23rd Vancouver Geotechnical Society Symposium
Friday, June 12, 2015 – The Vancouver Marriott Pinnacle

Soil Structure Interaction

07:30 - 08:30	**Registration**
08:30 - 08:45	**Opening Remarks**
08:45 - 09:45	Keynote Presentation: "Large-Scale Physical and Computational Simulation of Soil-Structure Systems"; Ahmed Elgamal, Professor, University of California, San Diego
09:45 - 10:15	"Interaction between Soft Sensitive Clay and Steel Pipe Piles under Earthquake Loads for a Multi-story Building"; Mustapha Zergoun and James Munro
10:15 - 10:45	**Coffee Break**
10:45 - 11:15	"Seismic Soil-Structure Interaction Analyses for an Elevated Guideway Structure of Evergreen Line"; Ali Azizian et al.
11:15 - 11:45	"Interpretation of Static Pile Loading Test Results and Application for Design of Pile Groups"; David J. Tara and Steven N. Coulter
11:45 - 12:15	"Numerical Modeling of the 3D Behaviour and 2D Equivalence of Deep Soil Mixing During Lateral Loading"; Jeffrey Barrett

12:15 - 13:15	**Lunch**

13:15 - 13:30	**VGS Award**
13:30 - 14:30	Keynote Presentation: "Challenges and recent progress in the analysis, design and modelling of geosynthetic reinforced soil walls"; Professor Richard J. Bathurst, GeoEngineering Centre at Queen's-RMC, Kingston, Canada
14:30 - 15:00	"Development of Lateral Earth Pressures on a Rigid Wall due to Seismic Loading"; Gordon Fung et al.
15:00 - 15:30	**Coffee Break**
15:30 - 16:00	"New Approach to Assess Soil-Geosynthetic Interaction in Reinforced Slopes and Walls"; Lalinda Weerasekara
16:00 - 16:30	"Undrained Shear Strengths derived from Pile Load Tests for use in Designing Helical Screw Piles and Stelcor Piles in Sensitive Clay Soils"; Mahmoud Mahmoud et al.
16:30 - 17:15	**Panel Discussion**
17:15 - 17:20	**Closing Remarks**

ABSTRACTS

Large-Scale Physical and Computational Simulation of Soil-Structure Systems

Keynote Presentation by Ahmed Elgamal, Professor, University of California, San Diego

Based on earthquake reconnaissance observations and data from shake-table/centrifuge experiments, calibration efforts continue to promote the development of more accurate computational models. Capabilities such as coupled solid–fluid formulations and nonlinear incremental-plasticity approaches allow for more realistic representations of the involved static and dynamic/seismic responses. High-performance parallel computing environments are permitting new insights, gained from analyses of entire ground-foundation-structural systems. On this basis, the horizon is expanding for large-scale numerical simulations to further contribute toward the evolution of more accurate analysis and design strategies. The presentation addresses these issues through recently conducted three-dimensional (3D) representative research efforts that simulate the seismic response of: (1) Pile-group foundations and pile-supported Wharf systems, (2) Liquefaction countermeasures, (3) Full bridge-ground systems, and (4) Embedded large structures, cut-cover tunnels and earth pressure considerations. Enabling tools for routine usage of such 3D simulation environments will be highlighted, as an important element in support of wider adoption and practical applications.

Interaction between Soft Sensitive Clay and Steel Pipe Piles under Earthquake Loads for a Multi-story Building

Mustapha Zergoun, Thurber Engineering Ltd.
James Munro, Read Jones Christoffersen Consulting Engineers

This paper presents a case history of the interactive analysis and design of the foundation system for a multi-story building in Burnaby, British Columbia. The building is located within the Still Creek floodplain area and consists of a 5 stories reinforced concrete structure with ductile concrete shear walls. The subsurface conditions included peat underlain by soft, highly compressible, sensitive clay over dense glacial till at a depth ranging from 4 to 20 m. The building included one level concrete basement supported on steel pipe piles driven to end-bearing into dense glacial till. Large horizontal forces and moments were expected on the pile heads due to the design earthquake forces from the site specific earthquake design spectra. The pile foundation analysis and design required a careful consideration of the soil-structure interaction and an iterative communication between the geotechnical and structural design professionals. This paper reviews the initial design based on the preliminary characterization of the subsurface conditions and the joint geotechnical and structural analysis that continued during pile installation as actual pile length and estimated available resistance became known.

Seismic Soil-Structure Interaction Analyses for an Elevated Guideway Structure of Evergreen Line

Ali Azizian, Lalinda Weerasekara, Brian Hall – Tetra Tech EBA
Ernie Naesgaard, Ali Amini – NAGL
Saqib Khan, Monty Knaus – MMM
Meiric Preece – EGRT

The Evergreen Line Rapid Transit Project (ELRT) is an 11 km extension of the existing SkyTrain system through Burnaby, Coquitlam and Port Moody in the Lower Mainland of British Columbia.

The ELRT includes several elevated guideway structures supported on deep foundations. One of these structures extends from the North Tunnel Approach, across Schoolhouse

Creek and the Reichhold Chemical Industries facility to tie into the at-grade guideway through Port Moody.

The structure is approximately 324 m in length and supported on eight piers. Each pier is supported on a group of 762 mm, 914 mm or 1828 mm diameter driven open-ended steel pipe piles filled with concrete. Pile lengths vary from about 20 m to 35 m.

The subsurface condition consisted of fill of variable thickness, over loose to compact debris fan deposits (Salish Sediments), over marine silt and clay, grading with depth into glaciomarine deposits of sand, silt and gravel (Capilano Sediments), over very dense glacially overridden till-like deposits. Organics, wood fragments and shells, as well as cobbles and boulders were encountered in some testholes. Groundwater level ranged from 0.5 to 2 m below grade. In addition, high artesian pressures up to 11 m were encountered within the deep till-like materials.

The loose sand and silty sand layers (Salish sediments) and low plastic silt layers (Marine deposits) are likely to liquefy or undergo cyclic softening under the 975-Year and Subduction seismic events. Lateral spreading, exceeding 2 m at some locations, is anticipated. The large lateral spreading and differential lateral spreading was accounted for in the structural design of the guideway structure, piers and pile foundations. Ground improvement was not used to mitigate liquefaction because of the disruption it would cause to the Reichhold facility.

This paper will present the seismic design strategy and the methodology used for soil-structure interaction analyses that were completed for several earthquake events to satisfy the performance requirements of the project.

The ELRT project is being delivered as a Design/Build/Finance project by Evergreen Rapid Transit Construction (EGRT), an SNC-Lavalin Inc. company, to the Province of British Columbia (the Province). Tetra Tech EBA was retained by the SNC-Lavalin Graham Joint Venture (SGJV) to provide geotechnical recommendations for the structural design and construction. Numerical seismic FLAC analyses were undertaken by Naesgaard-Amini Geotechnical Ltd. (NAGL). The structural design was undertaken by MMM Group Ltd.

Interpretation of Static Pile Loading Test Results and Application for Design of Pile Groups
David J. Tara and Steven N. Coulter, Thurber Engineering Ltd.

Recent major bridge projects in Metro Vancouver and the BC Interior showcase the experience of local geotechnical engineers. Large static pile loading tests have been carried out a number of projects including the Pitt River Bridge, Golden Ears Bridge and Okanagan Lake Floating Bridge projects. This paper briefly discusses different analytical approaches for load test interpretation and reviews these approaches as applied to some classic case histories and also some recent local case histories. Where applicable, the paper also considers the influence of reaction piles on the initial stiffness of the test pile and explores the application of different methods of interpretation to published test data. The paper summarizes the results of the analyses and provides recommendations for interpretation and design.

Numerical Modeling of the 3D Behaviour and 2D Equivalence of Deep Soil Mixing During Lateral Loading
Jeffrey Barrett, Stantec

Deep soil mixing is a technique where cementitious materials are blended with the in situ soils to increase the compressive and shear strength and can be used to mitigate failures due to liquefaction. Individual columns of soil can be treated or adjacent columns can be overlapped and interlocked to form soilcrete panels. Common layouts include treated panels arranged into either square or rectangular sections forming a cellular structure within the ground improved area. When an earthen berm containing landfilled material is constructed above improved foundation soils, lateral forces result within the ground improved area from both static and dynamic loading. These lateral loads are assumed to be carried entirely within the soilcrete panels when the untreated foundation soils liquefy. Two-dimensional numerical modelling is used more commonly to predict the stresses and displacements within the soilcrete panels during the dynamic loading from an earthquake event. Using weighted averages based on the area replacement ratio, the composite strengths of the soil mass are estimated for complex three-dimensional soilcrete layouts. In this study it is shown that the three-dimensional layout of the ground improvements makes it difficult to determine the appropriate stiffness parameters for a two-dimensional model. However, three-dimensional numerical modelling to analyze the problem is much more computationally intense and can result in extremely long run times, especially when simulating earthquake events. Therefore, a method to model the equivalent three-dimensional behaviour of the ground improvements during lateral loading using appropriate composite stiffness parameters in a two-dimensional numerical model is presented.

Challenges and recent progress in the analysis, design and modelling of geosynthetic reinforced soil walls (2014 Giroud Lecture)

Keynote Presentation by Professor Richard J. Bathurst, P.Eng., Ph.D., FEIC, FCAE, GeoEngineering Centre at Queen's-RMC, Kingston, Canada

Geosynthetic reinforced soil retaining walls are a mature technology with proven success extending back more than three decades. Nevertheless, new approaches for design and analysis of these systems are required to improve performance predictions for operational conditions, to extend their utility to harsher environments including earthquake areas, and to allow the use of alternative backfill materials. The lecture briefly reviews a body of work by the writer and co-workers that has advanced the understanding of the behaviour of these complex systems through physical and numerical modelling. Topics include examples of data from instrumented field walls constructed with both geosynthetic and relatively inextensible steel reinforcement. These databases have been important for the development of empirically-calibrated stiffness-based working stress methods for both geosynthetic and steel reinforced soil wall systems. A comparison of design outcomes for a production wall using conventional and stiffness method approaches is presented. Examples of the influence of details of numerical modelling on predicted behaviour are given. A novel experimental technique using a pullout box in combination with a transparent granular soil and a typical geogrid is described. The results are used to provide quantitative insight into soil-geogrid interaction mechanisms and to develop interface shear models for numerical simulation.

Development of Lateral Earth Pressures on a Rigid Wall due to Seismic Loading

Gordon Fung, Ender Parra, and John Sully, MEG Consulting Ltd.
James Scott and Jamie McIntyre, Hatch Mott MacDonald

This paper presents the seismic modeling performed for the design of a number of buried structures to depths of up to 25 m below the ground surface. Analyses were performed for both future and existing structures to assess the development of seismic earth pressures in potentially liquefiable soils. The FLAC (Fast Lagrangian Analysis of Continua) finite difference program was used to model the buried structures with earthquake ground motions representing return periods ranging from 100 to 2,475 years. Interfaces around the buried structure were used to model the soil-structure interactions during seismic loading conditions. The seismic earth pressures obtained from the FLAC analyses have been compared with the pressures calculated using the standard code-based approaches from current engineering practice. Recent results presented in the literature suggest that the development of earth pressures on rigid walls may lie below the code recommendations. This appears to be the case for rigid walls, but the actual seismic earth pressures developed are sensitive to even small degrees of wall movement. The analyses consider seismic earth pressures developed in stable and potentially-liquefiable ground on buried concrete box-like structures as well as anchored concrete retaining walls.

New Approach to Assess Soil-Geosynthetic Interaction in Reinforced Slopes and Walls

Lalinda Weerasekara, Tetra Tech EBA

The use of soil reinforcing for modern retaining wall construction has come a long way and gained popularity since it was pioneered by French architect and engineer Henri Vidal in the 1960s. In particular, the geosynthetic reinforced structures (e.g., walls and slopes) are extensively used in high-importance constructions mainly due to lower cost and other associated advantages. Nevertheless, current understanding of the soil-geosynthetic interaction mechanism in these structures is still limited, which is a key consideration in effective design of these structures. In essence, the interface frictional resistance between the reinforcement and soil causes the stress from the soil to transfer into the reinforcements as tensile forces - in turn, creating a composite soil mass with an equivalent shear resistance significantly higher than that generated from soil alone.

The current state-of-practice (e.g., AASHTO or similar) does not capture the actual soil-geosynthetic interaction mechanism, in order to determine the deformation, strain (or forces) and mobilized length. For example, it is erroneous to assume that frictional resistance is distributed uniformly along the entire geosynthetic. Instead, it is known that friction along the geosynthetic will develop progressively as the displacement increases, and also depends on the thickness, stiffness and stress–strain behavior of the geotextile, which are not accounted in the current methodology. Furthermore, the soil-geosynthetic interaction is complex because of the nonlinear characteristics of the interface friction and stress-strain response of the geosynthetic.

To overcome these limitations, Weerasekara and Wijewickreme (2010) developed a new analytical approach to model the soil-geosynthetic interaction in each geosynthetic layer. The model was validated by modeling over 25 pullout tests conducted by 7 different researchers. The analytical solution employs a more refined interface friction model. All the input variables associated with the analytical solution have a physical meaning (i.e., not empirical) and directly obtainable using independent experiments or direct measurements (e.g. elastic modulus of geosynthetic, lateral earth pressure at-rest, etc). Most importantly, this model forms an analytical framework that link displacement, strain/force and frictional length mobilized along the geosynthetic, such that risk of tensile failure and pullout failure can be evaluated.

This paper discusses the extension of this framework that was developed for modeling the interaction occurring in individual geosynthetic to the entire reinforced wall/slope. In summary, the proposed approach will include (a) estimation of the net destabilizing force for the slope/ wall using traditional slope stability analysis and (b) estimation of tensile force and pullout length of the geosynthetic using the above analytical solution by incrementally increasing the displacement such that cumulative pullout resistance developed in all the geosynthetics is equal to the unbalance force. In this process, the analytical model was updated to include different boundary conditions that may encounter in reinforced wall/slopes.

The validity of this analytical approach is also verified by modeling a couple of well-documented reinforced slope/ wall case histories.

Undrained Shear Strengths derived from Pile Load Tests for use in Designing Helical Screw Piles and Stelcor Piles in Sensitive Clay Soils

Mahmoud Mahmoud and Z. Kheyruri, GES Geotech
Simon Whippy, TerraCana Construction

To verify the undrained shear strengths as input data for use in the design of helical screw piles and Stelcor piles in sensitive clay and silty clay deposits at the Barnston Pump Station in Maple Ridge, BC, a series of full compression and tension pile load tests were carried out. Both compression and tension pile load tests were performed in accordance with ASTM D1143, with load-settlement characteristics being recorded, including ultimate bearing capacity. The test piles were required to be loaded to 200% of the design load. However, both the Stelcor piles and the helical screw piles failed before reaching the targeted design loads. Given the pile load tests results, it was important to derive the back-analysed values of undrained shear strength that were mobilized following pile installations. Back-analysis indicates that the undrained shear strengths (cu=18-22 kPa) that were mobilized following pile installations were significantly lower (by about 2-2.5 times) than the values (cu=40-50 kPa) that had been recommended for design by the geotechnical firm that had completed the field investigation and design recommendations regarding the use of helical screw piles. The subject screw pile load test results are compared with other full-scale load tests on screw piles in a) lightly overconsolidated sensitive clayey silts in South Surrey, and b) cohesive soils in Alberta and British Columbia. It is concluded that the undrained shear strength recommendations for use in the design of helical screw piles should take account of significant disturbance effects that impact soft, sensitive silty clay deposits during pile installation. Back-analysed values are the most realistic parameters for use in the design of helical screw piles and Stelcor piles in sensitive clay and silty clay soils.