries. Of the many thousands of hazard areas, only a tiny fraction receive a full risk management cycle from hazard identification to risk control. Since development exists within these geohazard susceptible expanses, communities require support to make risk-informed decisions about regulation, mitigation, and emergency management.

Flood, steep creek, or landslide-dam flood risk prioritization studies are being completed for approximately 320,000 km^2 of British Columbia, with about 200,000 km^2 completed to date. While most creeks' headwaters are mostly undeveloped, the central valley floodplains and lower reaches of steep streams contain the majority of development and lifelines infrastructure. The assessment applies a consistent methodology to characterize geohazards and elements at risk at a regional scale, prioritize areas based on relative risk, and organize large volumes of geospatial data. Thus far, over 50,000 geohazard areas, including about 2,000 steep creek fans subject to debris flows and debris floods, have been prioritized.

This talk will present approaches to prioritize geohazard risk across large and typically data-scarce regions like British Columbia and discuss how their results support development planning, regulation, and emergency management.

Risk management for geotechnical consultants: how to avoid potential claims and manage them when they (inevitably) arise

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Geotechnical engineering consultants often face a disproportionate amount of risk in relation to other engineering consultants on a project. The ability of a geotechnical engineer to fully investigate subsurface site conditions may be limited by the financial constraints or considerations of the project owner/developer. If those financial constraints or considerations translate into a limitation upon the consultant to conduct representative subsurface investigations, the consultant may not be able to reliably evaluate the entire subsurface of the site.

Unforeseen geotechnical conditions and associated geotechnical problems can contribute to project delays, cost overruns, construction defects and, almost inevitably, claims against the geotechnical engineer. Given that geotechnical issues are often not detected until construction is complete, they can be extremely expensive to remediate.

While it is never possible to entirely eliminate potential claims, there are steps that can be taken by geotechnical engineers to allocate and manage risks arising in the course of a project. We will review those steps, which include a focus on contractual issues and insurance, and provide advice for geotechnical engineers as to how best mitigate potential risks. We will also review how to manage potential claims when they arise and (although not always possible) resolve them sooner rather than later.

Evaluating quantitative and qualitative benefits of geogrid in design applications

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Geogrids and other geosynthetics are increasingly being used by engineers to solve a variety of design challenges. Stabilizing weak subgrades, increasing the bearing capacity of construction pads, reinforcing base courses to optimize pavements, as well as reducing construction materials and costs associated with construction are among some of the benefits associated with incorporating geogrids into design.

One of the main challenges associated with calculations that incorporate geogrids has been the lack of generalized methodologies that can evaluate the qualitative and quantitative benefits of geogrids into a design based on the material properties or other standardized geogrid properties. The absence of nationally recognized design procedures, the narrow range of applicable empirical data pertaining to geogrids and proprietary design methods that apply to specific geogrid products are all challenges recognized by the National Highway Institute as limiting the widespread use of geogrids in base reinforcement applications.

In the absence of generalized analytical solutions for evaluating the qualitative and quantitative contribution of geogrids into design, a variety of empirically based approaches have been used. These methods range from extrapolating the quantitative results of small scale laboratory tests to regionally developed “rules of thumb” based on successful local applications to automated plate load tests and full scale field tests. The lack of uniformity in design approaches and geogrid specification can yield a variety of unequal designs, based largely on engineering judgment, when other design variables are held constant.

To suggest criteria for how engineers can more accurately evaluate the quantitative and qualitative contributions of geogrid into design, we reviewed two case studies, (1) a stabilized platform with bearing capacity design criteria and (2) a roadway with pavement performance design criteria. These two case studies highlight some of the general design standards used in design along with their limitations, and suggest criteria for empirically based design approaches that can reduce subjectivity and risk associated with varying engineering judgment used in place of industry standard analytical solutions or nationally recognized design criteria.