
GeoVirtual
2020
September
14-16
Resilience and Innovation
CGS.ca
73rd
CANADIAN
GEOTECHNICAL
CONFERENCE
SEPTEMBER 14-16, 2020
Conference Program / Abstracts

CONTENTS

GREETINGS (CO-CHAIRS)

Welcome to GeoVirtual 2020, the 73rd annual conference of the Canadian Geotechnical Society (CGS). Under normal circumstances we would be welcoming you to our beautiful city of Calgary, but the plans for GeoCalgary 2020 had to be altered due to the current pandemic. However, COVID-19 did not restrain our spirit or prevent us from having a conference this year, and we are very excited to greet you in this virtual environment, experimenting with new ways of communicating, staying connected and sharing knowledge. For these reasons, the theme for the 2020 conference was updated to Resilience and Innovation. The local organizing committee (LOC), along with the executive committee of the CGS and their unwavering support, have demonstrated a lot of resilience and innovation in the last few months, enabling us to offer you this first very virtual CGS conference.

We are very proud that several eminent geotechnical professionals agreed to join us in this endeavor. The conference program includes the R.M. Hardy Keynote Address by Dr. Dennis Becker from Golder on Monday, the CGS Colloquium by Dr. Arianne Locat from Laval University on Tuesday and a special Heritage Session on Wednesday during which Dr. Norbert R. Morgenstern will reflect on learnings from successes and failures over the past fifty years. Each day will comprise three blocks of five concurrent technical sessions, just like a normal face-to-face conference, with the difference that all presentations will be available for streaming for a month after the conference, allowing you for once to actually see all the presentations! The conference program also includes several special sessions: a panel on Women in Geotechnique, a networking and panel session for Young Professionals, and a Professional Practice Committee special session. All special sessions will feature several exceptional professionals and include live periods of Questions and Answers.

During breaks, the conference platform will allow participants to gather around “virtual coffee tables” for some networking opportunities or to reconnect with other members of the profession. The breaks will also feature the prestigious Leggett award presentation, the CGS Annual General Meeting and the CGS Awards, all held during the “Mountain Time” lunch periods.

This conference would not be possible without the strong support of our sponsors who did not hesitate to join us on this virtual journey, the dedication of the LOC and CGS executive committee and last but not least, the participation of all the authors who stepped up to the challenge and submitted their papers. We hope that you will find the 73rd Canadian Geotechnical Conference to be both enjoyable and memorable, and we are looking forward to seeing you in person in Calgary in 2022!

Justyna Kos-Fairless **Daniel G Bertrand**

MOT DE BIENVENUE (CO- PRÉSIDENTS)

Bienvenue à GéoVirtuel 2020, la 73ième conférence annuelle de la Société canadienne de géotechnique (SCG). Normalement, nous vous aurions reçus dans notre belle ville de Calgary, mais nos projets pour GéoCalgary 2020 ont dû être modifiés en raison de la pandémie actuelle. Cependant, même la COVID-19 n'aurait pu empêcher la tenue d'une conférence cette année. Nous sommes ravis de vous accueillir dans cet environnement virtuel qui nous permettra de découvrir de nouvelles façons de communiquer, de demeurer en contact avec la communauté géotechnique et de partager nos connaissances. Pour ces raisons, le thème de la conférence de 2020 portera sur la résilience et l'innovation. Le comité organisateur local de pair avec le comité exécutif de la SCG qui a démontré un soutien sans faille, ont fait preuve d'énormément de résilience et d'innovation au cours des derniers mois pour vous offrir cette toute première conférence virtuelle.

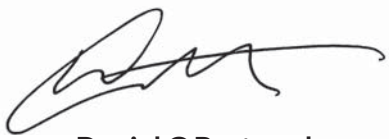
Nous sommes honorés que plusieurs éminents professionnels de la communauté géotechnique aient accepté de se joindre à nous pour faire de cette conférence un succès. Le premier jour de la conférence, soit le lundi 14 septembre, le programme débutera par l'allocution d'ouverture R.M. Hardy prononcé par M. Dennis Becker, PhD, de Golder, suivi le mardi par le colloque de la SCG par Mme Arianne Locat, PhD, de l'Université Laval. Finalement, une séance spéciale sur le patrimoine le mercredi au cours de laquelle M. Norbert R. Morgenstern, PhD, partagera divers apprentissages tirés de succès et d'échecs au cours des cinquante dernières années aura lieu lors de la journée de clôture.

Chaque journée comprendra trois blocs de cinq sessions techniques simultanées. Le format s'apparentera à celui des conférences passées à cette différence près que toutes les présentations seront disponibles en diffusion jusqu'à un mois après la conférence, une rare occasion qui vous permettra de voir l'intégralité des présentations ! Le programme de la conférence comprendra également plusieurs séances spéciales : une table ronde sur les femmes en géotechnique, une séance de réseautage et une table ronde pour les jeunes professionnels, une session spéciale du Comité de pratique professionnelle, ainsi que la séance spéciale sur le patrimoine tel que mentionné ci-dessus. Toutes les séances spéciales mettront en vedette plusieurs professionnels exceptionnels et comprendront des périodes de questions et réponses en direct.

Pendant les pauses, la plate-forme de la conférence permettra aux participants de se réunir autour de « tables virtuelles » pour rencontrer ou renouer avec d'autres membres de la profession. Certains entractes comprendront également la remise du prestigieux prix Leggett, l'assemblée générale annuelle de la SCG et la remise des prix de la SCG; ces événements auront lieu pendant les pauses « déjeuner » de l'heure des Rocheuses.

Cette conférence n'aurait pu avoir lieu sans le ferme soutien de nos partenaires financiers qui n'ont pas hésité à se joindre à nous pour cette aventure virtuelle, le dévouement du comité d'organisation local et du comité exécutif de la SCG et, enfin, la participation de tous les auteurs qui ont relevé le défi. Nous espérons que vous trouverez la 73ième conférence de la SCG à la fois agréable et mémorable, et il nous fera grand plaisir de vous accueillir en personne à Calgary en 2022 !

Justyna Kos-Fairless



Daniel G Bertrand

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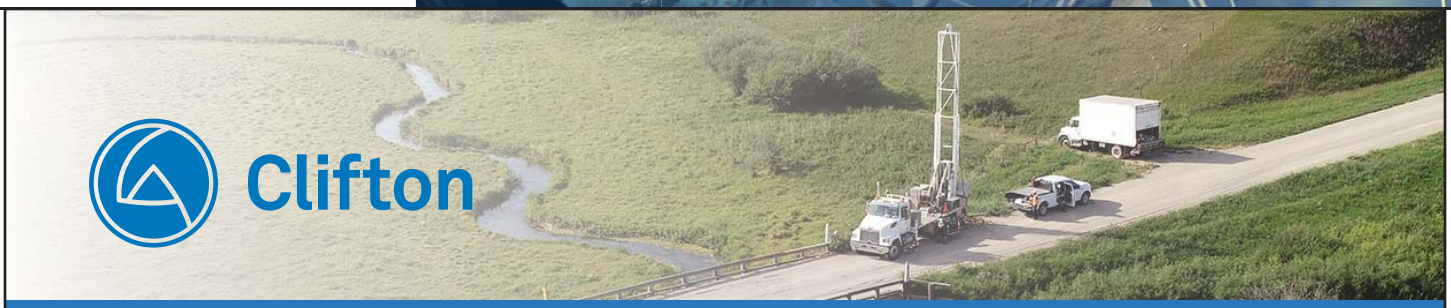

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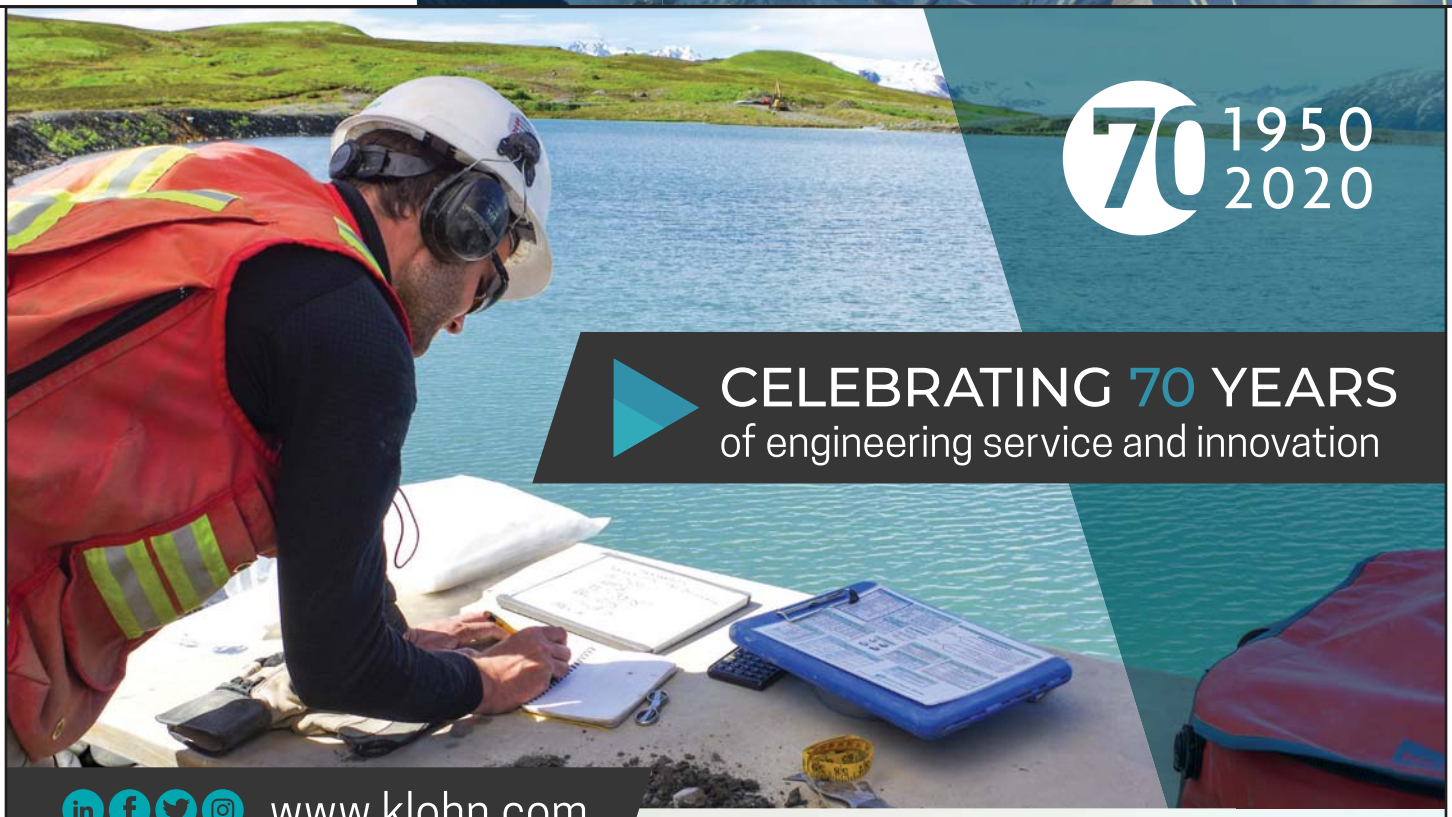

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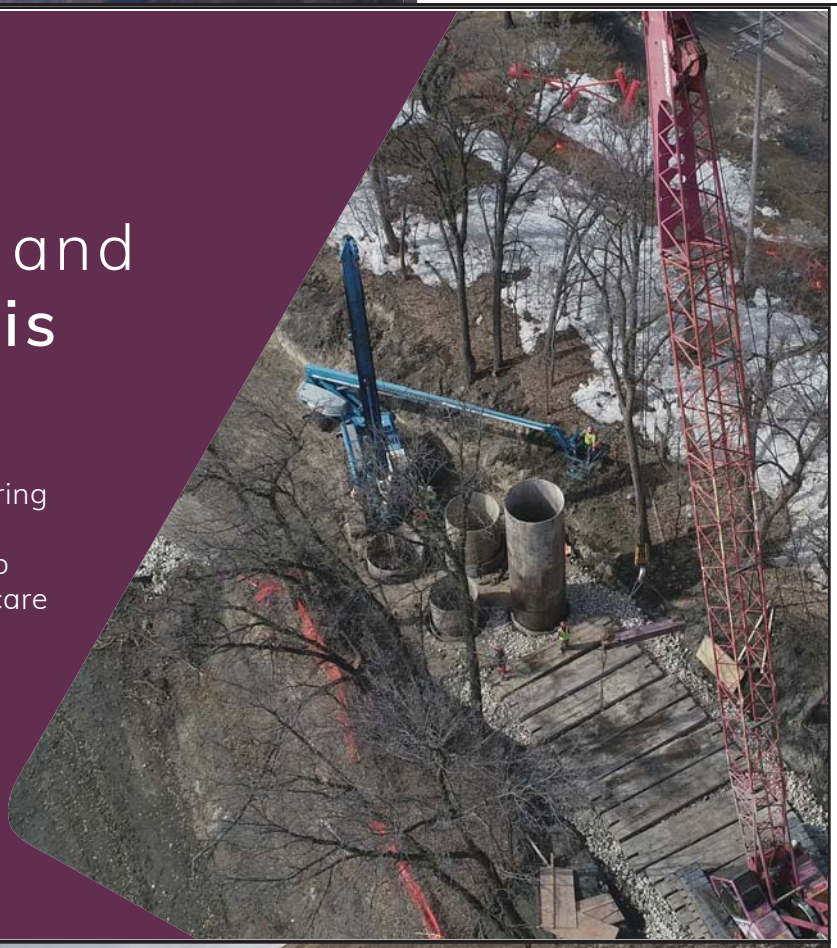

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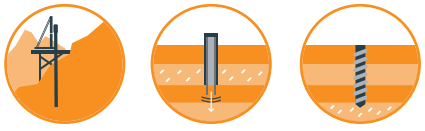

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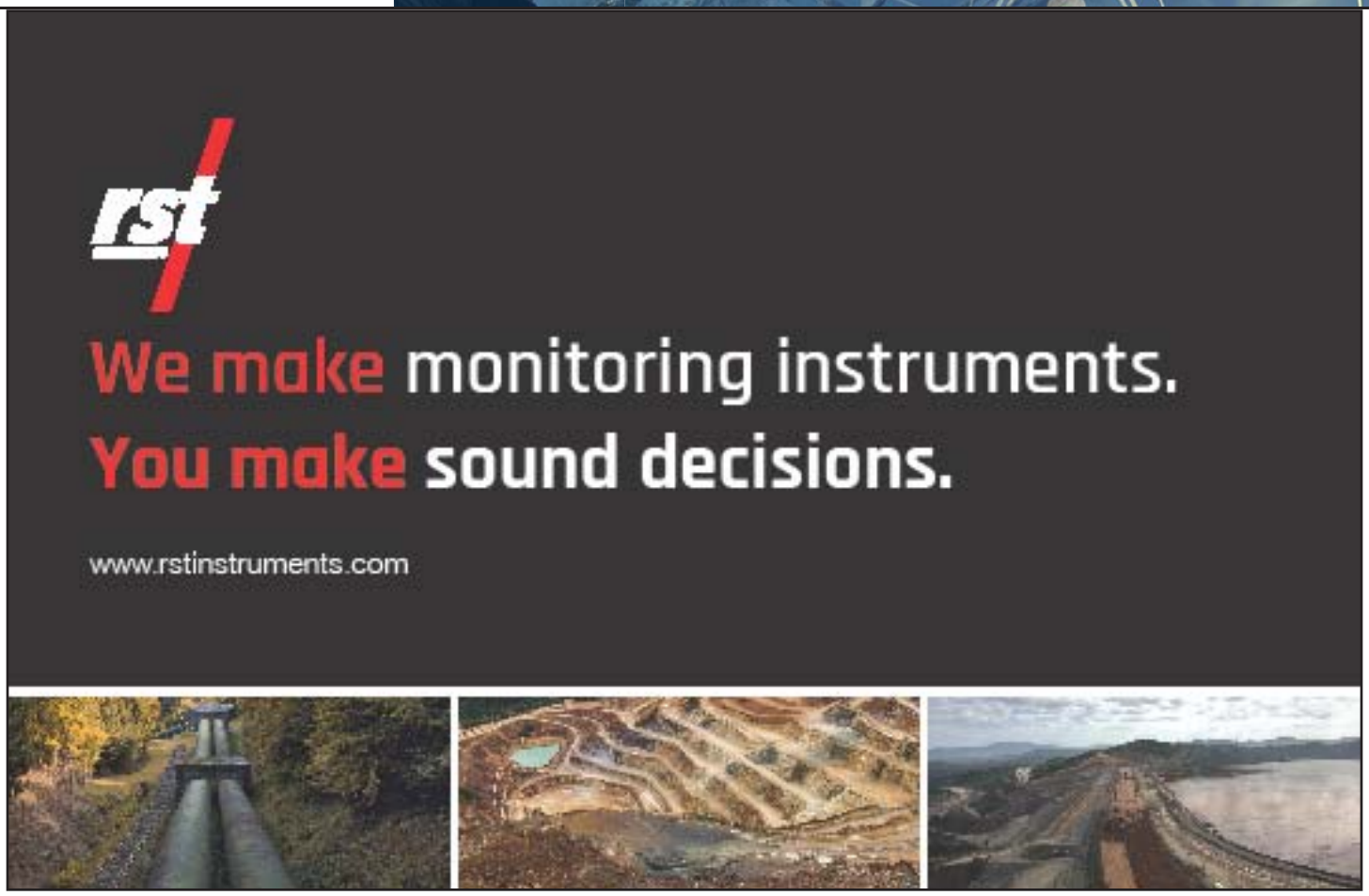

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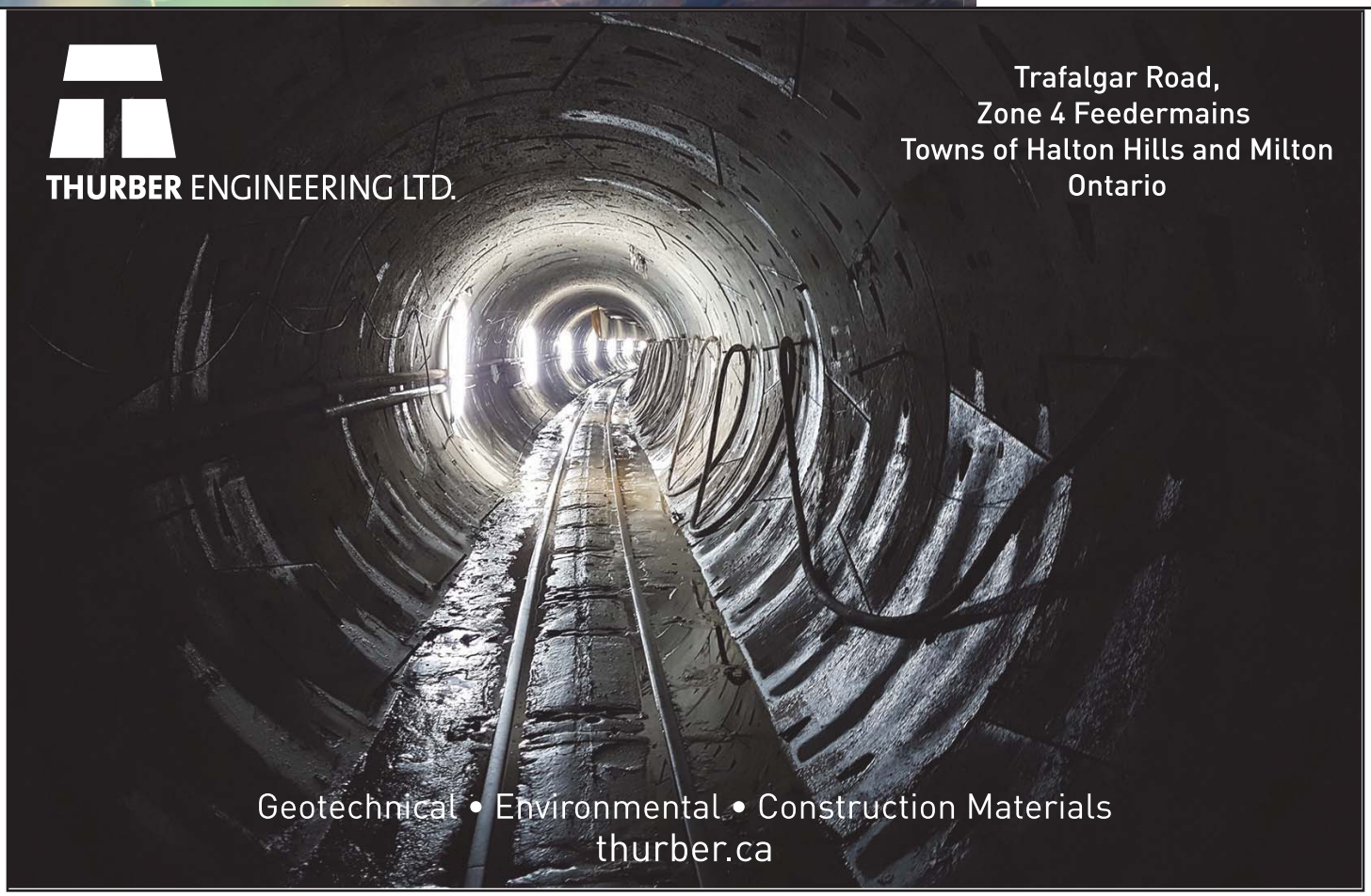

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We are proud to celebrate our 10-year milestone this year and want to thank our staff, clients, and partners who have contributed to our success.

We have benefited tremendously from our involvement in the CGS community and want to congratulate the organization on their commitment to holding this event through such an unusual time. We remain a steadfast sponsor of the event and wish everyone a safe and productive year ahead.

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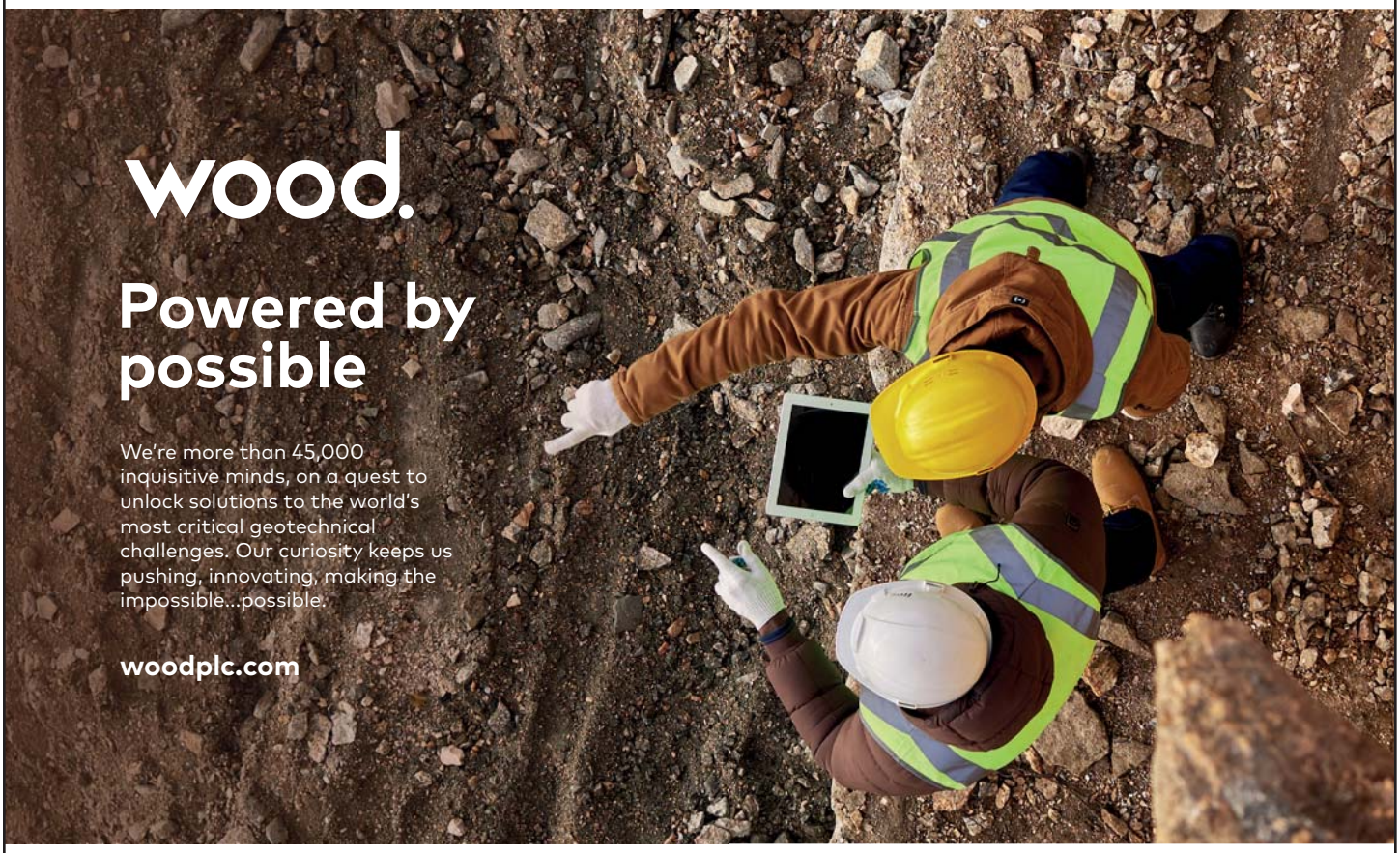

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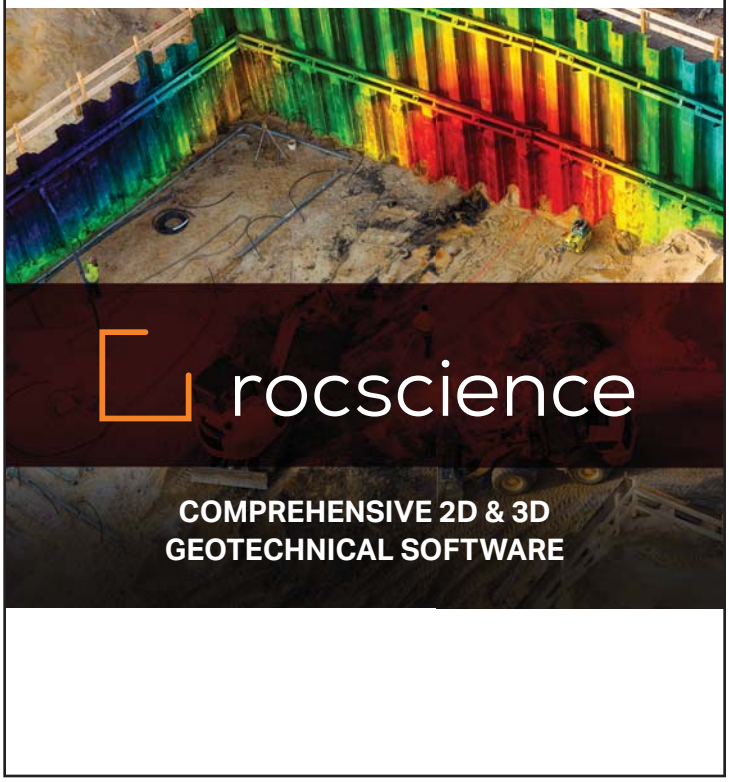

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CONFERENCE PROGRAM AND TIMETABLE / PROGRAMME ET HORAIRES DE LA CONFERENCE

MONDAY, SEPTEMBER 14 / LUNDI 14 SEPTEMBRE

Opening Ceremony / Cérémonie d'ouverture

R.M. Hardy Keynote Address / Allocution d'ouverture R.M. Hardy - Dr. Dennis E. Becker

You Gotta Laugh: A Pandemic Pick-Me-UP Yoga Movement Session	NETWORKING BREAK 1			
Soil Mechanics and Foundations I / Mécanique des sols et Fondations I **Session Chair: Marty Sangster**	Mining Geotechnics and Hydrogeology I /Géotechnique minière et Hydrogéologie I **Session Chair: Scott Martens**	Geoenvironmental Engineering I / Génie géoenvironnemental I **Session Chair: Laxmi Kant Kachwal**	Dams and Embankments I / Barrages, digues et remblais I **Session Chair: Arash Eshragian**	Landslides and Geohazards I / Glissements de terrain et Géorisques I **Session Chair: Will Smith**

for index of abstracts see pages 33-58

RF Legget Medal Presentation

Workout Session	NETWORKING BREAK 2			
Soil Mechanics and Foundations II / Mécanique des sols et Fondations II **Session Chair: Khokan Debnath**	Mining Geotechnics and Hydrogeology II / Géotechnique minière et Hydrogéologie II **Session Chair: Yetimgeta Mihiretu**	Geoenvironmental Engineering II / Génie géoenvironnemental II	Dams and Embankments II / Barrages, digues et remblais II **Session Chair: Rob Charron**	Landslides and Geohazards II / Glissements de terrain et Géorisques II **Session Chair: Lee Martin**
		Cold Regions Geotechnology I / Géotechnique en régions froides I **Session Chair: Bahaa Mekalled**		

for index of abstracts see pages 59-86

Mindfulness Meditation Break 1

Women in Geotechnique / Femmes en Géotechnique

BYO Wine and Cheese

TUESDAY, SEPTEMBER 15 / MARDI 15 SEPTEMBRE

CGS Colloquium 2020 / Colloque de la SCG 2020 — Dr. Ariane Locat

Graduate Student Presentation / Présentation des étudiants diplômés

GEOTrivia Game

NETWORKING BREAK 3

Soil Mechanics and Foundations III / Mécanique des sols et Fondations III **Session Chair: Kshama Roy**	Mining Geotechnics and Hydrogeology III / Géotechnique minière et Hydrogéologie III **Session Chair: Cathy Williamson**	Soft and Sensitive Clays I / Argiles molles et sensible I **Session Chair: Georgina Griffin**	Transportation Geotechnics I / Géotechnique des transports I **Session Chair: Sam Proskin**	Rock Mechanics and Engineering Geology I /Mécanique des roches et Géologie de l'ingénierie I **Session Chair: Bogart Mendez**

for index of abstracts see pages 87-111

Mindfulness Meditation Break 2

CGS Business Meeting / Réunion d'affaires de la SCG

Soil Mechanics and Foundations IV / Mécanique des sols et Fondations IV **Session Chair: Gennaro Esposito**	Soil Mechanics and Foundations V / Mécanique des sols et Fondations V **Session Chair: Leanne McLaren**	Professional Practice Committee Special Session / Séance spéciale du comité de pratique professionnelle **Session Chair: Sean MacEoin**	Transportation Geotechnics II / Géotechnique des transports II **Session Chair: Peter Thomson**	Dams and Embankments III / Barrages, digues et remblais III	Pipelines and Trenchless Technologies I / Pipelines et Technologies sans tranchée I **Session Chair: Tamer Elshimi**

for index of abstracts see pages 112-132

YP Special Session / Séance spéciale pour jeunes professionnels

WEDNESDAY, SEPTEMBER 16 / MERCREDI 16 SEPTEMBRE

SPECIAL PRESENTATION / PRÉSENTATION SPÉCIALE
Dr. Norbert Morgenstern, Distinguished University Professor Emeritus, University of Alberta

Geotechnical New Concrete Curing Solution video

CGS Heritage Session / Séance sur le patrimoine de la SCG

Photo Contest

NETWORKING BREAK 4

Application of Remote Sensing and Mapping I / Application de la télédétection et de la cartographie I	Landslides and Geohazards III / Glissements de terrain et Géorisques III **Session Chair: Tiequn Feng**	Geosynthetics I / Géosynthétiques I **Session Chair: Andrew Bidwell**	Geoenvironmental Engineering III / Génie géoenvironnemental III	Oil Sands Geotechnology I / Géotechnologie des sables bitumineux I **Session Chair: John Sobkowicz**
Structures Founded on Clay Shale I / Fondations de structures sur schistes argileux (Clay Shale) I **Session Chair: Jesse Mysiorek**			Sustainable Geotechnics I / Géotechnique durable I **Session Chair: Catherine Mulligan**	

for index of abstracts see pages 133-158

Mindfulness Meditation Break 3

AWARDS PRESENTATION;
Divisions Stermac Life member Best papers Students Awards CGS and CFG

Soil Mechanics and Foundations VI / Mécanique des sols et Fondations VI **Session Chair: Leanne McLaren**	Soil Mechanics and Foundations VII / Mécanique des sols et Fondations VII **Session Chair: Ertan Ozmen**	Site Improvement Techniques I / Techniques d'amélioration des sols I **Session Chair: Rocky Wang**	POSTERS	Offshore and Nearshore Geotechnical Issues I / Enjeux géotechniques des zones extracôtières et sublittorales I **Session Chair: Lijun Deng**
		Geophysical Methods I / Méthodes géophysiques I		

for index of abstracts see pages 159-178

Closing Remarks / Remarques de clôture

GPR Concert — For Those About to Rock

THURSDAY, SEPTEMBER 17 / JEUDI 17 SEPTEMBRE

SHORT COURSES / COURS INTENSIFS DE COURTE DURÉE

SC1: Introduction to BUILD3D

Instructors: Dr. Edward Dzik and Erika Harrison, M.Sc.

SC2: In-situ testing using pressuremeters

Instructors: Dr. David Elwood, P.Eng. and Robert Whittle

SC3: Using numerical tools Settle3, Slide3, RS2 and RS3 for geotechnical applications

Instructor: Dr. Sina Javankhoshdel

SC4: Instrumentation and monitoring for oil and gas industry and in mine tailings

Instructors: Dr. Pierre Choquet, Jeff Barrett, James Saunders, Alan Jones, and Dr. Vincent Le Borgne

KEYNOTES / CONFÉRENCES D'HONNEUR

MONDAY, SEPTEMBER 14, 2020

R.M. Hardy Keynote Address / Allocution d'ouverture R.M. Hardy – Dr Dennis E. Becker

Practical Aspects of Geotechnical Risk Management and Lessons Learned

Effective management of geotechnical risk is a requirement for successful geotechnical engineering design and construction. The presentation provides an overview of geotechnical risk management approaches that are available in state-of-practice, including observational approach, failure modes and effects analysis (FMEA), risk assessments, and reliability and probabilistic methods that are inherently linked to reliability based design (RBD) methods such as Load and Resistance Factor Design (LRFD). All these approaches provide necessary input into risk-informed decision making. The presentation will interrogate the advantages and limitations of these approaches, and how they can be appropriately used in practice. A thorough understanding of credible failure modes and how they develop in structures such as dams, embankments and foundations is a requisite of effective geotechnical risk management towards satisfying project objectives and needs. The important roles of site characterization, rationale design basis, analysis and design are also briefly examined. Implementation challenges being faced by geotechnical practitioners and lessons learned from projects are identified and discussed.

Aspects pratiques de la gestion des risques géotechniques et leçons apprises

La gestion efficace du risque géotechnique est nécessaire pour réaliser avec succès la conception géotechnique et la construction d'ouvrages. L'exposé présentera un aperçu des approches de gestion du risque géotechnique disponibles dans l'état actuel de la pratique, y compris l'approche par observation, l'analyse des modes de défaillance et des effets (AMDE), les évaluations de risque et les méthodes probabilistes de fiabilité qui sont intrinsèquement liées, par leur nature, aux méthodes de conception aux états limites comprenant des facteurs de charge et de résistance. Toutes ces approches fournissent l'apport nécessaire à la prise de décisions fondées sur la connaissance du risque. L'exposé portera sur les avantages et les limites de ces approches et sur la façon dont elles peuvent être mises en application de façon appropriée. Une compréhension approfondie des modes de défaillance crédibles et de la façon dont ils se développent dans des structures telles que les barrages, les digues et les fondations, est une condition préalable à une gestion efficace du risque géotechnique pour rencontrer les objectifs et besoins des projets. L'importance de la caractérisation de site, d'une base de conception rationnelle, de l'analyse et de la conception sera également brièvement examinée. Les défis de mise en œuvre auxquels font face les géotechniciens et les leçons tirées des projets seront recensés et débattus.

TUESDAY, SEPTEMBER 15, 2020

CGS Colloquium / Colloque de la SCG – Dr. Ariane Locat

Understanding spreads in Canadian sensitive clays

Spreads are one type of large landslides occurring in Canadian sensitive clays. They are characterized by the rapid lateral spreading of a series of coherent clay blocks, having horst and graben shapes, moving on an almost horizontal layer of remoulded clay. Spreads cover large areas (> 1 ha), develop rapidly with no warning signs, and conventional stability analysis do not apply, as they give too large factor of safety when back calculating entire spread. This leaves geotechnical engineers without tools in order to evaluate the risk regarding spreads. For the past decades, Université Laval, Ministère des transports du Québec and Ministère de la sécurité publique du Québec have worked together in order to answer the following question: what are the geotechnical and morphological parameters controlling initiation, propagation and extent of spreads in sensitive clays? This presentation portrays the latest advancement of the research program put in place with the goal to answer this question by integrating detailed field investigation, advanced laboratory testing and analysis and numerical modeling. It therefore presents the state of the art of our understanding of spreads in Canadian sensitive clays, focusing on three aspects: (i) synthesis of spreads in Eastern Canada, (ii) laboratory shear strength characterisation of sensitive clays, and (iii) application of progressive failure to spreads. Although it focuses on sensitive clays, the work presented has important applications to other materials presenting a strain-softening behaviour, such as rock, soft rocks, and snow, for example.

Comprendre les étalements dans les argiles sensibles au Canada

Les ruptures par étalement sont un type de grands glissements de terrain qui se produisent dans les argiles sensibles du Canada. Ils se caractérisent par l'étalement latéral rapide d'une série de blocs d'argile cohérents, ayant des formes de horst et de graben, se déplaçant sur une couche presque horizontale d'argile remaniée. Ces étalements couvrent de grandes surfaces (> 1 ha), se développent rapidement sans signes avant-coureurs et les analyses de stabilité conventionnelles ne s'appliquent pas, car elles donnent un trop grand facteur de sécurité lors du calcul à rebours de la rupture. Les ingénieurs en géotechnique ne disposent donc d'aucun outil pour évaluer le risque lié aux étalements. Au cours des dernières décennies, l'Université Laval, le Ministère des Transports du Québec et le Ministère de la Sécurité publique du Québec ont travaillé ensemble afin de répondre à la question suivante : quels sont les paramètres géotechniques et morphologiques qui contrôlent l'initiation, la propagation et l'étendue des étalements dans les argiles sensibles? Mme Locat présentera les derniers progrès du programme de recherche mis en place dans le but de répondre à cette question en intégrant des enquêtes détaillées sur le terrain, des essais et des analyses de pointe en laboratoire et de la modélisation numérique. Ce programme reflète donc l'état de l'art de notre compréhension de la propagation dans les argiles sensibles canadiennes, en se concentrant sur trois aspects : (i) synthèse des étalements dans l'est du Canada, (ii) caractérisation en laboratoire de la résistance au cisaillement des argiles sensibles, et (iii) application de la rupture progressive aux étalements. Bien qu'ils se concentrent sur les argiles sensibles, les travaux présentés ont des applications importantes pour d'autres matériaux présentant une dégradation de leur résistance mécanique en fonction de la contrainte appliquée, comme le roc, les roches tendres et la neige, par exemple.

WEDNESDAY, SEPTEMBER 16, 2020

Tribute to Dr Norbert Morgenstern

Dr. Morgenstern's presentation will reflect on Learnings from Success and Learnings from Failure over the past fifty years. The contributions of Dr. Morgenstern's to geotechnique in Canada and worldwide will be highlighted in introductions by some distinguished Canadian professionals. Norbert Morgenstern, Ph.D., P.Eng., FEIC, FCAE is a Distinguished University Professor Emeritus at the University of Alberta. He is an internationally recognized authority in the field of geotechnical engineering and a highly sought-after consultant. He has helped agencies and owners all over the world with the design of dams subjected to difficult conditions and with the evaluation and remediation of landslides. He has served on numerous technical committees throughout the world, including chairing the panels conducting the review into the causes of failure for the Mount Polley tailings dam in BC in 2014, and the Fundão Tailings Dam in Brazil in 2015. He has received some of the highest honours in our field, including the Rankine Lecture (1981) from the British Geotechnical Society, the Terzaghi Lecture (1992) and the Seed medal (2011), both from the American Society of Civil Engineers, and the Legget Award (now Medal), the Canadian Geotechnical Society's most prestigious honour. He has been inducted into the Alberta Order of Excellence and the Order of Canada for his outstanding achievements in and life-long contributions to geotechnical engineering. He has received honorary degrees from the University of Toronto, Queen's University and the University of Alberta, and is an Honorary Professor at Zhejiang University, PRC. Dr. Morgenstern is a past president of the Canadian Geotechnical Society (CGS) and of the International Society for Soil Mechanics and Geotechnical Engineering.

Hommage au Professeur Norbert Morgenstern, PhD

Cette présentation spéciale du professeur Morgenstern portera sur les leçons tirées des succès et les leçons tirées des échecs au cours des 50 dernières années. Les contributions de M. Morgenstern à la géotechnique au Canada et dans le monde entier seront mises en évidence dans des allocations d'introduction par d'éminents professionnels canadiens œuvrant dans le domaine de la géotechnique. Norbert Morgenstern, Ph.D., P.Eng., FEIC, FCAE est professeur émérite à l'Université d'Alberta. Il est une sommité internationalement reconnue dans le domaine de l'ingénierie géotechnique et un consultant très recherché. Il a aidé des agences gouvernementales et des propriétaires du monde entier lors de la conception de barrages en conditions difficiles, de même que pour l'évaluation et la remédiation de glissements de terrain. Il a fait partie de nombreux comités techniques dans le monde entier, notamment en présidant les commissions chargées d'examiner les causes de défaillance du barrage de résidus de Mount Polley en Colombie-Britannique en 2014 et du barrage de résidus de Fundão au Brésil en 2015. Il a reçu certaines des plus hautes distinctions dans notre domaine, notamment la conférence Rankine (1981) de la Société britannique de géotechnique, la conférence Terzaghi (1992) et la médaille Seed (2011), toutes deux de l'American Society of Civil Engineers, ainsi que le Legget Award (aujourd'hui Medal), la distinction la plus prestigieuse de la Société canadienne de géotechnique. Il a été intronisé dans l'Ordre d'excellence de l'Alberta et dans l'Ordre du Canada pour ses réalisations exceptionnelles et sa contribution de toute une vie à l'ingénierie géotechnique. Il a reçu des diplômes honorifiques de l'université de Toronto, de l'université Queen's et de l'université de l'Alberta, et est professeur honoraire à l'université de Zhejiang, en République populaire de Chine. M. Morgenstern est un ancien président de la Société canadienne de géotechnique (SCG) et de la Société internationale de mécanique des sols et de génie géotechnique.

SPECIAL SESSIONS / SÉANCES SPÉCIALES

MONDAY, SEPTEMBER 14

Women in Geotechnique

Some of the most respected and inspirational members of the geotechnical community are women. Join our panellists on Monday, September 14, for a special session celebrating women in geotechnique and exploring the journey of women who aspire to join the STEM career path. We hope to inspire, encourage, and educate women who are new to the community, and to highlight the strong female role models who are all around us. Our panellists will approach topics relevant to women in geotechnique as well as respond to your questions during the live Q&A session.

Confirmed Panellists:

Dr. Suzanne Lacasse — Technical Director, Norwegian Geotechnical Institute

Dr. Jocelyn Hayley — Professor and Department Head of Civil Engineering, Schulich School of Engineering, University of Calgary

Dr. Heinrich Heinz — Senior Geotechnical Engineer, Thurber Engineering

Leanne McLaren — Junior Geotechnical Engineer, Thurber Engineering

Karen Sagar — Engineering Manager, Systra Ltd.

Femmes en Géotechnique

À quoi ça ressemble d'être une femme dans la communauté géotechnique? Comment le monde géotechnique a-t-il évolué au fil des ans dans son accueil des femmes? Que pouvons-nous faire pour promouvoir l'égalité sur le lieu de travail?

Certains des membres les plus respectés et les plus inspirants de la communauté géotechnique sont des femmes. Rejoignez nos panélistes le lundi 14 septembre pour une session spéciale célébrant les femmes en géotechnique et explorant le parcours des femmes qui aspirent à rejoindre le cheminement de carrière des STIM. Nous espérons inspirer, encourager et éduquer les femmes qui sont nouvelles dans la communauté et mettre en valeur les modèles féminins forts qui nous entourent. Nos panélistes aborderont des sujets pertinents pour les femmes en géotechnique et répondront à vos questions lors de la session de questions-réponses en direct.

Panélistes confirmés:

Suzanne Lacasse, PhD — Directrice technique, Institut géotechnique norvégien

Jocelyn Hayley, PhD — Professeur et chef du département de génie civil, École d'ingénierie Schulich, Université de Calgary

Heinrich Heinz, PhD — Ingénieur géotechnique senior, Thurber Engineering

Leanne McLaren — Ingénieur géotechnique junior, Thurber Engineering

Karen Sagar — Responsable de l'ingénierie, Systra Ltd.

TUESDAY, SEPTEMBER 15

Professional Practice Committee Special Session / Séance spéciale du comité de pratique professionnelle

Geotechnical risks and other issues pertaining to different procurement models

The panel discussion will consider different procurement models, pros & cons, and how geotechnical risk is managed under each model. The discussion will follow a typical project timeline, illustrated with examples from the panelists' experience. Hosted by Seán Mac Eoin (Tetra Tech), Chairman of the PPC, the panel will include the following.

Risques géotechniques et autres questions relatives aux différents modèles d'acquisition

La table ronde portera sur les différents modèles d'acquisition, les avantages et désavantages, et comment le risque géotechnique peut être géré selon chacun de ces modèles. La discussion suivra la chronologie d'un projet typique, illustrée avec des exemples tirés de l'expérience des panélistes. La session sera dirigée par Sean Mac Eoin (Tetra Tech), président du Comité de pratique professionnelle, et la table ronde comprendra :

Neil Abbott (Gowling WLG), Construction Law specialist, spécialiste en droit de la construction

Henrik Kristiansen (Kiewit), Geotechnical Engineer , ingénieur en géotechnique

Steve Panciuk (Marsh), Professional Liability Insurance specialist, spécialiste en assurance responsabilité professionnelle

TUESDAY, SEPTEMBER 15

YP Special Session

This networking and panel session for students and young professionals will address topics relevant to their career in geotechnique within the current social and economic context. The session will feature a brainstorm session to allow students and young professionals some time for networking and discussion, as well as a live Q/A session with three distinguished panelists: Dr. Dennis Becker from Golder, Dr. Ariane Locat from Université Laval and Dr. Marc Smith from WSP.

Séance spéciale pour jeunes professionnels

La session spéciale pour les jeunes professionnels et étudiants abordera des sujets pertinents pour leur carrière en géotechnique dans le contexte social et économique actuel. La session comprendra une séance de réflexion et de discussion en petits groupes dynamiques pour permettre aux étudiants et aux jeunes professionnels de réseauter et de discuter. Une session de questions-réponses en direct suivra avec des panélistes de renom : Dennis Becker, PhD, de Golder; Ariane Locat, PhD, de l'Université Laval et Marc Smith, PhD, de WSP.

WEDNESDAY, SEPTEMBER 16

CGS Heritage Session

The special CGS heritage session will include a total of six presentations by distinguished professionals on topics that are of significant historical relevance to the geotechnical community. The historical projects, endeavors, testing methods or resources that will be presented during the session include:

The Kemano Project – 70 years of development

The Canadian Geotechnical Heritage Book project of the Canadian Geotechnical Society

The evolution of direct simple shear testing

Paper and real pipelines of the Canadian Arctic

The Canadian Geotechnical Virtual Archives

The Terzaghi, Peck and Casagrande Historical Libraries – a resource for the geotechnical profession

Séance sur le patrimoine de la SCG

Cette séance sur le patrimoine de la SCG comprend six présentations par d'éminents professionnels sur des sujets d'une grande importance historique pour la communauté géotechnique. Les projets, méthodes d'essai ou ressources qui seront abordées pendant la session incluent :

Le projet Kemano – 70 années de développement

Le livre du patrimoine de la géotechnique canadienne de La Société Canadienne de Géotechnique

L'évolution de l'essai de cisaillement direct simple

Les pipelines sur papier et réels de l'Arctique canadien

Les archives virtuelles de la géotechnique canadienne

Les bibliothèques historiques de Terzaghi, Peck et Casagrande – une ressource pour la profession géotechnique

INDEX OF ABSTRACTS

INDEX DES RESUMES

SEPTEMBER 14, 2020 - MONDAY AM

SOIL MECHANICS AND FOUNDATIONS I

SESSION CHAIR: MARTY SANGSTER

22 | On the determination of unsaturated soil property functions

PRESENTING AUTHOR: Dr. Delwyn Fredlund[1]

CO-AUTHORS: Dr. Murray Fredlund[2], Mr. Michael Courtin[2]

[1]Golder, Saskatoon, Canada, [2]Bentley Engineering, Saskatoon, Canada

The volume-mass properties of an unsaturated soil can change significantly with changes in negative pore-water pressure (i.e., soil suction). Changes in the soil properties are hysteretic with respect to drying and wetting; however, it is commonly considered adequate to first focus on the drying behavior as a "reference behavior" and then estimate the effect of hysteresis. Unsaturated soils analysis can be based on two unsaturated soil tests readily performed in a geotechnical laboratory. These are: i.) the gravimetric water content versus soil suction test, and ii.) the shrinkage curve test. In addition to data reduction, calculations for subsequent unsaturated soil property functions, USPFs, (e.g., permeability function, water storage function, shear strength function, etc.), are substantial and time-consuming. The reported research study shows that a series of Spreadsheet templates can be used to greatly expedient and ease the calculation of other remaining volume-mass versus soil suction relations as well as other physical properties related to unsaturated soil property functions. The calculations involve: i.) integration, ii.) differentiation and iii.) regression analyses to best-fit published equations for unsaturated soils behavior. Estimation of the magnitude of hysteresis between drying and wetting can also be incorporated. The calculated USPFs can then be imported to numerical modeling software and used to model soil behavior of a saturated-unsaturated soil continuum.

27 | Application of a generalized subgrade model in the analysis of circular plates on elastic foundations

PRESENTING AUTHOR: Ms Meron Alebachew[1]
CO-AUTHORS: Amlesu Tewoldebrhan[2]
[1]Philips Medical Systems, Addis Ababa, Ethiopia, [2] China Communication Construction Company, Addis Ababa, Ethiopia

The solution to the problem of beams and plates on an elastic foundation has been attempted in the past using various subgrade models developed by many researchers, one of the pioneers being Winkler. Most recently, a new calibrated and more advanced multifaceted continuum foundation model has been presented by Worku without neglecting any stress, strain, or deformation component in the continuum unlike previously proposed models.

The study of interaction between a plate and an elastic medium has useful applications in geotechnical engineering. This research investigates the use of a generalized continuum subgrade model of Worku for analyzing circular plates resting on an elastic foundation. The approach employed is both analytical and numerical. In the analytical work, the governing differential equations of an axisymmetric circular plate on a homogeneous elastic foundation has been formulated that incorporates Winkler and Pasternak-type subgrade models. Closed form particular solutions have been presented for different loading conditions of small and large circular plates after obtaining a general solution of the differential equations. A math solving software (i.e. Mathematica) is used to compute the deflections and internal actions in a spreadsheet program due to the complexity of the functions. In the numerical study a FEM based software (i.e. PLAXIS 2D) is used to calibrate the analyzed circular plate using the presented models by seeking adequate agreements with the FE outputs. At last, numerical examples are solved using these models and compared with PLAXIS 2D for small and large radii circular plates of some loading conditions. From the plots of the outputs, it is observed that the generalized models of Worku are suitable and more appropriate than classical models to analyze circular plates on elastic foundations.

Keywords: Continuum subgrade model, Circular plate, FEM, Mathematica and PLAXIS software.

31 | An overview on the determination of the shear strength of coarse grain materials (rockfills) from small scale laboratory tests

PRESENTING AUTHOR: Ms Akram Deiminiat[1]
CO-AUTHOR: Prof. Li Li[1], Feitao Zeng[1], Mr. Thomas Pabst[1], Prof. Robert Chapuis[1], Mr. Paul Chiasson[2]
[1]*Polytechnique De Montreal, Montreal, Canada*, [2]*Université Moncton, New Brunswick, Canada*

The shear strengths of in situ large-scale rockfill are key parameters required in stability analysis of structures made of rockfills. These materials contain a wide range of particles from fine particles as fine as silt to coarse particles as large as boulders. Doing laboratory test using a full scale rockfill and respecting the minimum required ratio between specimen size to the maximum particle size, dmax, specified by divers standard is very difficult and overly expensive if not impossible. To overcome this difficulty scaling down techniques were proposed by excluding the over-size particles in sample preparing. The most popular scaling down techniques are scalping, parallel, replacement, and quadratic methods. Among theme, parallel method has gained popularity over the years and largely used. In this paper, the four scaling down techniques are reviewed along with some available experimental results. The reliability of these methods used to extrapolate the shear strength of in situ large scale rockfill is reviewed, analyzed and discussed.

40 | New method of laboratory determination of the coefficient of earth pressure at rest, K0

PRESENTING AUTHOR: Michael Braverman[1]
CO-AUTHORS: Keisuke Adachi[1], Caren Ackley[1], Bruce Polan[1]
[1]*Ghd Ltd., Waterloo, Canada*

Two main elements of earth pressure – vertical and lateral – must be considered in the design of structures such as tunnels and retaining walls, and during deep excavations. While vertical pressure is easy to determine by direct measurement, or calculated if the depth and material characteristics of the overburden are known, lateral earth pressure is difficult to measure accurately. Risks of unknown or inaccurately estimated lateral earth pressure include soil movement and wall collapse, which can lead to personal injury, and equipment and infrastructure damage, therefore knowledge of the lateral earth pressure is vital for sound infrastructure design and long term integrity. Vertical pressure can be converted to lateral pressure with the empirical coefficient K0, defined by Terzaghy as the coefficient of earth pressure at rest. The accepted theoretical approaches to estimate K0 are based on the Rankine and Coulomb theories; however, both make assumptions and often cannot be

considered as accurate. There are several known laboratory tests for K0 determination, most of them requiring complicated and sometime cumbersome equipment. A new method for determining K0 was developed in the GHD Geotechnical Laboratory. A series of drained K0 tests were performed on saturated soil using standard triaxial equipment with some minor modifications. The objectives of this paper are to describe the experimental equipment and present and discuss the obtained results.

54 | Viscous (time-dependent) behaviour of saturated clay in consolidated undrained triaxial compression

PRESENTING AUTHOR: Dr. Chee Wong[1], Prof. Ron Wong[1]
CO-AUTHORS: Prof. Biao Li[2],
[1]*University of Calgary, Calgary, Canada,* [2]*Concordia University, Montreal, Canada*

The strength-deformation-pore pressure characteristics of saturated clay under consolidated undrained (CU) triaxial compression are highly dependent on the applied strain rate. An increase in strain rate causes an increase in undrained peak strength, reflecting the viscous plastic behaviour of the material. Based on the theory of critical state plasticity, the increase in undrained peak strength due to the increase in strain rate could be modelled by an apparent increase in overconsolidation pressure or ratio (OCR). Since the OCR controls the loci of the yield surface or function, the yield surface becomes non-stationary (dynamic) and rate-dependent. Based on the strain rate dependency among the undrained peak strength, OCR and dynamic yield surface, this paper develops an interpretation technique to correlate the undrained strength parameters measured in CU tests with the Hvorslev drained strength parameters. The drained strength parameters are rate-dependent (viscous) cohesion and rate-independent (intrinsic) true friction angle. Data of CU tests on resedimented Boston blue clay will be processed and analyzed using the proposed interpretation technique.

19 | Rethinking the strength properties of soils in the Greater Toronto Area

PRESENTING AUTHOR: Geoffrey Creer[1]
CO-AUTHORS: Dmitry Olshansky[1], Andrew Drevininkas[1]
[1]*Toronto Transit Commission, Toronto, Canada*

An extensive laboratory testing program was carried out for recent transit expansion projects in the Toronto area. The testing included routine characterization index testing - moisture content, grain size distribution, Atterberg Limits and unit weights - and a suite of advanced testing consisting of approximately 181 triaxial compression test sets (in the order of about 540 specimens) to define the strength properties (friction angle, ϕ', and the cohesion, c') of the soils for use in design. In this paper, we present a summary of the characterization and triaxial compression results, classified using the physical properties of the TTC Soil Groups.

Two different sampling methods were used to obtain triaxial test samples conventional PQ coring and the faster Sonic coring method. A comparison of the results indicates that the sampling method (PQ or Sonic) had minimal impact on friction angle results, with the Sonic soil samples generally indicating a slightly lower friction angle when compared to those soil samples obtained using PQ methods.

A review of strength parameters recommended for various new developments and transit infrastructure improvement projects was carried out and compared to the results obtained from the triaxial compression testing. Based on this review it appears that geotechnical design engineers may be underestimating the strength of the soils in the Greater Toronto Area favouring to use more conservative values for friction angle and cohesion.

MINING GEOTECHNICS AND HYDROGEOLOGY I

SESSION CHAIR: SCOTT MARTENS

29 | Earth pressure coefficient in a vertical backfilled opening

PRESENTING AUTHOR: Dr. Jian Zheng[1]
CO-AUTHOR: Prof. Li Li[1]
[1]*Research Institute of Mining and Environment (RIME UQAT-Polytechnique), Ecole Polytechnique De Montreal, Montreal, Canada*

Earth pressure coefficient, K, is a key parameter. It is defined as the ratio between the horizontal and vertical effective (principal) stresses. It is a required parameter in numerous analytical solutions developed to estimate the stresses in backfilled openings such as retaining walls, silos, trenches and mine stopes. Some researchers proposed to use the Jaky's at-rest earth pressure coefficient K0 as long as the confining walls are immobilized while others proposed to use the Rankine's active earth pressure coefficient Ka even though the confining walls are immobile. Li and coworkers have further indicated that the immobilization of confining walls is a necessary and sufficient condition for the soil to be remain in an at-rest state only when the soil is initially at an at-rest state. When a confining structure exists or is built first, the state of the backfill later placed is unknown. It can be in an at-rest or active (yield) state. An active state is totally possible even though the confining walls remain immobile during and after the placement of the backfill, depending on the values of friction angle and Poisson's ratio and the considered position. As the Poisson's ratio of granular material is very difficult to measure and generally unknown, the state of a backfill placed in a confining structure remains unknown. In this paper, a few results of measured values of K will be presented and discussed.

33 | Effect of height and downstream slope on the seismic behavior of tailings impoundments reinforced with waste rock inclusions

PRESENTING AUTHOR: Ali Reza Zafarani[1]

CO-AUTHORS: Prof. Samuel Yniesta[1], Prof. Michel Aubertin[1]

[1]*Polytechnique Montréal, Montréal, Canada*

Tailings storage facilities can be designed with retaining dikes built using three different disposal techniques: the upstream, downstream and centerline methods. The upstream-raised method is the most common due to its simplicity and low cost. However, the stability of such impoundments is often fragile, and these have been observed to be prone to dramatic failures, especially in high seismicity regions. To improve the stability of tailings impoundments with upstream-raised dikes, the use of waste rock inclusions was proposed. This method of co-disposal of tailings and waste rock consists of placing rows of waste rock within the impoundment prior to each dike raising. Recent studies on the effects of waste rock inclusions on the stability of tailings impoundments have indicated that this co-disposal method may improve the geotechnical behavior of the impoundments under both static and dynamic conditions. This paper presents finite difference analyses of the seismic behavior of simplified tailings impoundments reinforced with waste rock inclusions. The effects of the downstream slope and height of the impoundment on the seismic stability were investigated through a parametric study. The effect of each parameter was investigated individually by assessing its effect on various indicators such as the critically displaced volume of tailings, the deformation of the impoundment crest, and the permanent displacement of the downstream slope. Simplified design equations and charts are provided to estimate the permanent displacement of the downstream slope of tailings impoundments as a function of waste rock inclusion's configuration, and the geometry of the impoundment.

38 | Numerical modeling for determining the local vertical hydraulic gradient at the wall of a tunnel

PRESENTING AUTHOR: Mr. Alireza Shahbazi[1]
CO-AUTHORS: Prof. Ali Saeidi[1], Prof. Romain Chesnaux[1]
[1]*Université du Québec à Chicoutimi, Chicoutimi, Canada*

The determination of the flow rate in the underground excavation is a very important parameter in the design of the structures. Among all parameters that have an impact on the inflow rate to the tunnel, the hydraulic gradient is one of the most effective one that, according to Darcy's law, controls the tunnel inflow rate. An empirical-numerical equation is proposed for the determination of the vertical hydraulic gradient in the wall of a tunnel excavated below a water table. The horizontal hydraulic gradient is not supposed to have a significant impact on the tunnel inflow rate as its value is very low. By contrast, the existing vertical hydraulic gradient is among the most effective parameters. On the other hand, in the case of an underground excavation, no equation exists for the determination of the hydraulic gradient that considers more than one parameter, i.e., the depth. Using the results of the numerical simulations, it was deduced that the depth of the tunnel, the ratio between principal hydraulic conductivities, and their relevant directions are the most effective parameters that have a significant influence on the hydraulic gradient and inflow rate to the underground tunnels. The resultant hydraulic gradients in the vicinity of the wall of the tunnel were obtained using the RS2 Roc Science software. The mathematical relationship between the input data, i.e., the depth (z), ratio between hydraulic gradients (a) and their relevant directions (α), and the result of the simulation, i.e., the hydraulic gradient (iz), have been derived by curve fitting. Finally, for each orientation of the principal hydraulic conductivity, an equation is proposed for the calculation of the hydraulic gradient.

43 | The effect of waste rock inclusions on the static stability of tailings dikes

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Mine operations typically generate two primary types of solid wastes: waste rocks and tailings. Coarse grained waste rocks mainly result from the blasting activities performed to access the ore zones in underground or open pit mines; these are usually disposed in waste rock piles on the surface. Tailings are fine grained materials produced by the milling treatment of extracted ore; they are generally disposed hydraulically as slurry in surface impoundments confined by retaining dikes. The design of surface impoundment raises various geotechnical issues, including the risk of static instability of the external slope. Waste rock inclusions (WRI) can be used to improve the geotechnical response of tailings impoundments. This method consists of placing waste rock strategically inside the impoundment to improve drainage and reinforce the retaining system.

In this paper, numerical results will be presented to illustrate the effect of inclusions on stability of tailings dikes under static loading conditions, based on the characteristics of typical tailings and impoundments. The calculations are conducted with GeoStudio and FLAC for cases with and without waste rock inclusions. The numerical modelling calculations, simulating the behavior of dikes during and shortly after deposition of tailing in the tailing impoundment, illustrate how WRI can enhance the safety factor of dikes.

The results are part of a global research program aimed at developing an optimization strategy for the use of waste rock inclusions inside tailings impoundments for increasing the stability against static and dynamic loading.

53 | Two case studies: Efficient design of mine structures using the observational approach at Kearl

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The Alberta oil sands contain approximately 27 billion m3 of bitumen at depths sufficiently shallow to be commercially surface-mined. These operations require removal of the mine wastes and ores, which form pit walls, and use earth dams either ex-pit or in-pit to store process water for bitumen extraction and to contain tailings after the oil is removed. These large earth structures are typically designed using general geological information, discrete subsurface boreholes, piezometric data and laboratory testing on selected samples to characterize foundation conditions and material properties. Significant investments are necessary for site investigation and design, notwithstanding reliance on the observational approach to manage uncertainty associated with geologic, geometric and operational variabilities. The observational approach promotes efficiency while managing risk, provided the strategy is implemented appropriately.

This paper presents two cases studies, in which the observational approach was successfully applied to the designs and construction of the mine structures at Imperial's Kearl oil sands mine.

The first case study demonstrates efficiencies by embracing a 3D limit equilibrium method for the mine pit walls where 2D analysis did not meet the target Factor of Safety. As part of observational approach, the 3D analysis method was validated using instrumentation and visual performance observations. As mitigation, a mine-replace strategy was adopted to allow mining to progress and confirm 3D design results.

The second case study relied on the observational approach in dealing with potential inflow from Basal or Devonian aquifers under an in-pit tailings dyke, in which shutdown-recovery tests were conducted to confirm whether or not potential conduits or hydraulic cracks exist in Devonian aquitard or in the Lower McMurray Muds. Significant cost savings were achieved by removing the requirement for sand blanket installation and long term operational costs of depressurization wells based on the shutdown-recovery test results.

115 | Scaled physical modelling of granular flow from storage hoppers and silos

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Understanding the storage and flow of granular materials in hoppers and silos is relevant to a wide range of industrial activities. However, common problems encountered with these activities are erratic flow, blockage and dead zones. Mechanical interaction between the particles can also give rise to asymmetrical distributions of dynamic stresses and anomalous stresses damaging silos, e.g. Jenike's 'switch stresses'. Unfortunately, the key factors needed for optimum design of storage silos based on the physical characteristics of the contained granular materials, silo quasi-static yield and rapid flow are still poorly understood. Hence the applicability of current experimental and computational tools is generally limited. Furthermore, most non-intrusive experimental measurements evaluate only bulk-flow parameters at the outlet of the silo, boundaries of the flow field, or dimensions that are orders of magnitude smaller than those in 'field' applications.

The classic Beverloo equation defines the flow of granular solids through an orifice, where mass outflow-rate is a function of orifice diameter, material bulk density, average particle size and silo geometry. The study described in this paper has investigated the outflow behaviour of different scaled physical model granular storage hoppers containing fine-grained silica sands. The model geometries include classical vertical-sided silos, cones and hourglass-shapes, with varying diameter, depth, relative orifice and particle diameters; and gravity effect in geotechnical-centrifuge.

This approach is designed to provide a better understanding of the governing phenomena in falling and constant head orifice flow problems and assess the effectiveness of the geotechnical centrifuge as an experimental tool for investigate the behaviour of storage silos. Granular deformations were investigated using particle image velocimetry (PIV) to analyse propagation of strain localizations and flow regimes during outflow. The results were used to calibrate the Beverloo flow equation for the different models and check the model scaling laws for these structures and granular flow phenomena.

GEOENVIRONMENTAL ENGINEERING I

SESSION CHAIR: LAXMI KANT KACHHWAL

13 | Numerical and experimental investigation of bentonite-sand mixtures

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Deep geological repository (DGR) is one of the most preferred options for the long-term disposal of low, intermediate, and high-level radioactive wastes in many countries. DGR safety depends mainly on the multi-barrier system of both natural and engineered barriers. Bentonite-based materials have been suggested as engineering barrier in DGR, due to their low permeability, high swelling pressure, and retention of radionuclides. Swelling characteristics of bentonite-based materials is a crucial factor in assessing the long-term permeability, hence the safety of DGR. Numerous laboratory tests have been conducted to determine the swelling properties of bentonite-based sealing materials. In this study, laboratory tests on swelling pressure will be performed using different standard methods such as free swelling and constant volume method. In addition to that, a numerical simulation of swelling tests will be conducted to predict the swelling characteristics of various mixture of bentonite -sand, and calibration will be done using laboratory data.

109 | Determination of unsaturated hydraulic properties for low impact developments

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With the increase in extreme rainfall events and rapid urbanization, the risk of flooding has increased substantially. Low Impact Developments (LIDs) can assist in decreasing this risk within certain areas. The soil is generally considered to be completely saturated when designing for the LIDs. However, this may not always be an accurate or realistic approach, as the soil could be variably unsaturated leading to inaccurate designs. To analyze the flow under variably unsaturated conditions, Richards' equation can be used. In order to solve the Richards' equation, two nonlinear hydraulic properties namely, soil water characteristic curve (SWCC) and the unsaturated hydraulic conductivity function are required. Laboratory and field measurements of unsaturated hydraulic properties are cumbersome,

expensive and time-consuming. An alternative approach is to estimate unsaturated hydraulic properties using pedotransfer functions. Pedotransfer functions estimate soil hydraulic properties using routinely measured soil properties, such as soil texture, grain size distribution, bulk density, or porosity. This research presents a comparison between the direct measurement obtained through experimental procedures and the use of pedotransfer functions to estimate soil hydraulic properties for two green roof and three bioretention soil medias. Design implications are also part of this research effort.

113 | Synthesis and application of nanoparticles and biosurfactant for oil-contaminated soil removal

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Oil exploration, production and use may cause oil leakage, which can contaminate surrounding soil. Biosurfactants are biologically produced surfactants, which are produced by yeast or bacteria from various substrates like sugars, oils, alkanes, and wastes. Biosurfactants have been used in some remediation technologies for removal of metals and hydrocarbons from contaminated soils. In addition, some nanoparticles have already shown their effective treatment of petroleum-contaminated soil. This research will study the application of various biosurfactants and nanoparticles for treatment of oil-contaminated soil from China. The specific objectives of this work include investigation of the removal of oil from contaminated soil by experimental columns containing some selected biosurfactants and nanoparticles in the lab, evaluation of the effect of some factors, such as pH, temperature, biosurfactant concentration on the removal efficiency, and determination of the range and sustainability of the developed process. Some preliminary results including the synthesis and characterization of nanoparticles, characterization of soil, and removal of oil-contaminated soil by column tests are also included.

335 | The effect of mechanical loading and carbonation on the physical properties of solidified sand

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Information on the long-term performances of the stabilization/solidification (S/S) technique under real field conditions remains sparse. In this study, a modified triaxial cell was developed to evaluate the physical properties of silica sand solidified with cement. The modified triaxial cell was required to study the influence of loading and carbonation under a confining stress simulating field conditions. The permeability and compressive strength were measured at different stages of four main scenarios involving carbonation only, axial loading only, carbonation first then loading, and loading first then carbonation. The influence of external loading and carbonation on the physical properties of solidified sand is complex. It involves creating new voids (fractures) that increase the permeability, lower the shear strength, and channel the water flow. It also involves calcite precipitation that fills the pore space with opposite effects on the mechanical and hydrodynamic properties of the solidified sand. Results indicate that the mechanical loading accelerated the damage to the S/S samples and increased their permeability. Deterioration owing to loading decreased in the presence of carbon dioxide. The results of this ongoing study will help to understand the long-term performances of the S/S technique.

422 | Development of fragility curves for soil embankment slopes due to future extreme rainfall events

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The performance of earth embankments is essential in sustainable transportation infrastructure. The consequence of embankment instability can have significant safety impacts on the traveling public and financial impacts on moving goods and services on our highways and roadways.
The stability of earth embankments is susceptible to water infiltration as a result of intense rainfall events. Climate change is predicted to continue over this century increasing the likelihood of extreme participation events that can create embankment failures.

The objective of this research is to develop fragility curves for earth embankments under extreme rainfall events in several different locations across Ontario. For this purpose, a series of reliability analyses were carried out to consider the effects of soil parameter uncertainties on the stability of the embankment slopes under various extreme rainfall events. Variably saturated flow modeling and limit equilibrium assessments were primary inputs for the reliability analyses.

The results were compiled to develop fragility curves that present the conditional probability of slope failure for different rainfall return periods and durations. These curves were developed for embankments constructed with sand and silt materials. The developed fragility curves for sand embankments show a decreasing trend in the probability of failure with an increase in return period and rainfall duration. Contrary to sand embankments, the developed fragility curves for silt embankment generally show an increasing trend in the probability of failure with increasing rainfall return period. It can also be observed that the probability of failure for silt embankment is higher for future conditions in comparison to historical conditions. Furthermore, wetter initial conditions cause a considerable increase in the probability of failure for silt embankments, which is in contrast to the results for the sand embankment.

DAMS AND EMBANKMENTS I

SESSION CHAIR: ARASH ESHRAGIAN

16 | On the development and challenges of particulate flow modeling in geotechnical engineering

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Flow of combined particulate media and fluids is relevant to many industrial applications and natural phenomena, yet, not fully understood due to its complex physics. Over the past five decades, significant achievements were accomplished in particulate flow modeling aided by the rapid advances in computer hardware. It is notable that most of the major developments in particulate flow modeling were presented in the context of chemical engineering (e.g., fluidized beds and pneumatic conveying), while contributions to civil and geotechnical engineering are still relatively limited. One of the main reasons for this relatively small contribution is the inherent large-scale nature of many geotechnical applications such as earth dams and natural slopes, which are computationally expensive to model. Although different up-scaling techniques were presented to overcome the obstacle of high computational cost, the accuracy of up-scaled simulations is still questionable. Therefore, it is important for geotechnical engineers and researchers to have a good understanding of particulate flow methodologies and its corresponding accuracy and computational cost. This study aims to present a critical summary of the existing approaches for particulate flow modeling and their direct application to geotechnical problems. The majority of existing models can be classified into three main categories from the perspective of the numerical solution: Eulerian–Eulerian, Eulerian–Lagrangian, and Lagrangian–Lagrangian models. Under this classification, we discuss the different models presented to date and the advantages and disadvantages of each model. Our evaluating criteria depends on the accuracy of results, computational expense, and availability of modeling tools (e.g., commercial or open source codes). We also include a brief review of published work in the geotechnical field, in which, these different models were used. We believe that this study would help geotechnical engineering practitioners to identify the available methods, modeling tools, and challenges associated with particulate flow modeling.

25 | Tailings dike seepage mitigation through adaptive tailings deposition sequencing

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This paper presents the summary of a seepage remediation strategy put in place to mitigate the supernatant water seepage observed underneath a tailings retention dike at a mine site located in a permafrost environment in Northern Canada. Effective seepage mitigation was achieved through adaptive tailings deposition sequencing. Following the first observations of a seepage, field investigations and extensive numerical modelling were performed to understand the seepage mechanism, establish appropriate mitigation options and quantify the efficiency of the mitigation strategy over time as the tailings storage facility was operated and sequentially raised. In addition, the seepage mechanism understanding gained was incorporated into a detailed Trigger Action Response Plan for the dike. This paper provides an overview of the evolution of the situation over the operational life of the structure, which is now nearing closure stage, and provides insights about the use of tailings deposition as a seepage mitigation tool.

34 | Monitoring of the change of moisture beneath railway embankment and effectiveness of a wicking geotextile

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A 36 m section of railway embankment was remediated on Canadian Pacific Railway's (CP) Scotford subdivision to address issues of ongoing settlement and mud pumping. The track panel and embankment materials were replaced with new materials inclusive of a geotextile between the ballast and subballast layers, and a wicking geotextile between the subgrade and subballast. The wicking geotextile is designed to draw the moisture from the base of embankment and surface of subgrade towards the shoulders. This site provided the opportunity to monitor the seasonal changes of moisture content within the clayey subgrade and to evaluate the effectiveness of the chosen remediation method. 5TE moisture sensors are installed at both the remediated section and an adjacent control section, along with access tubes for the use of a "Diviner 2000" probe to measure profiles of moisture with depth. This allows for a direct comparison of the performance of the two sections under the same meteorological conditions. Currently the change of volumetric

water content (VWC) within fill and subgrade is being measured by 5TE moisture sensors twice daily and profiles of VWC are obtained every two weeks. This paper will present a comparison of the trends of the VWC with time between the two adjacent sites along with the impacts of precipitation events and a spring thaw; and, an interpretation of the impact of these changes in VWC on the unsaturated strength of the soil based on laboratory testing results.

36 | A case study of reinforced soil slopes in Ontario

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Roadway embankments approaching a culvert or bridge are often constrained by retaining walls due to limited space. Flexible retaining walls such as reinforced earth wall and reinforced soil slope (RSS) are generally used as they are tolerant of the ground settlement under the weight of embankment fill. However, if the face units of the reinforced earth wall and RSS are not properly designed and constructed, the serviceability of the roadway could be significantly affected.

This paper presents a case study of RSSs along Bathurst Street in the Region of York, Ontario. Six RSSs were designed to be up to 10.4m in height reinforced with geogrids at vertical spacings of 0.6m for the roadway embankment over three culverts. The slope angle was 70o and slope face units consisted of vegetated geocells. Two years after the RSS construction, the face units of one RSS collapsed after a significant rain event. Field investigation and global stability analysis were carried out. It was found that the possible failure mechanisms of the RSS were the infiltration rate of surface water exceeded the drainage capacity of the RSS and the built-up hydrostatic pressure exceeded the sliding resistance between the geocells. The failed face units were then reinstalled using the same geocells with the installation of a vertical drainage layer behind the geocells. Following the reinstallation of the face units of the RSS, ground movement monitoring was conducted for all RSSs over the culverts. Field inspection was carried out one year after the reinstallation of the face units. It was found that all RSSs were globally stable. The reinstalled face units were stable. However, localized soil erosions and geocell displacement were observed at the face units of remained five RSSs. Improvements for the design and construction of the RSS are recommended.

147 | Post-seismic stability of a tailings impoundment reinforced with waste rock inclusions

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Generation and redistribution of excess interstitial pore water pressures generated during a seismic event can lead to the instability of tailings impoundments after the earthquake. In such cases, the driving forces induced by the event tend to exceed the available shear strength of the retaining dike materials. Examples of such ruptures include the Mochikoshi tailings impoundment (1978) and the Lower San Fernando Dam (1971), which occurred one day and thirty seconds, respectively, after the events.

This paper will present numerical analyses to evaluate the post seismic stability of a tailings impoundment with upstream dikes constructed with a downstream slope of 1V:8H, with and without waste rock inclusions. The tailings are modelled in the shaking phase using FLAC and the PM4SAND constitutive model, with parameters calibrated based on an extensive laboratory and field-testing program. The post-seismic stability of the tailings impoundment is assessed by performing a static analysis based on the final shaking conditions with a shear strength reduced by the excess pore water pressures.

The results show that even if the impoundment without inclusion shows limited displacements at the end of shaking, an unstable zone surface may develop due to excessive shear strains during the post-seismic phase. Such large displacements can lead to failure of the supporting dikes. Conversely, an impoundment with waste rock inclusions tend to show much smaller displacements under post-seismic conditions, even when excess high pore water pressures are generated during shaking.

119 | Geotechnical and geophysical investigations for a dam safety review project

PRESENTING AUTHOR: Allen Xu[1]
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Advisian was retained to undertake a dam safety review (DSR) for a client. The facility was constructed in the 1970's and very limited technical and background information was available for the facility. Further, no previous DSR was completed for the facility since it

was constructed in the early 1970's and no geotechnical data required to complete the DSR were available. Consequently, Advisian recommended geotechnical and geophysical investigations to capture the necessary data to complete the DSR for the dam.

The geotechnical investigation included advancement of seven (7) boreholes through the dam fill into the foundation material, the depths of the boreholes ranging for 11 to 20 meters (m) below ground surface. The geotechnical field program also included the installation of 10 vibrating wire piezometers in six (6) boreholes and one slope inclinometer casing in the seventh borehole. To provide complementary information on the internal dam structure and the underlying native material, a geophysical investigation was completed using electrical resistivity tomography (ERT), multichannel analysis of surface waves (MASW) and seismic refraction methods, along 4 lines spanning 120 m to 240 m long. Data interpreted from the two investigations were utilized to complete the dam modelling and assessment.

The DSR activities followed the 2013 CDA Guidelines. Two separate DSR reports we submitted to the client, namely a report related to the liquefaction and risk analyses and a report for other activities.

Geotechnical recommendations for the new smelter building included, among other, shallow foundations and a cast-in-situ piling (were subsequently substituted by micro piles).

This paper discusses the geotechnical and geophysical investigations findings and sheds light on the lessons learnt from the investigations and the finding of the DSR.

LANDSLIDES AND GEOHAZARDS I

SESSION CHAIR: WILL SMITH

49 | Probabilistic analysis of three-dimensional slopes using the stochastic response surface method

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Three-dimensional slope stability analysis using limit equilibrium methods is a time-consuming procedure. Using traditional sampling methods such as Monte Carlo or Latin Hypercube may take days of computation, especially when there are multiple random variables and complicated geometries that require advanced analysis methods. Stochastic response surface (SRS) method is a very fast and effective approach for probabilistic analysis of 3D complicated geometries which reduces the number of simulations and simulation time dramatically. The stochastic response surface method takes a fraction of spread out samples that cover the parameter space and uses those to train the model. Any number of samples can then be plugged into this model and will result in the estimated factor of safety values for each sample.

In this study, an SRS algorithm using third order Hermite polynomial expansion, developed for complex 3D probabilistic analysis is presented. A multilayered slope with several random variables has been investigated using the SRS method and the results are compared with Latin Hypercube simulation results. The results using both methods are in good agreement. However, the SRS method computation time is a fraction of that of the Latin Hypercube simulation.

85 | Design of deflection berms for small post-wildfire debris flows

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The 2017 Elephant Hill wildfire burned 190,000 hectares in British Columbia. In August 2018, intense rainfall over the burned area initiated many debris flows that swept across Highways 97 and 99, which endangered people and properties and caused a fatality. Areas of high burn severity continued to generate debris flow activity in 2019, with highways blocked numerous times by debris and mudflow deposits. Two mudflows in a small valley-

side watershed were triggered by intense rainfall in June 2019. These mudflows blocked Loon Lake road and affected a private residence located on a fan deposit at the Bonaparte River. Debris flow hazards are widely acknowledged to increase after a wildfire causes significant burn severity in a watershed. Increased awareness of the hazard level is necessary, but this is often insufficient to reduce the risk for homeowners with structures built on old fans. Mitigative measures are required. This paper uses the June 2019 mudflows to illustrate how relatively low-cost deflection berms can be designed and implemented to mitigate geohazards. A key design element is the use of a detailed topographic map containing 0.5 m contours of the fan and the locations of structures requiring protection. For this purpose, a Remotely Piloted Aircraft System was used to collect aerial images. In this case study, images were taken several days after the mudflows occurred. However, the goal of this paper is to highlight a hazard mitigation workflow that can be completed following a wildfire, yet before small debris flows have the opportunity to affect developments on a fan. The aerial images were processed in Structure-for-Motion software to generate a digital elevation model, fan topography, and orthophotos. These provide the basis for locating deflection berms and channels to direct future debris away from vulnerable structures.

86 | Field application of inexpensive custom-built programmable dataloggers for routine instrumentation needs

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A low-cost datalogger was built in the lab and installed in place of conventional, commercially available datalogging systems. The units have been deployed at three sites across western Canada in British Columbia, Alberta, and Saskatchewan. The project involved the modification of open source software and programming readily available on the Internet. Data collected with conventional units and the constructed datalogger were compared to determine the accuracy and precision of the lower cost units. Testing of the low-cost datalogging units have shown them to be highly adaptable, with the ability to measure negative pore water pressure (matric suction), volumetric water content, and temperature from SDI-12 sensors as well as positive pore water pressure and temperature from vibrating wire piezometers. Telemetry has been built into the more remote set of dataloggers to transmit occasional data points and periodically verify that the unit and

sensors are logging as expected. Assembly, installation, and ongoing monitoring using the low-cost datalogging system has occurred over the past two years as these units have proven durability and continue to operate at each location. Field application of these dataloggers to date has encountered some challenges that are addressed, documenting some limitations to the development of a low-cost datalogger for geotechnical instrumentation.

91 | Probabilistic 3D modeling of layered soil deposits: Application in seismic risk assessment

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Delineating the soil properties and the associated uncertainties are critical in geotechnical risk assessment, particularly in a regional urban area and for infrastructural development projects. Modeling the spatial distribution of the topsoil morphology (i.e. thickness) and properties (sand, clay, till, etc.) is the first step of a regional geotechnical risk analysis. This is particularly challenging in areas with highly variable soil properties and limited soil sampling. The assessment of soil properties and associated uncertainties need a proper estimation procedure to depict a realistic variability in a design model. We propose a probabilistic approach to model the soil types at a regional scale, and to produce a thickness map of topsoil and consequently of the bedrock topography, assisted by kriging interpolators. The highly clustered sampling pattern results in highly skewed data distribution with weak spatial stationarity; the estimation process included in the proposed approach alleviates this cause of uncertainty. The methods comprise Transformed-Gaussian kriging (via Box-Cox method), kriging with external drift, and Empirical Bayesian Kriging (EBK) in addition to Triangulated Irregular Network. The results show that the approach of locally varying mean and variance in EBK outcomes a more accurate method in regional studies involving extensive data. After indicator transformation of soil types, the spatial dependency, and the geological continuity of domains are appraised by indicator variograms. Then the soil types and associated probability of occurrence are delineated within the space between bedrock and the ground surface topography using sequential indicator simulations. The predicted soil types and their probabilities improve key geological points for probabilistic geotechnical risk evaluation.

188 | How differences between snow avalanches and other slope hazards affect mapping and mitigation

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Snow avalanches differ from other geohazards such as debris flows and landslides in ways that affect mapping and mitigation. In contrast to other geohazards: snow avalanches consist of a material that exists and fails near its melting point; have more frequent occurrences in a specified track or path; and the deposits melt within months.

Snow avalanches, especially those of small magnitude, occur frequently in same path. Where observations are available for a decade or more, this often results in better occurrence and runout records. Runouts can be linked to return periods, often for return periods up to 10 or 30 years. Runouts can then be extrapolated up to a return period of ~100 years. However, because snow avalanche deposits melt within months, subsurface sampling cannot detect avalanche runouts with a long return periods, e.g. 1000 years.

Snow avalanches start as a result of failure in a bonded granular material in which the bonds are usually within 10°C of the melting point. (This temperature threshold cannot be used to predict avalanche release since most snow in a temperate climate exists in this temperature range.) Periods of instability are often limited to hours or days after which an increase in bonding restores stability. Explosives can be effective triggers of unstable snow, thereby shortening periods of instability and allowing recently threatened terrain to be re-opened for human activity quickly.

As a result of these differences: snow avalanche mapping and land-use guidelines in most jurisdictions do not refer to return periods longer than 300 years; short term closures of human activity in snow avalanche runout zones are often practical; and human activity with moving elements at risk such as roads and ski operations are more often located in areas threatened by snow avalanches than by other geohazards.

189 | Exploration of X-ray CT as an analysis tool for a slow-moving landslide in clay shale

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Slope stability is a critical terrain characteristic for safe rail operation and a focus of geotechnical engineers globally. Recent studies indicate that the impacts of landslides within the Canadian Prairies cost Canada's two major rail service providers between $10 and $18 million dollars annually in direct damages and prevention funding. The Assiniboine River Valley is a critical transportation corridor located within the Canadian Prairies which links the east to the west. X-ray computer tomography (CT) is a powerful non-destructive analysis tool that has been in use since the early 1970's where internal structures of objects can be observed based primarily on variations in density and atomic composition. The original applications were primarily reserved for the medical industry to make qualitative observations such as dark areas in human lungs. More recently, it's gained increasing popularity in the geoscience community due to an increase in availability and affordability of scanners, particularly medical grade and desktop scanners capable of micro CT imaging. This coupled with the increase in computing power and post processing software development now allows quantitative analysis. This technology, however, still appears to be under utilized as a core analysis tool for slope stability. This paper aims to present available techniques, explore the reasons for under-utilization of this technology and assesses its overall validity as an analysis tool for slope stability purposes using an active slow-moving landslide in the Assiniboine River Valley that is affecting Canadian Nationals Mainline

SEPTEMBER 14, 2020 - MONDAY PM

SOIL MECHANICS AND FOUNDATIONS II

SESSION CHAIR: KHOKAN DEBNATH

358 | Effect of specimen size on normalized dissipated energy per unit volume

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The quantity of energy dissipated in a unit volume of soil during cyclic loading can be used as a measure of the soil's ability to withstand liquefaction. This energy is referred to as the normalized dissipated energy per unit volume (NDEPUV). The greater the NDEPUV required to induce liquefaction, the more seismic energy must be input into the soil during an earthquake for liquefaction to occur. The NDEPUV for a soil subjected to a seismic event or a laboratory test can be calculated from the stress-strain behavior of the soil.

In this study, the effect of specimen size on NDEPUV was examined using stress-controlled cyclic triaxial tests performed on specimens of uniform sand prepared to a relative density of 40%. Four specimens were tested at each of four volumes and the NDEPUV required to induce liquefaction was determined. The specimen volumes ranged from 87 to 1647 cubic centimeters.

It was found that the total amount of dissipated energy required to initiate liquefaction increased linearly with specimen volume, while the NDEPUV was found to be independent of the specimen volume. The fact that the NDEPUV is independent of specimen size means that no adjustments need be made to the laboratory testing results when using them to predict liquefaction in the field.

74 | The application and development of Continuous Flight Auger (CFA) piles in the Prairies

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Continuous flight auger (CFA) pile is a cast in-situ concrete pile constructed by using a fully flighted hollow stem auger. CFA piles were introduced in the UK in 1960s as a solution to the construction difficulties associated with conventional piling techniques especially the need for temporary casings or slurry. Over the years, CFAs has spread across the world making its way into many construction markets, including Canada.

A CFA pile is installed in one continuous operation consisting of advancing a continuous flight auger of pile design diameter to the target depth. As the auger is advanced, its flights are filled with soils which provides lateral support to the drilled hole. Concrete is placed by pumping through the hollow centre of the auger to its tip during auger retrieval which also support the surrounding soils by positive concrete pressure. Reinforcement is installed into the pile shaft filled with fluid concrete immediately after auger withdrawal.

Initially, CFA piles were limited in diameter and depth and were used to carry light to moderate loads as a structural support element and were constructed in soft to medium soils. Technological development has expanded its use and constructability enormously. Today, it is very common to install CFA piles of diameters ranging from 300mm to 1200mm and as deep as 50m or more as well as in a variety of subsurface conditions. Technological development has led to numerous enhancements in CFA rig instrumentation with Data Acquisition (DAQ) which provides key quality control parameters on a real-time basis related to geotechnical and structural aspects of the pile.

Continuous flight auger piles have been successfully introduced in the Prairies over 15 years and installed on numerous sites as technically viable and cost-effective deep foundations system. This paper presents an overview of CFA pile background, technical considerations and case histories.

87 | Centrifuge modeling of helical piles in stiff clay: installation torque and pore pressure response

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Helical piles have been extensively used in the civil engineering practice in North America in the past decades. However, the inter-helix-spacing-based failure mechanisms (FM) of these piles, currently recognized by engineers, are still obscure to engineers, as suggested by field load tests in the past decades. In addition, an affordable alternative to expensive field tests of piles is needed for soil-pile interaction investigation. Centrifuge modeling technique provides an effective approach for research in helical piles. Although centrifuge modeling has been well known, there is a lack of research of helical piles in clays on centrifuge. This research is intended to evaluate the influence of inter-helix spacing on the FM in stiff clay using the centrifuge at the University of Alberta. A single-helix and three double-helix model piles with the inter-helix spacing varying from 1.5 to 3.5 times of helix diameter were tested. The target undrained shear strength of soil was about 120 kPa. Helical piles were installed in-flight. The installation torques and axial load distributions were measured by multiple strain gauges installed along the pile shafts. These strain gauge readings provide solid evidence that supports the determination of the FM's during axial loading. Based on the test results, three FM's were confirmed for the three double-helix piles: two conventional FM's, i.e., "individual plate bearing" and "cylindrical shear", and one "transitional shear". The end bearing factors were calculated based on the load – displacement curves. Results of the present study confirmed that geotechnical centrifuge modeling is an effective research tool that can simulate the installation and loading procedures for helical piles.

82 | Effect of water and organic contents on the index and compressibility properties of organic soils

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Twelve percent of Canadian landforms are covered with Muskeg. Muskeg is the landform that represents the organic terrain. Organic soils are distinguished by their high initial water content. The other two main properties of organic soils are organic content and fiber content. These three significant parameters are affecting the index and compressibility properties of organic soils. The effect of water content on the index and the compressibility properties of organic soils has been studied by many authors. However, the influence of organic content on these properties was not well examined. In this study, the effects of both the organic and water contents on different index properties (void ratio, bulk density, specific gravity, and liquid limit) and the compression index have been studied based on many data points gathered from literature for different organic soils studied in various countries. Fiber content, texture, and origin are affecting the properties of organic soils as well, but the available data for these features are not enough to be used in this study. The new relations that correlate the different index and compressibility properties with the water and organic contents are presented in this study. The results revealed that void ratio, liquid limit, and compression index are better estimated based on the water content, whereas, the unit weight and the specific gravity showed a better correlation with the organic content.

94 | Shear Strength Deterioration of Saline Intact Loess during Freeze-Thaw Cycling

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Abstract: Salt accumulation in the surface of soil mass and the structural damage during freeze-thaw cycling is a key parameter that contributes to the collapse of loess slopes in northwestern China. A simple method that is referred to as the leaching method in the literature is used for preparing intact specimens containing soluble salt for determining the shear strength. This method facilitates in uniform distribution of sodium sulfate by infiltration technique with limited disturbance to the soil structure. Triaxial shear test results on salt infiltrated test specimens show that the cohesion of specimens decreases typically after one or two freeze-thaw cycles. Specimens with more water or sodium sulfate exhibit lower values of cohesion. The cohesion-based damage coefficients are calculated based on a specific damage path considering both freeze-thaw cycles and salt erosion. The damage coefficient of freeze-thaw decreases at higher salt contents while salt erosion accounts for a major part to the total damage at salt contents that is higher than 1.0%. The ratio of freeze-thaw damage coefficient to that by salt erosion decays especially in the initial five freeze-thaw cycles, beyond which it stabilizes, similar to the attenuation of cohesion.

MINING GEOTECHNICS AND HYDROGEOLOGY II

SESSION CHAIR: YETIMGETA MIHIRETU

120 | Hydrogeological simulation of an experimental waste rock pile with a flow control layer

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Mining operations produce large volumes of waste rocks to access economically valuable mineralized zones. These waste rocks are usually stored in surface piles, and their construction and reclamation are often a challenge. A flow control layer (FCL) made of crushed waste rocks or sand, installed at the surface of the pile, could control infiltration, thus improving geotechnical stability and limiting water contamination. An experimental pile was built and instrumented at the Tio mine (Rio Tinto Fer et Titane, Quebec) to validate the concept of FCL at large scale. Large infiltration tests were carried out and rainfall was monitored to evaluate the performance of the technique in situ. Measured outflow and water contents were also used to calibrate numerical simulations. However, data were noisy, difficult to calibrate, and sometimes incomplete. A new calibration approach based on the determination of the parameters describing the hydrogeological response to water infiltration (such as water content variation amplitude, arrival time and damping), was therefore proposed. An algorithm was developed to automate the numerical simulation calibration, using a black box optimization method to minimize the error between simulated and measured data. Hydrogeological properties of the waste rocks and flow control layer materials were calibrated and the models were then used to optimize the flow control layer design. The proposed method reduces the bias induced by a manual calibration and allows for a rapid and automatic multi-variable calibration. This paper presents the optimization process and discusses the reliability of the results obtained.

122 | Waste rock disposal and segregation: Validation and upscaling of discrete element simulations

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Large amounts of waste rocks are usually produced during mining operations and are often disposed of in large piles on the surface. Waste rock segregation can occur during deposition because of waste rock particle size distribution and deposition method. Segregation usually causes complex heterogenous structures within the piles, increasing the risk for instabilities and preferential flow paths. The optimization of waste rock disposal (e.g. bench height, deposition technique) could improve the geotechnical and hydrogeochemical stability of piles but are difficult to test at field scale. The discrete element program Particle Flow Code (PFC) was therefore used in this study to investigate the behavior of waste rock during disposal. Laboratory tests were used to determine repose angle of samples up to 38 mm diameters and to calibrate numerical simulations. Main input parameters included friction coefficient, rolling resistance coefficient and Young's modulus. Segregation tests were also conducted in the laboratory to validate and calibrate simulations. The effect of maximum particle size was specifically investigated. Once calibrated, large scale numerical simulations were carried out and field observations were used to validate the results. Relationships between calibrated parameters and particle sizes were used to extrapolate the simulations to field scale. Results show that friction coefficient and rolling resistance coefficient can significantly affect the macro-properties of waste rock and are highly related to the particle size. A relationship between these numerical parameters and waste rock particle size was proposed. Main experimental and numerical results will be presented and discussed in this paper.

135 | Comparative experimental study of consolidation properties of hard rock mine tailings

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Tailings consolidation properties are critical parameters to estimate storage capacity of tailings storage facilities (TSF) and plan mine waste integrated management. In this study, consolidation parameters of tailings from different mine sites were experimentally evaluated using various consolidation tests, including column tests, constant rate of strain (CRS) tests and conventional oedometer tests. Column tests with an internal diameter of 10 cm and a height of 45 cm were used to determine the compressibility of the saturated tailings under incremental loadings and to estimate compression index, Cc, coefficient of consolidation, Cv, and saturated hydraulic conductivity, ksat. Pore water pressure at three different elevations along the column and the displacement of the sample were continuously measured during the tests. Several CRS tests and conventional oedometer tests were also conducted to determine the compression behavior of the tailings. Results obtained from these different approaches were compared (also their reproducibility and precision). The effect of initial water content, sample size and loading steps was assessed. Experiment procedures and representative results will be compared, analysed and discussed in this paper. Recommendations will also be proposed regarding choice of experimental approach depending on the application and field conditions

163 | Influence of flocculant feed rate and solid content of fluid fine tailings on flocculation quality

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Fluid Fine Tailings (FFTs) produced during bitumen extraction from oil-sands ore is often treated with synthetic polymer to enhance binding of colloidal fine particles into larger flocs. This process is known as flocculation and aimed at improving the dewatering, settling, and strength behaviors of the FFTs. The flocculation quality, however, is influenced by the several in-put parameters into the process including the mineral composition of the FFTs, feed rate of polymer solution, shear rate and shear time during mixing. In this study, in-real time assessment of the effects of the in-put parameters on the flocculation quality was

conducted. The study employed FFTs with various solid contents ranged between 30 and 40% (w/w) treated with a synthetic polymer at feed rates ranged between 5 and 36 ml/min. The flocculation process was conducted in an Advanced Couette Rheometer and controlled via the Torque Force-based Technique (TFT). The preliminary results showed that the faster the feed rate the larger the exerted torque force. This coincided with better immediate dewatering and better longer-term dewatering and settling behaviors.

171 | Effect of climatic conditions on AMD generation in filtered tailings storage facilities

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Filtered tailings are often considered a promising alternative to conventional deposition methods and may contribute to improve the geotechnical stability of tailings storage facilities. However, the risk of generation of acid mine drainage (AMD) or contaminated neutral drainage (CND) can be increased by desaturation if the tailings are reactive. The purpose of this study was to evaluate the impact of the climatic and deposition conditions on reactive filtered tailings facilities on AMD/CND generation. Cell tests (an adaptation of kinetic tests) and laboratory column tests were carried out to determine the critical degree of saturation at which AMD generation starts. The influence of layer thickness and compaction on the hydrogeological behaviour of filtered tailings was also investigated to propose recommendations to optimize deposition and improve their geochemical stability. Mine tailings were received from a partner mining company and compacted in 4 columns (70 cm in height, 36 cm in diameter) in successive layers of 7.5 cm for final thicknesses of 15 cm, 30 cm, 45 cm and 60 cm. The void ratio was similar to the one expected in the field. Each column was instrumented with water content and suction probes installed every 15 cm. Columns were placed on scales to continuously monitor their mass to estimate the evolution of water balance with time. The top of the columns was left open and evaporation was controlled by a fan. An outlet was installed at the base of the columns to allow drainage and to sample leachate. Several wetting and draining cycles were applied to the columns.
Numerical hydrogeological and geochemical simulations completed the study. Models were calibrated and validated using the laboratory test results. Results indicate that the thickness of the tailings layers upon disposal and compaction, and the disposal rate can be optimized to minimize the risk for AMD generation.

377 | Essais de traceur en écoulement rectiligne uniforme

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De nouvelles équations ont été développées pour interpréter des essais de traceurs, en prenant en compte la déformation d'un champ de vitesse initialement rectiligne uniforme par la présence du puits d'injection, phénomène souvent négligé par les méthodes déjà existantes. Le potentiel complexe d'un aquifère plan dans lequel une injection est effectuée a été calculé par superposition du potentiel complexe d'un écoulement rectiligne uniforme déformé par un cercle de conductivité infinie, et du potentiel complexe d'un écoulement radial uniforme correspondant à une injection ponctuelle seule. Le potentiel complexe a ensuite été dérivé en champ de vitesse, puis une relation entre la position du front d'avancée du panache de traceur et le temps depuis le début de l'injection a pu être établie, en ne considérant que la partie advective du transport. Ces nouvelles équations ont été testées par simulations numériques avec un modèle permettant de faire des écoulements, du traçage de particules et de l'advection-dispersion. Les résultats ont montré que les nouvelles équations sont significativement plus précises que d'anciennes équations ne prenant pas en compte la déformation du champ de vitesse par le puits, notamment lorsque la vitesse d'injection est suffisamment faible devant la vitesse naturelle d'écoulement, pour un puits de diamètre assez grand et au voisinage du puits. Les nouvelles équations ont également mis en évidence un paramètre liant le rapport entre la vitesse d'injection et la vitesse naturelle d'écoulement, et le diamètre du puits. La valeur de ce paramètre permet de distinguer trois formes de panaches observées numériquement.

GEOENVIRONMENTAL ENGINEERING II & COLD REGIONS GEOTECHNOLOGY I

SESSION CHAIR: BAHAA MEKALLED

436 | Assessment of the long-term chemical stability of till-sludge mixtures for potential use as cover materials

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When mine wastes are potentially acid generating, various management options and reclamation strategies may be used to inhibit acid production. In most of the Canadian provinces with a humid climate, oxygen barriers such as cover with capillary barrier effect (CCBE) are considered as the most viable reclamation option. In the context of sustainable development, it is strongly recommended to use natural (silt and/or sand) or recycled (from mine activities such as non-reactive tailings and waste rocks) materials available around the mine sites for their reclamation; these materials can be used as moisture retention layer (MRL) in the CCBE.

Sludge generated by the active treatment of acid mine drainage by neutralization with an alkali product (such as lime) can also be valorized, particularly in soil-sludge mixtures (SSMs). However, the long-term chemical stability of such SSMs to acid rainwater still needs to be investigated beforehand.

The objective of this paper is to assess the long-term chemical stability of glacial till-sludge mixtures (TSMs) as MRL materials. For this purpose, sludge sampled from two mine sites (A and B) located in the Abitibi region were used. Each sludge was mixed with a till material to achieve six homogenized mixtures (TSMs) at different mass ratios. Indeed, the TSMs were prepared using different wet proportions of sludge (10, 20, and 30% by wet mass of till). The physical, chemical and mineralogical properties of all the materials were then characterized. The sludge A & B, till and TSMs were used in nine column and submitted to wetting (with rainwater) and drying cycles (in total 12). The leachates were collected after each cycle for physicochemical analyses. Then, the chemical stability of the mixtures is assessed from the results, which are also discussed in terms of lifetime assessment of the till-sludge mixtures based on the carbonate dissolution potential.

463 | Preliminary study of the effect of pre-hydration and freeze-thaw cycles on GCL/Geomembrane interface transmissivity

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CO-AUTHORS: Professor, Dr. Richard W.I. Brachman[1], Professor, Dr. R. Kerry Rowe[1]

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Recently, the use of geosynthetic clay liners (GCL) in composite liners has extended to harsh environments like Arctic and Antarctic regions as the main purpose of using GCLs in composite liner is to minimize the advective flow of contaminant if there is any hole in the geomembrane. The two parameters controlling the effectiveness of this composite system are the hydraulic conductivity, k, of the GCL and interface transmissivity, θ, of the GMB/GCL interface. This paper reports a new laboratory test setup to simulate the field condition for applying freeze-thaw cycle on the interfaces of the GCL-GMB and also reports the results of a preliminary study of a more conventional approach to subjecting freeze-thaw cycles by putting the specimens in and out of a fridge for 5 and 16 freeze-thaw cycles, and the effect of hydrating fluid and permeant solution on interface transmissivity for a range of stresses (10 kPa, 15 kPa, 20 kPa) typical for cover applications. The new test setup allowed the hydration from the subgrade as well as the application of freeze-thaw cycles which attracted water and formed ice lens at the GMB-GCL interface and in the GCL itself due to cryosuction. The preliminary results show that the formation of ice lenses after applying freeze/thaw cycles had significant effect on the interface transmissivity at 10 kPa. On the other hand, when the GCL was prehydrated, subjected to 5 and 16 cycles of freeze-thaw and permeated with RO water and pore fluid there was no significant effect of 5 freeze/thaw cycle but there was an effect for 16-cycles freeze-thaw cycles.

39 | Constitutive modeling uniaxial compressive behaviors of an artificial frozen sandy clay at different temperatures

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Frozen soil has a rheological behavior close to the soft rock category and the rate-dependent behavior of frozen clay soil is complex and affected by a number of factors (i.e. clay mineralogy, void ratio, stress history, pore fluid salinity, and available interlayer unfrozen water). Large number of experimental studies illustrated the rate-dependent mechanical behaviors of frozen soil. Nevertheless, there were limited studies on constitutive modeling of the time-dependent stress-strain behavior of frozen clay soils at different frozen temperatures. The objective of this study is to numerically investigate the time-dependent behavior of frozen clay soils at temperature ranges from -2oC to - 15oC. The Drucker-Prager model is adopted along with the Singh-Mitchell creep model to simulate time-dependent uniaxial compression behaviors of two frozen sandy clay soils. The constitutive modeling is validated against a series of experimental uniaxial compressive test results, where results show that a high deformation rate tends to generate brittle failure with post-peak softening behavior and a low deformation rate result in a diffuse failure associated with strain hardening.

50 | Monitoring the performance of wood blocking system for remediating timber piles in the Arctic

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The infrastructure in the Canadian Arctic has been influenced by climate change in the past decades. Timber piles, traditionally used as the primary pile type in the Arctic, are particularly vulnerable to climate change and other environmental impacts. The serviceability of timber piles is impaired by the seasonal temperature change that leads to subsidence and heave of the piles, and the pile shaft materials are being decayed by physical, chemical and biological actions. A technique is needed to refurbish damaged timber pile foundations in the Arctic. Among various remediation methods, the wood blocking system is often adopted in Northwest Territory owing to cost-effectiveness and

efficiency. The present paper shows a wood blocking system for the remediation of timber piles supporting a three-story apartment building in Inuvik, NWT. The natural topsoil was removed and refilled with compacted coarse gravels. The wood blockings were located on the new filling material. Four sides of the wood piece stack were arranged to enclose the damaged pile and two pairs of the wood wedge were adapted between the floor beam and the wood piece stack. Although this technique is common, monitoring of the performance has been rare. To validate the workability of the wood blocking system and provide early warning for excessive building movement, a field monitoring program consisting of 6 Linear Potentiometers was deployed in October 2019. The movement data has been collected and transferred with a cellular modem via the mobile network. The ground temperature and air temperatures can be obtained from existing monitoring programs in Inuvik. By combining the measurement of displacement and temperature of more than a 6-month period, the factors that dominate the performance of wood blockings and the building will be identified in the present paper.

78 | Laboratory investigation of mechanical behaviour of cement-treated Edmonton clay subjected to freeze/thaw cycles

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Cement has been widely used to modify soft and problematic soils in North Europe, Japan, and the USA for decades via a deep mixing method. Nonetheless, most of the published research was limited to clays with high moisture content, low cement content, ambient condition, and short-term stability. The present research investigates the engineering properties of Edmonton cliff clay treated with a high content of Portland cement served as a deep mixing foundation for heavy load and subjected to severe weather conditions in the long-term point of view. The cement content is higher than 20% and the cement-treated clay would suffer freeze-thaw cycles during its lifespan due to the seasonal temperature changes. This paper presents a series of laboratory tests of soilcrete specimens subjected to freeze-thaw cycles. The specimens of cement-treated clay (i.e., soilcrete) were cured for more than 28 days. A temperature control device was assembled to conduct the 3-D freezing and thawing on the cylindrical specimens at the target temperatures. Isotropically consolidated-undrained tests were used to measure the stress-strain relationship of soilcrete specimens under a confining pressure varying from 100 kPa to 3 MPa. The permeability of soilcrete specimens with various consolidation pressures, freezing temperatures, and curing days were determined. The microstructures of cement-treated clay failure planes and external surfaces were inspected using the scanning electron

microscope. The porosity of cylindrical samples and porosity distribution among them were determined by the computed tomography images. The results of these tests show the strain-softening behaviour of specimens. The cohesion of specimens remained very strong at the residual state. The new image analysis method predicted porosities that matched the estimated values.

146 | Axial performance of screw micropiles subjected to quick loads in frozen soils

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CO-AUTHORS: Dr. Jia Bin[2], Dr. Dave Sego[1], Dr. Lijun Deng[1]
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Screw micropiles have been recently introduced to North America as a new foundation type. The screw micropile is a steel pipe pile, threaded and tapered along its lower segment. It is installed using torque thus eliminating the need to excavate, or refill with concrete. Due to the unique characteristics, screw micropiles have major advantages such as lightweight, large capacities, reusability, and rapid installation, compared to conventional straight-shaft piles. Screw piles may present a better solution for arctic foundations that currently rely on drilled and backfilled with slurry or gravel straight steel piles, because conventional piles used in the Canadian Arctic require time-consuming freeze-back. However, currently there are no guidelines for use of screw micropiles in permafrost regions. The present research investigated the engineering behaviour of screw micropiles subjected to short-term loading conditions in frozen ground using the cold room facilities at the University of Alberta.

In the present research, segments of full-size screw micropiles with a shaft diameter of 89 mm were loaded under constant displacement rate in frozen soils to investigate the axial pile capacities and load-transfer mechanism. The effects of salinity, temperature, ice content and pile shaft shape upon the time-dependent deformation of model piles are being examined. Preliminary testing results showed that the pile capacities decreased with the increase in temperature and ice content. The torque when installing the piles was recorded and used to infer the torque required for field installation. The failure pattern of the piles was observed to be located along the edge of individual threads; this pattern suggests that the pile capacities may be greater than conventional smooth piles in the Arctic.

DAMS AND EMBANKMENTS II

SESSION CHAIR: ROB CHARRON

166 | Impact of seismic hazard on the ground response in Eastern North America

PRESENTING AUTHOR: Ms. Jessica Huo-kang[1]

CO-AUTHOR: Prof. Samuel Yniesta[1]

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In practice, dynamic nonlinear simulations are performed considering a uniform hazard spectrum, and picking ground motions to match said spectrum over a period range, for a pair of moment magnitude and hypocentral distance. The latter are being picked based on a deaggregation analysis, which represents the contribution to the hazard of different scenarios defined by a given magnitude and distance. The selection of the seismic scenario and the period range over which the ground motion are scaled, has a significant impact on the selection of ground motions, and the results of the simulations. In Eastern North America (ENA), ground motion selection is further complicated by the lack of well-recorded ground motions at magnitudes and distances of interest. In ENA, it is common to use two different scenarios which are (1) low distances and magnitudes, controlling the hazard at short period and (2) high magnitudes and distances, which control the hazard at long periods. This paper discusses the influence of the selection of the seismic hazard scenario and ground motions for the simulation of the behavior of an earth dike with a short fundamental period, under seismic loading. To do so, six different seismic scenarios are simulated, and dynamic non-linear simulations are conducted using ground motions chosen to be consistent with the different scenarios. The results obtained are compared in terms of response spectra, lateral and vertical displacements, to determine the impact of the selection of seismic scenarios on the performance of an earth dike.

235 | A finite element analysis of the Fundão Dam failure

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CO-AUTHORS: Dr. Reza Moghaddam[1], Dr. Siavash Farhangi[1]
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The Fundão tailing's dam failure of November 2015 in Brazil is one of the deadliest and most environmentally damaging tailings dam breaches in recent history. Roughly 32 million cubic meters (Mm3) of iron mine tailings were accidentally released in this catastrophic collapse, claiming the lives of nineteen villagers and causing major environmental concerns after polluting local water systems. As part of the forensic investigation that followed, a finite difference analysis (FDA) numerical simulation using the NorSand constitutive model in FLAC software was conducted by the panel to test the hypothesis of lateral extrusion triggered failure. Given the numerical convergence limitations reported, the purpose of the present study is to simulate the static liquefaction failure of the Fundão dam using a finite element analysis (FEA) approach in which NorSand constitutive model is adopted in Rocscience RS2 software.

A selected number of the panel's laboratory test results were simulated in a series of FEA to determine the validity of the numerical results and the strain-softening behaviour of the tailings. Both fully undrained and drained constant shear stress tests were simulated. In addition, a computer model of the failing section of the dam's left abutment was subsequently generated for numerical analyses following depositional details provided in the panel's report.

The results of the FEA are compared with the FDA shear stress-strain behaviour of the tailings reported by the panel on a laboratory scale and for the dam's failing section supporting the hypothesis of a slope failure triggered by a lateral extrusion mechanism. The implications associated with the FEA are further discussed in this paper.

276 | Estimating the probability of failure of a dike due to post-liquefaction settlements

PRESENTING AUTHOR: Ms. Laura Luna[1]
CO-AUTHORS: Dr. Gordon Fenton[1], Dr. Roberto Olivera[2]
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Some areas in the Lower Mainland of British Columbia rely on a system of dikes as the primary flood defense system. Past studies estimate that many dikes do not meet current provincial design standards, and that a major flood could result in losses as high as $22.8 billion. The economic and social consequences of flooding combined with the vulnerability of the flood protection infrastructure in the region highlight the need for a systematic approach for prioritizing upgrades and enhancing system resiliency. Reliability-based analyses have gained popularity as a means of assessing the performance of geotechnical systems, as they allow owners and policy makers to account for uncertainties in the design process and prioritize upgrades of the areas that pose higher risks.

This paper quantifies the influence of a dike's length on the overall system reliability for a case study site in British Columbia. First, the probability of failure of a single cross-section is determined via stochastic slope stability analyses using the Random Finite Element Method (RFEM). Then, the number of independent reaches within the length of the dike is estimated. This is achieved by simulating Gaussian random processes over the dike's length for various correlation lengths, and determining the equivalent number of independent random variables which lead to the same failure probability as the continuous case. Finally, the overall system reliability is calculated by treating the dike as a series system of these independent random variables. Recommendations regarding the length effect of dikes on system reliability are then made for design purposes.

280 | Performance-based seismic analysis of embankments with DSM grid-type foundation improvement

PRESENTING AUTHOR: Vicki Nguyen[1]
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The Deep Soil Mixing (DSM) technique is mainly applied for foundation support, retention systems, hydraulic cut-off walls, environmental remediation, and liquefaction mitigation. Generally, the latter application is done by forming a grid pattern of DSM walls with area replacement ratios typically ranging between 30% and 50% depending on the seismic excitation. The common design methodologies for DSM grids are based either on numerical modeling, simplified analytical procedures, case histories, or a combination of these approaches. The common ground between these design methods is mitigating liquefaction of the enclosed soil within the DSM grid cells. This paper proposes a rational design of the ground improvement based on a performance-based methodology, focused on the seismic performance of a structure supported by improved ground. Similar approaches have been considered by Yamashita et al. (2018), who analysed the performance of a DSM grid under seismic loading, and by Namikawa et al. (2007) who studied the performance of both the DSM grid and the untreated soils subjected to earthquake loading. Under a performance-based approach, the design of the DSM grid would be conducted such that the target performance is achieved, thus not necessarily imposing the no-liquefaction condition on the enclosed soil within the grid. This concept is explored for the case of embankments supported on square DSM grids. Three-dimensional, non-linear numerical analyses are conducted for a generic embankment founded on DSM-improved ground. The variability of the DSM strength on the embankment performance is evaluated for a given grid configuration. Conclusions and recommendations for this type of analysis are provided.

Yamashita et al. Seismic response analysis of piled raft with grid-form deep mixing walls under strong earthquakes with performance-based design concerns, Soils and Foundations, 58, 65-84.

Namikawa et al. Finite element analysis of lattice-shaped ground improvement by cement-mixing for liquefaction mitigation, Soils and Foundations, 47, 559-576.

282 | Dependence the precision of dam's seismic analysis on dynamic behavior models of its constituent materials

PRESENTING AUTHOR: Ms. Samaneh Amirpour Harehdasht[1]
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Although earthquakes occur in all regions of Canada, certain areas have a higher probability of experiencing damaging ground motions caused by earthquakes. In these areas, the rigorous assessment of the dynamic behaviour of earth dams and their performance improvements are crucial to eliminate the risk of their failures under seismic loadings. A comprehensive understanding of the site condition, local seismic characteristics and dynamic behaviors of constituent materials of a simulated dam is of outmost importance to perform reliable dynamic assessment. A wide variety of laboratory apparatus (i.e, cyclic simple shear cyclic triaxial and cyclic triaxial simple shear apparatus, has been developed over the past few decades to replicate the seismic loading condition on reconstituted or intact samples. However, these laboratory apparatus may have some shortcomings to accurately characterize the dynamic behaviour of tested materials. In that case, the developed laboratory-based dynamic characteristics of a tested material may vary from one apparatus to another, which subsequently affect the seismic analyses outcomes of a simulated dam. To simplify the numerical model in this study, the simulated earth dam is considered as homogeneous in terms of the compactness and density, with uniform distribution of shear wave velocity. In first step, dynamic behaviours of constituent materials of the selected dam were determined using different cyclic laboratory apparatus. Thereafter, developed dynamic behaviors of tested materials obtained from each apparatus were implemented into the numerical model in FLAC to evaluate the behavior of the simulated dam under seismic loadings compatible with the site. At the end, the numerical results obtained for each set of the dynamic models were compared together. According to these comparisons, selecting materials' suitable cyclic models is of outmost importance to perform reliable dynamic analysis. So that, an earth dam's seismic behavior is strongly influenced by the dynamic model of its constituent material.

315 | Design, Construction and Long-Term Performance of a Major Highway Embankment Reconstructed using Tire Derived Aggregate (TDA)

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In 2007, Tire Derived Aggregate (TDA) was used as lightweight fill to repair a very significant embankment failure of a four-lane divided highway leading to the Canada-U.S. border crossing in St. Stephen, New Brunswick. The highway embankment was under construction when it failed at a height of 12.3 m just short of the design height of 14 m. The cause of the failure was attributed to the rapid rate of construction and the intensity of the embankment loading on the low-strength foundation soils, consisting of 15 m of soft marine clay. The reconstruction strategy used TDA lightweight fill from 1.4 million scrap tires, and a system of prefabricated vertical drains installed through the marine clay over the original failure location. The reconstruction process was staged and controlled using geotechnical instrumentation and the observational approach. The reconstructed TDA embankment was successfully completed to the original design height in 2008 and continued to be monitored into 2009. From the perspective of TDA volume, this project was the largest TDA embankment in Canada and the second largest in North America at the time of construction. This TDA highway embankment has been open to the general public and in full operation since 2008.

In 2020, twelve years after construction, the owner and original designers have gone back to the site to assess the long-term performance of the TDA embankment and compare against the 2008/2009 performance data and the original design assumptions. This case study reviews the design, construction and long-term performance of the TDA highway embankment from the perspectives of the owner and the designers. The long-term performance results show that the TDA highway embankment and pavement continues to perform in general accordance with the original design assumptions.

LANDSLIDES AND GEOHAZARDS II

SESSION CHAIR: LEE MARTIN

197 | Slope stability evaluation and monitoring of a sandy bluff on the shoreline of Lake Erie

PRESENTING AUTHOR: Mr. Hugh Gillen[1]

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In 2019, a geotechnical investigation and slope stability evaluation were conducted for an existing wind turbine site in the Long Point region of Southern Ontario, on the northern shoreline of Lake Erie. The investigation was followed by real-time geotechnical monitoring with an automated alarm system. The site features a 30-m high sandy bluff and evidence of past shoreline retrogression is apparent in satellite imagery and field observations. Geotechnical instrumentation was installed to provide on-going monitoring of the slope and to provide early warning for ground movements that could potentially affect the nearby wind turbine.

Two geotechnical borings were advanced between the crest of the bluff and the existing wind turbine, located about 60 m north of the crest at the time of the investigation. Sandy soils were encountered at surface to about 13 m depth, underlain by a siltier layer extending to borehole termination at 35 m depth. Thin (0.3 to 0.7 m), intermittent clay seams (CL) encountered within the silty layer indicate the presence of potentially weaker seams in the bluff. Groundwater was encountered at 17 m depth, about 6 m above lake level. A pair of nested vibrating wire piezometers was installed in one borehole using the fully-grouted method, and an in-place inclinometer string was installed in the other borehole.

The existing slope was modelled based on the observed site conditions and calibrated to reflect a pseudo-static state of stability at the bluff. Changes in groundwater and lake water levels, seepage at the bluff face, rainfall events and soil suction are all expected to influence the stability of the existing slope. Monitoring data obtained from the installed instrumentation combined with periodic field evaluations is anticipated to allow for further model refinement and possibly aid in the identification of precursory environmental factors leading to further erosion and instability.

213 | The importance of seismic nonlinear ground analysis in Eastern Canada

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In the current state of practice in Eastern Canada, the potential of ground motion amplification is typically assessed using the site amplification factors recommended by the National Building Code of 2015 (NBC 2015) or by performing equivalent linear ground response analysis, which considers an unrealistic assumption of constant dynamic properties. This paper compares site amplification factors from the National Building Code of Canada and computed using nonlinear and equivalent linear 1D ground response analysis. For a wide variety of soil sites in Quebec, dynamic simulations were conducted using the software DeepSoil to compute site specific soil amplification factors. The results suggest that the NBC 2015 may not be always conservative, and that the nonlinear analyses predict soil amplification factors often higher than the code. Notably, the disparity between the NBC 2015 predictions and those from the nonlinear analyses is greatest close to the site natural period or at periods slightly longer than the natural period, because of period lengthening effects due to strong nonlinearity of the soil behavior. At said periods, the amplification factors from nonlinear analyses present a sharp peak not included in the code.

231 | Behavior of a branched buried MDPE gas distribution pipe under axial ground movement

PRESENTING AUTHOR: Mr. Sudipta Chakraborty[1]
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Medium density polyethylene pipes (MDPE) are widely used for gas distribution systems in Canada and worldwide. These pipes are often exposed to relative ground movements resulting from landslides and earthquake. The effects of the relative ground movement on the pipes are influenced by the presence of lateral branches and the Tee-joint connecting the branch. Only a limited study is currently available in the literature on studying the behavior of branched pipe subjected to ground movements. This paper presents an experimental investigation of a branched MDPE pipe subjected to axial ground movement. A test with a 60.3 mm diameter gas distribution pipe is conducted using the laboratory facility at Memorial University of Newfoundland. Pipe wall strains and soil pressures

around the pipe are measured to capture the mechanism of soil-pipe interaction. Test results reveal that the pullout force and pipe wall strains are significantly influenced by the Tee-joint. The elongation of the flexible MDPE pipe also contributes to the pipe deformations and wall strains.

266 | Hazard assessment of debris flows initiated by breach of small earth dams in British Columbia

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There are many small earth dams perched high above the floor of the Okanagan Valley in British Columbia. Some of these dams pose a significant potential risk for destructive debris flow generation if they become breached. A relatively small outburst can trigger a much larger volume debris flow downstream of the dam. The failure of the Testalinden dam in the southern Okanagan region in June 2010 clearly demonstrated the destructive power of a debris flow triggered by the water released by a breach through a poorly maintained dam. Homes were destroyed and the property was damaged. This paper presents a methodology for preliminary assessment of potential debris flow initiation hazards caused by the breaching of small earth dams using digital elevation models, available maps, and limited monitoring records of dams. Further research can assist dam safety officers in better ranking the consequences of dam failure in sensitive environments. Empirical equations are used to predict the peak outflow if a breach occurs in a small earth dam. The creek gradient and the estimated height of water or outflow per unit width in the creek channel resulting from the outflow are used in debris flow initiation criteria to delineate possible locations along a creek where a debris flow may initiate. If debris flow initiation were possible, this would trigger the need for the more detailed assessment of dam failure consequences and will likely result in a higher dam failure consequence classification compared to consideration of flooding only.

306 | Results of several Eastern Canada site response analyses

PRESENTING AUTHOR: Mr. Michael Snow[1]
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Seismic response analyses at sites in eastern Canada is becoming more common than in the past with the typical approach being to use an equivalent linear site response model such as SHAKE. The authors conducted such site response analyses for several building and bridge projects in eastern Canada over the past years under a variety of design earthquake hazard levels, ground conditions and design objectives. The paper discusses the details of several case histories, the approaches used and observations on the outcomes achieved.

Of interest will be the observation that in these cases the seismic ground response is lower than would have been achieved using code-specified spectral values or cyclic-stress ratios obtained using simpler methods of analyses. The case histories also present an interesting array of input ground motion (both synthetic and recorded), methods of scaling (both linear and spectra) and design objectives (both liquefaction assessment and site-specific design spectra). Ground conditions vary from deep Champlain Sea clay to thick till, and intermediate ground conditions.
The results obtained represent valuable examples of the value of these types of analyses when properly done and would suggest that their more routine usage is warranted from a cost-benefit perspective. In some cases, the amplification of short period ground motions is much higher than expected for some earthquake records and ground conditions.

183 | Étude d'une coulée argileuse avec une approche à rebours et le recensement des glissements historiques

PRESENTING AUTHOR: Mr. François Saint-pierre[1]
CO-AUTHOR: Mr. André Rancourt[1]
[1]*Cima+, Montreal, Canada*

The Champlain River and its tributaries are located in the Champlain Sea formation and is the scene of a retrogressive clay slump and lateral spreading. In April 2017, a typical retrogressive clay landslide occurred in the territory Saint-Maurice, Municipality of Quebec. Aerial shots were undertaken a few days subsequently and have captured the scene of the landslide. Further data was collected with a LIDAR survey a few months after the slump. Finally, an extensive geotechnical borehole investigation was conducted in 2017 and 2018. Rapid data acquisition, a few days after the event was critical to this study. The

aerial photography indicated that there were two levels of landslides associated with successive slide circles and the steps of theses levels disappeared the next year due to surface erosion. These levels allow us to validate our reverse landslide modelling.

Since the occurrence of the clay slump, it is possible that further slumps have occurred upstream and downstream and the risk of new landslides has increased. The conventional approach consisting of modelling several consecutive breaking circles using parameters from the reverse study may be hazardous because it is difficult to anticipate the quantity of levels that may occur according to the height of a bank.

LIDAR mapping technology allows us to observe landslides that have occurred in the past. With software like ETL (Extract, Transform, Load) and using an algorithm of LIDAR data classification we are able to eliminate ground vegetation and show the scars of older landslides. Our case study demonstrates that the longest historical slump spread observed on the bank of a tributary of the Champlain river is 57 m.

SEPTEMBER 15, 2020 - TUESDAY AM

SOIL MECHANICS AND FOUNDATIONS III

SESSION CHAIR: KSHAMA ROY

107 | Deriving stress/strain relationships from the contraction phase of pressuremeter tests in sands.

PRESENTING AUTHOR: Mr Robert Whittle[1]
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Inserting a pressuremeter or dilatometer into sand inevitably results in significant alteration of the insitu state. However it has always been possible to work around this limitation by reversing the direction of loading having established a well-developed plastic condition. This stress reversal approach is already used to obtain high quality elastic parameters from unload/reload cycles. The same argument applies to the final cavity unloading. This makes it possible to derive sensible strength parameters from data where the influence of the insertion history has been minimised if not entirely erased.

The unloading behaviour of a sand is complex and is not amenable to approaches that impose a stress/strain response (for example Withers et al 1989). The problem invites numerical methods. Manassero (1989) developed a relatively simple method appropriate for high quality cavity expansion tests. This solution can also be applied to cavity contraction data. The great advantage offered by the Manassero solution over other potentially more exact analyses such as Yu & Houlsby (1995) is the minimal number of assumptions. Very little additional information from third-party tests is required before the pressuremeter tests can be interpreted.

Results from the unloading of self-bored, pre-bored and pushed pressuremeter tests in various dilatant materials are presented in the form of stress/strain curves with peak shear stress and friction angle identified. It is apparent that the shear strain is different for these two events, the peak shear stress occurring when the mobilised friction has reduced to the constant volume condition. Differences between the three pressuremeter insertion methods for the purposes of deriving strength are small, with differences attributable to more extensive particle crushing with pushed methods.

140 | Effect of loads, structural stiffness and soil variability on reliability and performance of pile foundation

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The vertical axial performance of pile foundations is generally expressed in terms of settlements caused by unfactored load effects (work loads). In the settlement calculation, piles and piles groups are considered as isolated structural elements, neglecting their connection with other structural elements and the effect of the structural stiffness. This paper presents the results of a reliability analysis that considers the piles as part of a reinforced-concrete five-bay two-storey square building. The results are expressed in terms of the probability that differential settlements between piles supporting adjacent columns exceed the limiting values given in the National Building Code of Canada. As the relative stiffness increases, the probability that differential settlements exceed the code limiting value largely decrease, indicating that the settlement estimates common in current practice can severely overestimate the actual values experienced by the superstructures.

160 | Effect of Soil-Water Characteristic on the Stability of Unsupported Vertical Cuts

PRESENTING AUTHOR: Ms. Mahsa Shafaei Bajestani[1]
CO-AUTHORS: Dr. Won Taek Oh[1], Dr. Othman Nasir[1]
[1]*University of New Brunswick, Fredericton, Canada*

A variety of geotechnical projects are initiated with unsupported vertical cuts in vadose zone. In this case, it is crucial to consider the contribution of soil suction in analyzing the stability of unsupported vertical cuts. Soil-Water Characteristic Curve (SWCC) is a main tool that can be used to estimate the variation of shear strength of soil with respect to soil suction. SWCC can be obtained using different fitting models based on experimental data. In this study, a series of numerical analyses are carried out to investigate the influence of SWCCs obtained using different SWCC fit models (i.e. Brooks & Corey, van Genuchten, and Fredlund & Xing models) on the safe height of unsupported vertical cuts in sandy soil. The analysis results showed that the safe heights estimated with the van Genuchten model are most reasonable for various levels of ground water tables.

390 | Matric suction and degree of saturation effects on shear strength of a sand and gravel

PRESENTING AUTHOR: **Prof. Paul Chiasson[1]**
CO-AUTHORS: Mr. Horace Tamegnon, Mr. Philemon Youfoulsou[2], Mr. Ousama Aabibou[3]
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Beaucoup d'ouvrages de génie civil sont construits en zone non saturée. Contrairement aux sols saturés, la maîtrise de la résistance au cisaillement des sols non saturés reste encore un grand défi surtout au niveau des sols granulaires. Des essais triaxiaux consolidés drainés (CD) et à teneur en eau constante (CW) ont été réalisés afin d'examiner l'influence de la succion matricielle et du degré de saturation sur un sable et gravier concassé, compacté à sa teneur en eau optimale. Les résultats expérimentaux montrent que, pour la même succion de rupture, la résistance au cisaillement des essais non saturés CW s'avère supérieure à celle des essais non saturés CD. D'autres résultats tirés d'essais CD sur des éprouvettes à des degrés de saturation préparés par sorption présentent pour la même succion de rupture une résistance supérieure à celle mesurée sur des éprouvettes préparées par désorption. La résistance au cisaillement (ainsi que d'autres propriétés mécaniques) ne dépendrait donc pas seulement de la contrainte nette et de la succion à la rupture, mais aussi de l'historique du cheminement en teneur en eau du matériau. L'hystérésis observée chez la courbe de rétention d'eau du sable et gravier concassé se répercuterait donc sur sa résistance au cisaillement.

This paper is written in French but the presentation will be in English

326 | Driven piles installed in soft soils subjected to vertical and lateral soil movement

PRESENTING AUTHOR: Jakub Kania[1,2]
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This paper presents the behavior of 406 mm diameter, 12 m long, instrumented, driven steel piles at a construction site in Esbjerg, Denmark. One pile was uncoated and one was bitumen coated. The piles were driven through a 1.5 m thick layer of reclaimed sand underlain by original soil consisted of a 2.0 m thick layer of sand, a 3.6 m thick layer of soft soil above a thick sand layer. The instrumentation comprised distributed fiber optic cables. Due to its spatial resolution (2.6 mm), very detailed strain profiles were obtained. The distribution of strain in the piles was affected by, first, the pile installation, building up a residual force in the piles and, then, additional force, drag force due to negative skin friction developing after placing a 3 m thick fill around the piles. Due to construction activities an unplanned one-sided loading occurred inducing considerable bending and lateral force in the test piles.

156 | Estimation of stability of an unsupported deep vertical cut in clay

PRESENTING AUTHOR: Mr. Geeshpati Yanamandra[1]
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Finite element analysis was performed to simulate the excavation of an unsupported deep vertical cut (depth = 9.75 m) in clay at Welland, Ontario (Kwan 1971). For this, SIGMA/W and SLOPE/W (GeoStudio 2019 R2) were used to simulate staged excavation and to estimate its stability, respectively. To maintain the consistency of obtained results with field conditions, the simulated excavation followed the same timeline as field excavation. There was good agreement between the measured post excavation pore-water pressure contours obtained from installed field instruments with those from the numerical modelling. The numerical analysis results also showed that the failure in the cut was attributed to a tension crack, which is consistent with field observations.

MINING GEOTECHNICS AND HYDROGEOLOGY III

SESSION CHAIR: CATHY WILLIAMSON

212 | Blasted damaged zone influence on water and solute exchanges between backfilled open-pit and the environment

PRESENTING AUTHOR: Moise Rousseau[1,2]

CO-AUTHOR: Dr. Thomas Pabst[1,2]

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In-pit disposal of mine wastes is a promising alternative management approach to waste rock piles and tailings impoundments. Yet, in-pit disposed wastes are in direct contact with the surrounding rock, and dissolved oxygen or ferric ions from regional groundwater could flow in the waste and contribute to acid mine drainage (AMD) generation. Contaminants contained in the waste pore water could also be dispersed in the environment. Blasting operations results in the creation of new fractures near the pit wall in a zone called the blasted damaged zone (BDZ). These new fractures could provide preferential path around the pit and could affect groundwater and solute fluxes between the backfilled open-pit and the environment. The present study aims to investigate the influence of the BDZ on water and solute exchanges between the pit and the surrounding rock mass. A 3D numerical model was built to simulate a pit backfilled with tailings using PFLOTRAN flow and transport finite volume code on a polyhedral Voronoi mesh. The BDZ was modeled using the equivalent porous media approach. A parametric study was also carried out on the BDZ properties to assess their influence on the water balance. The effect of the BDZ was first assessed by comparing the water fluxes between the open-pit and the environment. Next, the influence of the BDZ thickness, the equivalent permeability at the pit wall and the fracture orientation (BDZ permeability anisotropy) on water fluxes were evaluated. Finally, a solute transport simulation was carried out to analyze the BDZ effect on the solute balance. Main results will be presented and discussed in this paper.

222 | Applicability of the fully grouted piezometer installation method for transient seepage conditions

PRESENTING AUTHOR: Scott Martens[1]
CO-AUTHORS: Sam Li[1], Raisul Hoda[1], Sajid Iqbal[1], Pavol Oblozinsky[1]
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The use of the fully grouted method to install and backfill vibrating wire piezometers has been growing in popularity. Studies have been published with modelling results from finite element seepage analyses under steady state conditions, showing the range of grout/soil permeability ratios under which the fully grouted installation method is considered reliable. Most of the published studies have not examined transient seepage conditions. There is limited published literature with comparisons between the results of field installations using the fully grouted method and the traditional sand pack with bentonite chip seal method. Since much of the published data do not consider situations where transient porewater pressures resulting from application of external stresses (i.e. embankment construction) are induced in a low permeability layer, there remains a large degree of uncertainty about the range of soil and transient seepage conditions under which the fully grouted installation method will provide reliable results.
This paper reports the results of transient finite element analyses of fully grouted installations in low permeability clay layers with adjacent higher permeability soil layers, and provides additional insight into the applicability and limitations of the fully grouted method. The results of several parallel installations using the fully grouted method and the traditional sand pack with bentonite chip seal method are also reported to provide empirical reference cases.

257 | Numerical 3D model supporting decision of waterproofing or installing drainage system attenuating structures damages risks

PRESENTING AUTHOR: Ing., Ph.D Moussa Kfoury[1]
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On a complex site where overburden soil stratigraphy is very heterogenous and sensitive to settlement, several structures are planned to be built such as an underground station deep around 40 meters below surface level and associated transit structures allowing passengers to connect with the Express Network Metropolitan (REM) of Montreal, a major project for the collective transport of light rail trains in Montreal and surrounding area. Additional shallower structures such as multi-level car parks and buses facilities are

scheduled in the development plan. Authors have assessed the potential damages and risks related to drawdown of groundwater level under pumping operations. This assessment was made for the construction phases (transient state) and for the subsequent operation phase (steady state). In order to support the decision on waterproofing or installing a permanent drainage system for the numerous projected structures avoiding a potential damage risk on existing installations, the team has built a 3D numerical model by collecting data from all the hydrogeological and geotechnical studies carried out on the site since 1959.
This paper presents the different stages of building the numerical 3D model, discuss main parameters that impact the predictive hydrogeological results, describe the evolution of the groundwater flow rate for a construction sequence, compare drawdown of the underground water level following a waterproofing or a drainage decision and expresses monitoring approaches to act mitigating the risk of potential damage.

345 | Aging and large-scale consolidation of centrifuge cake oil sands tailings.

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Dewatering fluid fine tailings (FFT) in centrifuges has recorded large scale success, making it one of the technologies available to operators for tailings processing and improving deposits for reclamation in the oil sands industry. Further densification of tailings in these deposits occur through the natural process of consolidation which will take years to decades; this time factor increases the possibility of time-dependent behavior such as creep and aging effect having an influence on consolidation. This paper reports on experiments carried out to investigate aging effect and consolidation of centrifuge oil sands tailings on a larger scale. These experiments include column dewatering tests, fall cone tests, oedometer tests and modified consolidation test using a steel box with dimensions 0.49m x 0.35m x 0.72m. In order to better assess the centrifuge oil sands tailings dewatering behavior in the steel box, cores were extracted from the steel box; pore water pressure and volumetric water content measurements were taken with sensors inserted at different elevations. Preliminary results will be discussed.

510 | Mine dewatering wells: reducing economic risk and increasing the probability of success through diamond drilling.

PRESENTING AUTHOR: Mr. Patrick Moran[1]
CO-AUTHOR: Mr. Joe Ross[1]
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The Iron Ore Company of Canada Carol Lake Mine is located in western Labrador and has been operating since 1962. IOC has three shareholders, Rio Tinto, Mitsubishi Corporation, and Labrador Iron Ore Royalty Company and produces iron concentrate and pellets for sale on the international market.

Geologically, the mine is located in the Sokoman Iron Formation within the Labrador Trough. The orebody has been strongly metamorphosed, deformed, and subjected to variable supergene (limonitic) alteration resulting in a complex hydrogeologic setting. The hydrostratigraphy of the orebody is broadly divided into two hydrogeologic domains. Domain 1 is the largest and consists of un-weathered iron formation and associated rocks. Rock within this domain is relatively non-porous / non-permeable and the hydrogeology is dominated by complex fracture networks. Domain 2 consists of zones of weathered limonitic rock propagated to depth along faults. Rock within this domain is generally porous / permeable, is internally well connected, with high hydraulic conductivity values observed throughout.

Identifying productive dewatering wells, even with a broad understanding of the hydrostratigraphy, is challenging at IOC due to the complex geology. The stakes are high, as the drilling and construction of deep dewatering wells is both a time consuming and expensive endeavor. A dry well represents millions of dollars of lost investment and even higher additional future costs due to the absence of effective advanced dewatering infrastructure. For the cost of a diamond drill hole, which regardless of the intended outcome has inherent geological and geotechnical value, the risk to the business can be mitigated. This paper will examine how diamond drilling has been utilized to increase confidence in well targets and improve the success rate of drilling campaigns. Discussion is focused on the conceptualization and performance of currently operating wells at IOC and their positive impact on the operation.

72 | Prototype column test to estimate hydraulic conductivity of slurry tailings

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Large strain consolidation behaviour of mineral slurries regulates the performance of tailings management and reclamation plans. Hydraulic conductivity-void ratio relationship especially influences this behaviour, dominating the long-term performance of fine-grained slurries with higher initial water contents. However, determination of this function can be very challenging and time-consuming, considering the long durations of consolidations test and large variation in hydraulic conductivity with void ratio. A laboratory test column study was conducted to evaluate the consolidation behaviour of diluted Leda clay and thickened gold tailings . The test column was instrumented with tensiometers and Enviroscan (capacitance-based) sensors to determine the pore water pressures and volumetric water changes respectively. Also, a robotic arm was connected the sensors for more detailed profiling. The collected data is then utilized to estimate hydraulic conductivity of the tested materials using Instantaneous Profiling Method (IPM). Finally, the measured data and the predicted behaviour of the material is compared using a large strain consolidation software, UNSATCON, to tease out non-consolidation behaviours such as creep.

SOFT AND SENSITIVE CLAYS I

SESSION CHAIR: GEORGINA GRIFFIN

62 | Sustained capacity of friction piles in clay treated by electro-osmosis: Observations over five decades

PRESENTING AUTHOR: Mr. Keli Shi[1]

CO-AUTHORS: Dr. P.K. Chatterji[1], Mr. Murray Anderson[1], Mr. Ken Ahmad[2], Mr. Tae Kim[3]

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The 178 m long, three-span Pic River Bridge near Marathon, Ontario is founded on relatively short friction piles driven into an 18 m deep soft to firm clay layer underlain by over 70 m of stratified silt and silty fine sand deposits under a maximum 6 m of artesian head. Due to the artesian pressure at depth, the capacity of long friction piles driven into the silt and sand deposits was determined by load testing to be significantly less than that of short friction piles installed within the clay deposit. The original foundation design in 1959 was therefore based on 16.5 m long friction piles installed within the clay deposit. The clay properties were improved by applying electro-osmotic treatment at the two piers and east abutment. The electro-osmotic treatment doubled the ultimate pile capacity from 300 to 600 kN per pile. Subsequent load tests on selected piles conducted from 1961 to 1992 indicated that the increased pile capacities were being sustained.

Rehabilitation of the bridge involving a superstructure replacement was carried out in 2015 and 2016 along with settlement monitoring of the existing foundations. Static pile load tests were conducted on selected piles in 2013 to confirm that the pile capacities have not diminished with time. The results indicate that the pile capacity improvements achieved by the electro-osmotic treatment of the clay have been sustained over a 54-year period. Static cone penetration tests and shear vane tests were also undertaken near the test piles to assess the improvement of clay properties due to the electro-osmotic treatment. Pre-rehabilitation settlement analyses predicted negligible immediate settlement and 10 to 20 mm of long-term settlement in 25 years. The monitoring data collected between 2015 and 2017 indicated generally less than 5 mm of settlement at abutments and piers.

237 | Calibration of the Creep-SCLAY1S constitutive model parameters for champlain sea clay in Quebec

PRESENTING AUTHOR: Dale Brunton[1]
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The effects soil debonding and destructuration cannot be easily understood using conventional design methods. However, the impact of soil destructuring can be catastrophic for projects in certain soils.

The PLAXIS Creep-SCLAY1S constitutive model was developed to simulate the anisotropic, rate-dependent behavior of soft structured soils including creep. Champlain Sea clay is well known for its cemented structure and rapid transformations from a relatively brittle material to a liquid mass when disturbed. The structured behavior of the Champlain Sea clay makes it extremely sensitive to strains that may destroy the bonds between the soil particles. The Creep-SCLAY1S model is considered as an appropriate constitutive model for the analysis of Champlain Sea clay due to its ability to simulate the bonding and destructuration process of natural clays.

A calibration of the Creep-SCLAY1S model with site measured data from a site in Quebec was undertaken. Design parameters required for the Creep-SCLAY1S models were calibrated using the PLAXIS “Soil Test” module against laboratory tests and field testing measurements. The available laboratory tests were comprised of isotropically consolidated, undrained triaxial compression (CIUC), and 1-D incrementally loaded oedometer tests. Field testing included cone penetration testing (CPT) and peak and residual field vane measurements.

The PLAXIS “Soil Test” module outputs (Deviator vs. Axial Strain, PWP vs. Axial Strain) were plotted against available testing data and found to be comparable. Indicating that the PLAXIS Creep-SCLAY1S model was well calibrated to mimic the behavior of Champlain Sea clay at the site. This paper summarizes the range of calibrated PLAXIS input parameters for the Creep-SCLAY1S for Champlain Sea for a site in Quebec.

246 | Simulation of the Cyclic Response of Anisotropic Clay through Bounding Surface Viscoplasticity

PRESENTING AUTHOR: Mr Mohammad Zarrabi[1]
CO-AUTHORS: Dr Zhenhao Shi[2], Prof Samuel Yniesta[1], Prof. Giuseppe Buscarnera[3]
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Several constitutive models for sands for cyclic applications have recently been developed, and far less for clays. The behavior of clays is known to be strongly rate-dependent, and although, various viscoplastic models for monotonic loading for clays have been published, the use of rate-dependent models to model the behavior of clay under cyclic loading has remained sparse. In this study, a new bounding surface viscoplastic clay model for cyclic loading is introduced.

The model is anchoring the framework of the bounding surface plasticity and Perzyna's theory of viscoplasticity allowing it to consider underlying clay features such as anisotropy and consolidation state. In addition, the model captures more advanced clay features such as cyclic softening and rate effects. The performance of the model is validated against different monotonic and cyclic soil response. The model is shown to predict fairly well the behavior of clays under both rate-dependent and rate-independent monotonic and cyclic loading. The model recovers its rate-independent behavior under slow loading conditions. In addition, under higher loading rates, the model yields a higher soil stiffness response consistent with laboratory observations from previous researchers.

250 | Settlement behaviour of embankment placed over wash pond sediment

PRESENTING AUTHOR: Mr. Kevin Lee[1]
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This paper documents the settlement behavior of an 18 m high embankment fill that was constructed over two gravel quarry wash ponds in support of a new 2.6 km roadway alignment located in Cochrane, Alberta.
Due to the time and cost constraints of the project, removal of the wash pond sediments (silt and sand accumulated from gravel washing) was not a viable option. Backfilling over the pond sediment was considered as an alternate approach to meet the project objectives.

The proposed road embankment crossed over two wash ponds which were separated by a gravel berm access road. The wash ponds were approximately 6 m to 8 m below the surrounding ground surface and the pond base consisted of wet, fully saturated, soft, sandy silt material varying between 2 m and 5 m thick overlying native clay till soils.

The development plan consisted of installing a drainage blanket to dissipate and drain the porewater within the pond sediment off site and allow the consolidation of the pond sediment. The drainage blanket was installed over both ponds and comprised of a 1.0 m thick gravel layer wrapped with geotextile reinforcement/fabric. Embankment fill was subsequently placed over the drainage blanket.

Given the size of the project and amount of fill required, various types of backfill were utilized including reclaimed cobbles and boulders, drainage gravel, remolded clay till, and mixed sandy silt soils.

A series of vibrating wire piezometers, vibrating wire settlement gauges, and settlement monuments were installed to track porewater pressure and settlement throughout the embankment (pond sediment, various fill types, and various elevations). Monitoring of the settlement behavior was conducted during and after construction.

The results of the settlement monitoring and recorded field observations were compacted to the expected settlement of the embankment (included each backfill material type and pond sediment).

308 | Assessment of settlement in clayey soils under a new highway using 3D FEM

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Assessment of consolidation settlement in clayey soils under a new highway requires scrutiny in terms of embankment heights and fluctuating clayey strata. Complications further arise when a project consists of adding new roads to an existing highway where embankments cover significant parts of the studied area and overconsolidation margins vary considerably under different sections of the new highway.

Traditional methods for evaluating settlement often evoke the examination of the critical section, which is selected by considering several factors, such as the heights of new

embankments, the depths and elevations of subsoil layers, the hydrostatic conditions and the characteristics of compressible soils. This method is effective in evaluating settlements in the most vulnerable areas for which the geotechnical engineer provides the appropriate design solutions accordingly.

However, in vast areas covered with embankments and fluctuating clayey strata, the critical section may not yield the most efficient solutions. When such circumstances arise, geotechnical solutions established solely on the critical section(s) could lead to overt conservative design methods, which usually translates to higher costs and extended time periods during the execution of the project that could otherwise be avoided. Other solutions such as 3D modeling that study the entire area in its integrity could thus prove to be more efficient.

This seminar will examine settlement in clayey soils under a new highway using 3D FEM Modified Cam Clay theory. The construction of a new highway alongside autoroute 50 in Gatineau Quebec will be used as a case study and developed through GTS NX 3D settlement. The results obtained will be discussed in a thorough manner and compared with critical sections that were evaluated for the same area using 2D and 1D consolidation settlement theories. A technical comparative discussion regarding the design procedures and cost-effective solutions using the different techniques will then follow.

24 | Data collection and information management across champlain sea clay deposits of Eastern

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Several investigations were undertaken both by practitioners and academicians during the past five decades to understand and interpret the glaciomarine clay deposits of eastern Canada, The focus of these investigations and research studies was mainly directed to study the behavior of Champlain Sea Clay, which is widely deposited in eastern Ontario and Western Quebec. The body of knowledge on the Champlain Sea Clay is derived mainly from laboratory tests or in-situ field tests. Performing such tests routinely for the design of conventional projects such as the municipal or residential structures is cost-prohibitive. There is a vast amount of data that is collected on these clay deposits and summarized in several reports about various properties of clay, which include, Atterberg limits, particle size analysis, water content and unconfined compression tests. There is also a substantial

amount of data available on more intricate tests that is useful to interpret the hydraulic and mechanical behavior of these soils; these include hydraulic conductivity, consolidation tests and the shear strength properties. The wealth of this data is compiled and synthesized into a searchable database. This article provides a summary of the methodology of compiling the available information into an accessible database. In addition, it also provides information of how the user can extract required information from queries along with statistical information. The focused research is an attempt to propose simple tools that can be used in engineering practice by the geotechnical engineers who routinely work with the Champlain Sea Clay deposits.

TRANSPORTATION GEOTECHNICS I

SESSION CHAIR: SAM PROSKIN

366 | 3D Numerical modeling of the enkoping metal pipe

PRESENTING AUTHOR: Mr Islam Ezzeldin[1]
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The use of corrugated metal pipes as a soil-structure composite system in either culverts or soil steel composite bridges has become integral to the development of complicated roadways network and/or waterways paths that cope with the current unprecedented continuous urbanization. This paper presents the development of a three-dimensional numerical model of the Enkoping large diameter metal pipe that formed a flexible conduit made of corrugated steel sheets. The developed model considers the effect of representing the soil behaviour around the corrugated sheets utilizing using two commonly used constitutive material models, namely the Mohr-Coulomb (MC) and the Hardening Soil Model (HS), to assess their suitability and effectiveness in simulating the soil behaviour. The analysis compares the recorded field measurements of the internal forces in the Enkoping metal pipe with those numerically calculated. Moreover, the arching actions predicted by the numerical model will be compared to the behaviour of the soil represented by the different soil models.

375 | Endommagement des chaussées par érosion interne, gel et dégel

PRESENTING AUTHOR: Zahia Makkeb[1]
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On examine les déplacements des fines particules qui se produisent dans les fondations des chaussées. On sait depuis plus de 25 ans que les matériaux routiers respectent entre couches les critères de filtre, mais souvent ne respectent pas eux-mêmes les critères d'érosion interne. Bien que cela soit connu, il semble que rien n'ait été fait à ce jour pour corriger la conception des chaussées. Sous le béton bitumineux, des particules plus fines qu'un certain seuil, spécifique au matériau de la couche, peuvent se déplacer dans les pores entre les grains plus grossiers. Les mouvements se produisent sous l'effet des forces dynamiques de traffic, et sous l'effet de l'eau qui s'infiltre par les fissures. Il se forme alors de la ségrégation et des accumulations locales de particules fines. Un matériau, qui avait en

moyenne 6% de fines à la pose, peut se transformer en matériau hétérogène qui localement peut avoir de 0% à 30% de particules fines. Les accumulations locales, par une série de mécanismes, font apparaître des nids-de-poule, suite à des cycles de gel et dégel. L'article présente les mécanismes et propose des pistes de solutions pour éviter la création des nids-de-poule et autres désordres locaux, très gênants pour les usagers et très coûteux en entretien et réparations.

14 | Determination of resilient behavior of crushed waste rock using cyclic load CBR test

PRESENTING AUTHOR: Dr. Shengpeng Hao[1]
CO-AUTHOR: Prof. Thomas Pabst[1]
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Crushed waste rock (CWR) is commonly used for the construction of mining haul roads because of their low cost, high strength, and availability. The resilient modulus is the primary parameter for flexible road design and represent a basic material property that should be used in the mechanistic analyses for predicting different distresses such as rutting and corrugation. Cyclic load triaxial test is the most common method to characterize the resilient behavior (i.e., resilient modulus and permanent deformation) of unbound granular materials (UGM) and soils. However, this method is complex and time consuming, especially considering the short-service-life of mine haul roads. Some correlations between CBR and resilient modulus were proposed for natural coarse soils, but their applicability to CWR remains unclear.

In this study, the geotechnical properties of CWR (particle size distribution, particle density, X-Ray diffraction (XRD), modified Proctor compaction test, CBR, and cyclic load triaxial test) were characterized in the laboratory. A novel test method cyclic load CBR (CL-CBR) test, developed based on standard CBR test, was used to characterize the resilient behavior of CWR. The CL-CBR was further developed to study the stress-dependent behavior of CWR using different shapes and sequences of cyclic axial load. The CL-CBR test results were validated and verified using cyclic load triaxial test results. The existing correlations between CBR and resilient modulus for CWR were verified and modified according to the test results. The effect of moisture content and degree of compaction on the resilient behavior of CWR were also investigated.

The CL-CBR test is a relatively simple and effective method that can provide a good estimate of the resilient behavior of CWR, and can enhance the practical accessibility of characterizing the resilient behavior of CWR. Main results of this study will be presented and discussed in this paper.

37 | Optimizing approach slab design for settlement using soil-structure interaction modelling – A case study

PRESENTING AUTHOR: Ms. Christine Ko[1], Mr. Joe Carvalho[1]
CO-AUTHORS: Mr. William Cavers[1], Mr. Tony Sangiuliano[2]
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The Ministry of Transportation of Ontario (MTO) is considering alternative approach slab configurations to reduce the frequency and severity of pavement surface distress that is commonly observed at the end of approach slabs of bridges. The approach slabs are intended to provide a smooth transition from the embankment to the bridge structure but embankment settlements considerably greater than about 25 millimetres will result in approach slab settlements that impact the highway rideability and, more importantly, can lead to serious safety concerns. As an alternative to the standard approach slab typically used, the MTO is considering a number of approach slab designs ranging from angled slabs to buried slabs, with or without sleeper slabs, and potentially combined with soil or asphalt reinforcement, to reduce the effect of ground settlement on the transition from the approach slab to the bridge deck.

At the Highway 417 over County Road 3 site in Eastern Ontario, the approach slabs (constructed on embankments fills underlain by compressible soils) have experienced poor performance. The settlements at the County Road 3 overpass had been excessive and resulted in significant degradation of the pavement at the approach, which required speed reduction warnings. MTO therefore undertook a study to assess potential approach slab rehabilitation options at that location. The work undertaken included geotechnical investigations and laboratory testing to assess the current soil engineering parameters at the bridge, analysis to estimate the settlements that had occurred (in comparison to surveys of the pavement) and predict the ongoing settlements that might occur. Soil-structure modelling was then carried out to evaluate numerous combinations and permutations of approach slab and pavement configurations to arrive at the most effective design for the rehabilitation of the County Road 3 bridge approaches and to provide guidance for approach slab rehabilitation at other bridges with similar issues.

114 | Effect of TBM Tunnel advancement on raft twist of an existing raft foundation

PRESENTING AUTHOR: Mr. Ahmed Elmouchi[1]
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Constructing new underground tunnels is a necessity in urban areas to resolve the traffic congestion problems in such areas. The new tunnels are passing underneath existing buildings, which might rest on a raft foundation. This study focuses on the effect of the TBM tunnel advancement on the twist behavior of the existing raft foundation. The 3D nature of the TBM construction process has been simulated using PLAXIS 3D software. In order to validate the results of the numerical simulation, the resulted settlement trough has been compared to the measured field settlement trough of a selected case study (Second Heinenoord Tunnel). In the current student, an extensive 3D parametric study is conducted to check the effect of related parameters on the raft twist. The studied parameters include; tunnel cover (Z), raft Inclination (i), raft thickness (d), and raft weight. The results revealed that the raft twist is greatly affected by the tunnel cover (z), the raft inclination (i), and the raft thickness (d). However, the raft weight is not affecting the raft twist behavior.

142 | Geotechnical assessment of the 1930s Jacques Cartier bridge

PRESENTING AUTHOR: Mr. Michael Snow[1]
CO-AUTHORS: Dr. Fady Ghobrial[2], Mr. Hamid Ben Abess[2]
[1]Golder, Ottawa, Canada, [2]Golder, Montréal, Canada

As part of the seismic rehabilitation assessment of the Jacques Cartier bridge in Montréal-Longueuil, Québec, a detailed geotechnical investigation was carried out. The bridge represents a lifeline bridge as defined in CAN/CSA-S6-14 and is an important transportation link over between the Island of Montreal and the South Shore of the St Lawrence with a total span of 3km.

The bridge is supported on a range of different foundation types, including large piers supported directly on bedrock, large piers supported on over 140 wood piles, small piers supported directly on soils and small piers supported directly on wood piles. The bridge is supported on 55 piers and 2 abutments covering range of spans from about 30 m to 332 m, and includes a plaza structure within its overall length. The ground conditions cover a wide range of bedrock types, from breccia intrusions to shale sedimentary rock, and soils ranging

from silty clay to loose sands to dense glacial tills. Deep fills were also present in several locations.

The field investigation included boreholes, downhole geophysics and cone penetration tests (CPTs). A series of test pits were also excavated on the Montreal shore to expose and assess some of the wood piles dating back to the 1930s.

The results of the field investigation were used to assess site response relative to seismic loading, the potential for seismic liquefaction, and to model the dynamic axial and lateral load capacity/stiffness of the foundations. This case study reveals several interesting aspects relative to the seismic performance of the structure from the potential for seismic liquefaction, the dynamic response of specific sections of the bridge to seismic loads, the lateral dynamic stiffness and capacity of the existing foundation systems. Recommendations for additional field investigations as part of the next phase of bridge assessment were also provided.

ROCK MECHANICS AND ENGINEERING GEOLOGY I

SESSION CHAIR: BOGART MENDEZ

381 | Effect of spatial variability of foliation orientation on mining slope design

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Local variation of foliated nature of the rock mass can have a significant effect on mining slope design and it is often difficult to predict. This provide concern which should be considered for pit design and continuously monitored during the mine development. This paper describes the huge challenge that was to build the final southeastern wall of the Irene pit pushback by mitigating the risk of slope failure caused by spatial variability of the foliation orientation, knowing that previous mining in this sector of the pit had caused a multi-bench failure of 140 m high and 200 m wide. The developed methodology based mainly on the design conformance analysis, the televiewers investigations, the modification of blasting procedures and the photogrammetric mapping permitted to achieve optimal slope and to continue mining safely.

161 | Statistical quantification of earthquake effects on the excavation damage zone

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CO-AUTHORS: Dr. Magdalena Krol[1], Dr. Matthew Perras[1]
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Deep geological repositories are being designed to manage spent nuclear fuel of past and future reactors for up to 1 million years across the world. The geosphere surrounding a repository should be structurally stable against geological perturbations, such as earthquakes. Previous studies have evaluated earthquake effects on the repository showing that, there is a measured change in excavation damage zone due to a low probability earthquake event. However, a quantitative study has yet to be performed considering extreme events. In this study, a two-dimensional model was developed in RS2, from Rocscience, a finite element package and compared to a previous repository seismic model. The model utilized a Voronoi joint network around the repository to represent a crystalline rock formation (host rock) and allow for excavation induced damage to evolve during construction. The host rock as well as the engineered barrier system were then

subjected to glacial induced stress and earthquake loading. This model was then used to perform a statistical study using analysis of variance (ANOVA) to quantify the earthquake effects. The ANOVA analysis (significance level of 0.05) examined normal and shear stresses and displacements along the Voronoi joints after earthquake events of different seismic coefficients (model coefficients used to represent the peak ground acceleration as a fraction of the acceleration due to gravity), relative to the model with no earthquake events and no glacial loading. Glacial loading caused additional damage in the repository excavation damage zone and had statistically significant effect on joint normal stress. The seismic coefficients had no statistically significant effect on the joint parameters, although only the final state after the earthquake loading was investigated. Future research will examine the dynamic loading response during an earthquake.

162 | Time-dependent borehole deformation in shale rocks and the influences on in-situ stress inversion

PRESENTING AUTHOR: Hongxue Han[1]
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Maximum horizontal in-situ stress is often analytically calculated using linear elastic theory based on circular boreholes affected by the impacts of drilling events (the development of borehole breakouts or induced fractures) and pressure-time data from a leak-off test or a hydraulic fracture test. However, in the development of unconventional resources, it is noted that shale formations often deform in a time-dependent manner, and the borehole will become non-circular after deformation. Therefore, circular-borehole-based linear elastic analytical solutions are not always appropriate to solve field problems. This paper proposes a new method of in-situ stress inversion from calipers logging data with original borehole size considerations and the time-dependent behavior of shale rocks.
In this research, a three-dimensional poro-visco-elastic FEM model is developed to extend the standard simplified two-dimensional plane strain model to analyze shale deformation. A generalized Kelvin rheological model is used for modeling the visco-elasticity component of deformation. Analytical equations based on the Kelvin model are developed and used for numerical model verification to overcome the discrepancies and deficiencies of the existing analytical solutions and the theoretical Kelvin model results. In finite element modeling, the original borehole size must be considered, bringing an additional unknown parameter (the scale component) into the in-situ stress inversion process. Therefore, a weighted-sum multi-objective optimization of stress inversion from borehole deformation data using

finite element modeling is carried out to estimate the maximum horizontal stress, the corresponding original borehole size, and the timing after drilling.
The integrated methodology will be demonstrated by a field case study to estimate the adjusted borehole size and the in-situ stresses using borehole deformation information reported from four-arms caliper logs of 21 vertical boreholes in Duvernay formation in Western Canadian Sedimentary Basin.

289 | Determination of the effects of mineralogy on the point load compressive strength of rock

PRESENTING AUTHOR: Mr Mahdi Askaripour[1]
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This thesis is concerned with the issue of the effect of minerals in hard rock, mechanized underground mines. Specifically, given than a rockburst occurs, it quantifies the significance of the factor affecting the severity of the damage. Rockburst is one of the important types of rock mass instability where the magnitude of in-situ stresses are high enough. There are several significant parameters would may affect on severity of rockburst such as the magnitude of in-situ stresses, the effect of discontinuities of rock mass and etc. However, one of the significant parameters is the effect of minerals on the instability of rock during the excavation.
In order to obtain the objectives, more than 1500 Point Load Test (PLT) was applied to the study area (Westwood Mine). Also, 130 UCS tests, 78 Triaxial tests, and 57 Brazillian tests were carried out. Thin section analysis also used for at least 63 different samples from different depth and rock types. Then, Factor Analysis (FA) was first applied to explore the structure of the database, or how all variables associated with the strength of rock correlated with each other, so, the data reduction could be carried out. Quartz, Sericite, Epidote, Amphibole, chlorite, Plagioclase and Biotite were determined to be potential factors that could affect rock mass behavior. The load strength of the PLT was selected as the outcome variable. Then the logistic regression was applied to the data set, in order to determine the probability of failure as well as the weighting factor on minerals. Several statistical results were extracted from the logistic regression and the results showed how the low amount of each mineral can decrease or increase the strength of rock and instability of rock during excavation. The probability of rockburst occurrence in underground excavation with different amounts of minerals also was determined.

303 | The influence of rib spacing and borehole diameter on axial response of cemented rock bolt

PRESENTING AUTHOR: Mr. Kieran Moore[1]
CO-AUTHOR: Dr. Nicholas Vlachopoulos[1]
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For almost a century, rock bolts have become a widely employed method of providing support to excavations in the multi-disciplinary domain of underground construction and mining. Rock bolts serve to help provide stability to an excavation profile through a myriad of techniques, including the transfer of load from the unstable profile to more stable rocks, or the creation of an artificial arch. Research has been conducted to better understand rebar bond performance. Numerous investigations involving in-situ and laboratory testing have been conducted. As well, multiple analytical and numerical models have been developed in order to attempt to simulate the performance of rebar specimens within certain scenarios of ground type and support schemes. This has led to a better understanding of the multiple components, mechanisms and properties associated with such a composite rebar, grout and ground system. Due to practical and technological limitations, an in-depth investigation of the load transfer and continuous stress distribution along a fully grouted rock bolt has been challenging. The advent and application of Fiber Optic Sensors (FOS) in the geotechnical discipline has led to a methodology (developed by the authors) capable of providing a continuous strain profile for rebar support / structural members. Fiber optic technology involving Rayleigh Optical Domain Reflectometry (ROFDR) can be used to determine the strain profile and geo-mechanical performance of a rock bolt at an unprecedented scale as well as sampling interval. This paper summarizes such an innovative methodology that has been employed for a series of laboratory axial pullout tests in order to determine the effects of rock bolt rib spacing and borehole diameter on the geo-mechanical response of fully cement grouted rebar rock bolts within simulated rock masses. The results of the research will augment the current body of literature while also improving rock bolt development, design and implementation.

141 | Numerical modelling of fully grouted rock bolts using 2D Finite Element method

PRESENTING AUTHOR: Ms. Ya Su[1,2]
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Rock bolts are one of the primary underground support systems utilized to stabilize the rock mass surrounding the opening of excavation by transferring the load from the surrounding rock to the more stable rock mass further from the excavation. Modelling fully grouted rock bolts has been the focus of many researchers due to the difficulties of capturing the interaction mechanism of the interface between the rebar and the grout at the micro-scale. In this paper, two-dimensional numerical simulation has been conducted in order to model the behaviour of fully grouted rock bolts during the pullout tests. Joint parameters of the rebar-grout interface (i.e. shear stiffness, normal stiffness, and peak cohesion) are investigated as well as grout parameters (i.e. Poisson's ratio and Young's modulus) in terms of the influence on the rock bolt behaviour. The results indicate that the Young's modulus of the grout and joint shear stiffness have significant influences on the results. On the basis of these results, the upper and lower limit of strain distribution along with the rock bolt is determined. These results are also compared to the nominally identical laboratory rock bolt pullout tests that have been conducted as part of the physical testing components of the overall research program

SEPTEMBER 15, 2020 - TUESDAY PM

SOIL MECHANICS AND FOUNDATIONS IV

SESSION CHAIR: Gennaro Esposito

198 | Investigation on the mechanical and engineering properties of peat

PRESENTING AUTHOR: Mr. Aiming Liao[1]

CO-AUTHORS: Prof. Michael Hendry[1], Prof. Mahya Roustaei Hossein Abadi[1]

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Peatlands cover 113.6 million hectares in Canada, or 13% of the country's surface area and are present in all provinces. Due to the existence of the fibres, the application of conventional isotropic elastic soil theory is not appropriate for analysing the undrained behaviour of this material. Therefore, a better approach for understanding the mechanical and engineering properties of peat is required. In this research, results of consolidated undrained and drained triaxial compression and extension tests on undisturbed and remoulded peat specimens were used to fully quantified undrained tensile strength, and define an appropriated failure criterion for peat. Moreover, the impact of fibre orientation on the pore water pressure response, elastic stiffness, and undrained shear strength were further examined and the Poisson's ratio under drained compression and extension conditions was studied with the aid of characterizing the anisotropic properties of peat. The paper will present the results of this laboratory testing with a specific focus on the variation of tensile strength, and stiffness with the orientation of the principal stresses.

Keyword: peat, triaxial compression test, extension test, direct shear test, undrained tensile strength, pore water pressure response, elastic stiffness, Poisson's ratio.

214 | Geotechnical challenges associated with the design and construction of the new Champlain Bridge in Montreal

PRESENTING AUTHOR: Dr. Riad Diab[1]
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In 2014, the Canadian government awarded a $4.3 Billion Design-Build contract to the Joint Venture (JV) team Signature on the Saint Lawrence (led by SNC-Lavalin) for the design and construction of one of the largest infrastructure projects in North America, the new Champlain Bridge in Montreal. In addition to the new 3.5 km main bridge, the overall project involved the construction of tens of smaller bridges and over 20 retaining walls along the bridge approaches. The complexity of the project posed unique geotechnical challenges on many levels.

The west approach alignment was to be constructed over an old landfill where the subsurface investigation indicated up to 9 m of waste solid. A 7-m temporary embankment test was constructed on the existing fill, and 32 settlement platforms were installed during the design phase to monitor the settlement. The "consolidation" and strength parameters were then back calculated and used in the roadway embankment design. Moreover, part of the new highway alignment was to be construed over an existing 11x5 m COS collector with unknown structural condition. The owner requirement was to apply no additional load on the collector. Numerical analysis of the stress-strain conditions along with the use of lightweight fill was performed. Furthermore, the presence of a thick liquefiable silty soil deposit led the geotechnical team to design the foundation system to withstand seismic loading induced during a 2% in 50-year return period. Also, although most structures were constructed on drilled shafts, driven piles to refusal were also used. The nominal resistance was carefully assessed with thorough dynamic testing program due to relaxation phenomenon occurring on the shale formation.

This paper addresses the issues encountered and concerns raised during the geotechnical design and how these were addressed and resolved. Design and construction procedures, challenges and solutions are discussed in detail.

223 | Calibration of the hardening soil small strain constitutive model parameters for Toronto Glacial Till

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A light rail transit infrastructure project proposed in Toronto requires construction of deep retaining walls with excavations into approximately 18m of glacial till, consisting of silty clay and sandy silts. Due to the proximity of the proposed deep excavation to several sensitive existing infrastructures, an advanced finite element constitutive soil model, the PLAXIS Hardening Soil with Small Strain (HSs) model was used to perform non-linear ground movement analysis, and to assess the soil-structural interaction due to hysteresis effects under seismic condition. The HSs model is a rate-independent, hyperbolic, effective stress constitutive model.

The available laboratory tests comprised of isotropically consolidated, undrained triaxial compression (CIUC), and 1-D incrementally loaded oedometer tests. Field testing included geophysical acoustic velocity measurements, cone penetration testing (CPT), field vane, and TEXAM Pressuremeter.

The calibration of the model, based on a laboratory tests and small strain stiffness from geophysics, is demonstrated in this paper. The model was validated comparing the numerical predictions of shear strength, and stiffness with the values obtained from in-situ field testing. Selected parameters were compared with the local empirical correlations from typical index testing obtained by conventional geotechnical investigation. Results of ground movements behind the proposed excavation from the finite element model were then compared with the empirical normalized ground movements from local studies for deep excavations.

This study summarizes the range of HSs model parameters that are applicable for the project in the local Toronto geology. Through validation from field testing and comparisons with local empirical correlations with data from other local projects, it is shown that the model can predict the in-situ strength and stiffness of real soils with some certainty. Results of the finite element model show that the ground movements are comparable with local empirical experience.

226 | Assessment of shear strength parameters of moist sands using conventional triaxial tests

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Shear strength parameters of moist soil is often required for the design of underground pipelines since the soil around the pipelines is generally moist. The strength parameters for the sand are usually determined from laboratory tests conducted on dry or saturated sand samples. However, the difference between the the behavior of moist sand and dry or saturated sands are well-recognized. Researcher employed different methods through modification of conventional direct shear or triaxial test apparatus for testing moist sands. This approach is usually complicated and time-consuming, yet not flawless. In the present study, conventional triaxial test apparatus is used to assess the shear strength parameters of a moist sand. The tests are conducted using a local sand with varying moisture contents. Total stress analysis is adopted to interpret the test results for determining the strength parameters. Consolidated undrained test is also conducted on saturated sand for comparison of the test results with the moist sands. Test results are also compared with the results of moist sand available in the literature.

251 | Correlations of SPT, CPT and PMT for overburden soils along Lakeshore Corridor in Toronto, Canada

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Several Standard Penetration Tests (SPT), Cone Penetration Tests (CPT) and Pressuremeter Tests (PMT) were recently carried out along the Lakeshore West Corridor in the Greater Toronto Area. These tests were carried out in sets spaced at 3 to 5 m so that the same stratum was tested but also to avoid interference between each test. This paper will present a direct comparison of the SPT, CPT and PMT tests for different types of soil with same gradation and plasticity. The results will be used to evaluate the effect of mean grain size, fines content and plasticity which are known to affect the relations of the SPT, CPT and PMT values. The test data will be compared with available correlations in literatures, including CPT to SPT ratio versus mean particle size plot presented in Canadian Foundation Engineering Manual. Finally, improved correlation for the test data will be proposed and its difference with existing correlations in literature will be discussed.

254 | Driven pile capacity assessment using installation: Energy and pile set-up factor

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This paper will describe empirical assessments carried out to verify ultimate pile capacity on a wharf project in Western Canada. The wharf is in a river delta at the head of a major fjord system where the shallow stratigraphy typically consisted of interbedded gravely sands, sands, silty sands, silts, and clays.

On typical wharf projects involving driven tubular steel piles, capacity assessments are made based on combinations of static load and high strain dynamic load testing conducted only on selected piles. Remaining piles are evaluated using observations made during driving, such as hammer energy and penetration per blow.

Assessment of driven pile capacity during construction is complicated by time-related factors that arise primarily due to pore pressures developed during pile driving and their subsequent dissipation over time. The phenomenon of pile set-up typically results in final capacities being at a minimum shortly after driving and then increasing over time. Ideally, all pile capacity testing would be conducted a long time after initial driving, however construction schedule pressures dictate that piles must be tested as early as possible after driving.
On the subject project, pile set-up was significant and took relatively long periods of time. The paper describes the pile
assessments that were made including correlating pile capacity test results to pile driving records, long-term set-up factors and the relationship between pile set-up and time since driving.

Pile capacity was assessed by normalizing hammer energy and pile set per blow and correlating to capacity at the time of testing or driving using an initial data set of static load test and high strain dynamic test results. A site-specific correlation between set-up and time was established and used to predict the long-term pile capacity. Relatively high set-up factors were established, considering the predominantly granular nature of the soils at the site.

SOIL MECHANICS AND FOUNDATIONS V

SESSION CHAIR: LEANNE MCLAREN

291 | Differential settlement of foundations

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The serviceability limit state (SLS) design of foundations typically proceeds by limiting the total settlement of individual foundations and restricting the differential settlement between pairs of foundations. In fact, it is often the differential settlement which is more important to the performance of the supported structure. Unfortunately, due to the random nature of the supporting ground, the magnitude of differential settlement is also random, and is typically much more difficult to characterize than is the total settlement of individual foundations. This paper investigates the distribution of the maximum differential settlement between pairs of foundations as a function of the spacing between foundations and the number of foundations. The effects of the correlation lengths between the elastic properties of the ground under each foundation as well as the loads applied to the foundations on the distribution of the maximum differential settlement are investigated. Groups of 4, 9, and 16 foundations arranged in a regular grid pattern are considered and the maximum differential settlement between all possible pairs are studied. Since SLS limits are often expressed in terms of differential slopes, the distribution of the maximum differential slopes between foundations are also investigated. The overall goal is to establish design requirements on the total settlement of individual piles which simultaneously achieves acceptable performance with respect to differential settlement.

297 | Evaluating the capacity of helical piles in clay tills using pile load tests

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This thesis analyzes seven static load tests conducted on helical piles installed in clay till at a site in Northern Manitoba, Canada. Four methods, the Davisson Offset Limit, the Hansen Ultimate Load, the Chin-Kondner Extrapolation, and the Decourt Extrapolation are used to determine the ultimate capacity using the pile load test results. The ultimate capacities obtained were then used to determine the empirical parameter Kt for helical piles in clay tills, this parameter relates the pile capacity of helical piles to the installation torque of the

pile. The Davisson Offset Limit and the Hansen Ultimate Load provided consistent and conservative ultimate capacities based on the pile load test results and showed lesser variability in results compared with the Chin-Kondner Extrapolation and Decourt Extrapolation methods. The ultimate loads based from the Hansen and Davisson methods were used to calculate a Kt value. It was determined that a Kt value ranging from 9 m-1 to 11 m-1 is appropriate for evaluating the capacity of a helical pile in clay tills using the installation torque of the pile.

385 | Seismic performance of circular foundations resting on stone columns

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Circular foundations are mainly used in projects such as crude oil storage tanks, cylindrical water tanks, bridge piers, and silos. One of the main challenges in the designing of circular foundations is to control the settlement and uplift, especially when the foundation is resting on loose granular soils and subjected to seismic loads which may undergo large elastic settlements. One way to reduce the settlements of the foundation as well as its uplift is to use stone-columns below the foundation. The main objective of this study is to investigate the seismic performance of circular foundations resting on stone columns through a parametric numerical study. Abaqus software is used to simulate the interactions between structure, foundation, soil and stone columns. The effects of several parameters are investigated on the settlement and uplift of the foundations. These parameters include the diameter of the circular foundation, diameter and length of the stone-columns, and center to center distance of the stone columns. The settlement and uplift of the foundations in the both presence and absence of the stone-columns under seismic loads are discussed. The results revealed that increasing the length of the stone columns up to a threshold value decreases the settlements and after that, the increase will not cause significant changes in the performance of the foundation. In addition, stone columns diameter and distance play more important role than stone columns length in decreasing settlement and uplift due to seismic loads. Moreover, stone columns cannot have the same effect on reducing settlement as they do on decreasing uplift.

267 | Axial pile capacity from CPT data in difficult soil

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Dynamic pile load testing was performed during the driving of 610 mm displacement prestressed concrete piles into sandy soils, and actual pile capacity was determined during end-of-drive (EOID) and at beginning of restrike (BOR) using CAPWAP procedures. The load test provided an opportunity to compare pile design techniques to measured pile performance. The soils at this site prevent the pile driving process from being completed and the required pile length and capacity were not achieved due to early refusal.

An evaluation was carried out to evaluate nine Cone Penetration Test (CPT) methods based on their ability, to which predictive method would be best suited for estimating the pile capacity at a site where such soils may encountered. The study also compared the CPT methods to the results of the bearing capacity obtained from Standard Penetration Test (SPT) based methods presented in the literature for the same pile.

The ratio of predicted total capacity, Qp, to measured total capacity, Qm, is presented, along with the absolute percent difference between the predicted and measured capacities.

Four methods included Philipponnat (1980), De Ruiter and Beringen (1979), Price & Wardle (1982), Zhou Etal (1982) had slightly over predicted the capacities for test pile within 50% to 63% of the capacities determined by the 1-day BOR dynamic loading test. The Qp and Qm ratio was between 1.5 to 1.9 which showed good agreement between predicted and measured capacities.

Keywords- Driving piles, CPT, bearing capacity, large displacement piles

265 | Correlation between the standard penetration test and the dynamic cone penetration test for sandy soil

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In geotechnical engineering, in-situ penetration tests have been widely used for site investigation in support of analysis and design. The Standard Penetration Test (SPT) is the most common in situ test for soil investigations in sandy soils. On the other hand, The Dynamic Cone Penetration Tests (DCPT) is a rapid inexpensive field test that can be used to assess the engineering properties of soils. However, correlation between the results of DCPT and soil properties or any other trusted field test is not well established yet.

This study presents an evaluation of predictions SPT blow counts using Dynamic Cone Penetrometer Test. Database consisting of 39 SPT and 21 DCPT data sets was utilized to develop a correlation. Data of this study was drawn from 14 different sites located in north costal of Libya (City of Tripoli), served as the subject of SPT-DCPT correlations. The soil investigation program for each site included SPT borehole and adjacent DCPT tests.

The validity of the proposed correlation was verified using test results on similar soils from five new sites. The developed correlation indicates that the relation between the results of the two penetration tests is linear for sandy soils. Positive linear relationships were found between NSPT and NDCPT for sandy soils. To demonstrate the differences between the proposed and previous deterministic equations, comparative studies were performed. The suggested correlations may guide future more detailed correlations between these two in situ tests. N predicted versus N actual showed high correlation coefficients of 0.70.

In summary, direct correlations between SPT and DCPT were produced, showed that the light DCPT is suitable for sandy soils with low density NSPT 30 blows/0.3 m or less, and allowing estimation of NSPT from DCPT

TRANSPORTATION GEOTECHNICS II

SESSION CHAIR: PETER THOMSON

155 | A review of prediction methods of primary consolidation settlement from field monitoring data

PRESENTING AUTHOR: Mr. Matt Thibeault[1]

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The assessment of the degree of consolidation (U) during embankment construction has engineering and contractual implications. Determining U can be critical to confirm adequate shear strength gain has occurred during hold periods between lift placements to avoid embankment instabilities, or that sufficient settlement has been achieved prior to the end of a preload/surcharge period to maintain conformance with post construction settlement tolerances. Various methods have been suggested by researchers to estimate the degree of primary consolidation achieved during construction, with two commonly implemented approaches being: a comparison of peak pore water pressure measurements to the measurements at the time of the assessment, and an observational method utilizing available settlement data (Asaoka, 1978). For both approaches, uncertainty exists during construction as to the accuracy of the prediction of degree of consolidation; therefore, it is often necessary to supplement the predictions with engineering judgement when making decisions that could affect construction costs and schedule. Three Ministry of Transportation, Ontario (MTO) highway embankment sites in Northern Ontario are examined, where foundation monitoring data was collected throughout construction and where the preload or surcharge period has been completed and the end of primary consolidation settlement has been achieved. Installation of wick drains and restrictions on staging were carried out during construction at these sites to mitigate stability and settlement concerns. The range of error in estimating the degree of primary consolidation at various points in time during construction are explored, utilizing pore water pressure data, settlement data in conjunction with the Asaoka method, as well as 'curve-fitting' to attempt to match model predictions to monitoring data. Best practices for reducing the uncertainty of the predictions are presented with the intent to allow for improved decision making on future construction projects that involve wick drains, staging and preloading or surcharging.

236 | Stabilization of rail track, CN Dundas Sub, Dundas to Copetown, Ontario

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The paper summarizes the design of stabilization measures which were constructed in the portion of the Dundas Sub which lies between the towns of Dundas and Copetown, Ontario. Construction of the initial single rail track on the Sub took place in the early 1850's; the track was twinned in the 1890's. The affected section of track rises up from the base to the top of Hamilton Mountain (Niagara escarpment). It features a series of cuts, side slope fills, and embankments. Railway construction was carried out without the benefit of sophisticated construction equipment; construction fills were not subject to dense compaction. Cuts were made into hillsides to construct a level platform to support the track with fill being placed on the downhill side to add platform width. Design of the various sections of earth work associated with track construction was based on experience rather than analytical design methods. Over the past few decades, some sections of rail track which are supported by fill soils and track lying above native slopes on the downhill side, have experienced downhill movements as a results of much increased axles loads and much increased length of trains compared to the initial train loads.

The paper reviews the design of stabilization measures at five sections of track. These stabilization designs have featured: a conventional gravity berm; a gravity berm featuring geosynthetic reinforcement to provide an oversteepened slope face; tie backs which are anchored into bedrock; soil nails to stabilize the slope height from rail track down to base of slope; and soil anchors to support the outer rail track at the top of a high slope. The rationale for design method selection is discussed for each site in conjunction with site constraints such as urgency, property limits, ensuring minimal effect on rail operations, site access restrictions, and cost.

65 | Effect of fines on mechanical properties of coarse aggregate

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The supply of low-cost, quality aggregate in Ontario is decreasing. To mitigate this trend for granular (sub)base construction, a possible solution is to use quarried aggregate that does not meet current physical property requirements, but can be shown to maintain proper structural and hydraulic performance of the engineered layers

Two important factors for the design of pavement structures are the resilient modulus (Mr) and hydraulic conductivity of the granular (sub)base. The resilient modulus depends on aggregate type and particle shape, as well as grading and fines content, moisture content, density, stress level, stress history and the number of load cycles. The permeability is influenced by the gradation of the aggregates. The relation between the mechanical properties and drainage is important as the stress-strain-load cycle behaviour is sensitive to the degree of saturation and ability of the granular material to dissipate any generation of excess pore pressure. This study addresses the effect of fines on the mechanical properties of four different Granular A crushed rock materials. The objective of this paper is to report on the experimental findings regarding the influence of fines on the resilient modulus and hydraulic conductivity.

The Mr, which tended to decrease with an increase in fines content, was found not to be sensitive to the type of fines for the materials. Furthermore, as the amount of paste increased (percent water plus percent passing the 75-micron sieve) during specimen fabrication, the Mr for a given confinement decreased. Results from permeability tests confirmed that with zero fines present, the hydraulic conductivity was much larger than that when fines are present. The permeability did not change much for specimens in which natural fines were replaced by substitute fines. An important observation with regards to the migration of fines is that secondary effects cannot be captured by Darcy's law.

253 | Structural design of sheet pile shaft for GO Rail Expansion near Highway 401 and 409

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CO-AUTHORS: Tyler Lahti[1], Mary Jane Ferraro[2]

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As a part of upgrades to provide faster, more frequent and more convenient transit service across the Greater Toronto and Hamilton Area (GTHA), electrification of the core segments of the GO Rail network is part of the GO Expansion program. GO Rail Expansion will provide significant new travel choices for GTHA residents, including: electrified service on Metrolinx owned rail corridors, with trains running every 15 minutes in core areas of the network and two-way all-day service. As a part of this expansion program construction work is underway on the Kitchener GO Corridor. Due to limited height clearance in the existing tunnel rail on Kitchener Corridor under Highway 401 near Highway 409, a new twin tunnel is being constructed next to the existing tunnel under Highway 401 crossing 21 vehicular lanes.

A 26mx 10mx 9.8m deep strutted sheet pile shaft was designed to facilitate the installation of a tunnel pre-support pipe canopy by auger boring. The tunnel pre-support was required by the tunnel designer as part of the sequential excavation method (SEM) to provide ground support and minimize the settlements to the highway. The shaft was located in the median space between the Highway 409 eastbound ramp and bridge abutment and Highway 401 eastbound express lanes and abuts the existing rail tunnel along one side. The unbalanced loading on the shaft was considered due to the grade difference between the Highway 409 ramp and Highway 401 eastbound lanes. The temporary shaft structure was also used to control the movements of the adjacent rail tunnel and bridge abutment wingwall structures. This paper will provide a comprehensive overview of the challenges encountered during detailed design, analysis techniques adopted and a summary of the settlement profile observed on the ground surface around the shaft.

270 | Vision for geotechnical asset management at Alberta Transportation

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Geotechnical assets play a crucial role in the function of transportation corridors. Geotechnical assets such as soil and rock slopes, retaining walls, embankments, and subgrade soils serve to support the provincial highway infrastructure, but can also pose potential threats to the transportation system as a result of deteriorating condition, escalating maintenance costs or catastrophic failures. Asset Management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle. It focuses on economic analysis and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives. Public agencies are beginning to recognize the potential benefits of taking a proactive, systematic approach to the management of geotechnical assets, and geo-professionals are developing tools for the inventory, condition assessment, life-cycle cost prediction and risk assessment of geotechnical assets.

Alberta Transportation is responsible for managing approximately 500 identified geohazard sites through the province. This paper will describe Alberta Transportation's current Geohazard Risk Management Program (GRMP), and the vision for transforming this program into a formalized Geotechnical Asset Management (GAM) system. Part of the proposed transformation will be to develop and implement a condition rating system that is applicable to a range of geotechnical asset types (slopes, retaining walls, embankments and subgrades), with simplified deterioration models for projecting asset performance over time. The goals of Geotechnical Asset Management are to enhance the Department's ability to monitor the condition and deterioration of our geotechnical asset inventory, forecast future funding requirements to achieve desired levels of service and risk reduction, and facilitate evidence-based decision making that considers the full life cycle costs and benefits of our geotechnical assets.

353 | Two-Dimensional Performance of Integral Abutment Bridges using Finite Element Analysis

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CO-AUTHOR: Prof. Hany El Naggar[1]
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Deep geological repositories are being designed to manage spent nuclear fuel of past and future reactors for up to 1 million years across the world. The geosphere surrounding a repository should be structurally stable against geological perturbations, such as earthquakes. Previous studies have evaluated earthquake effects on the repository showing that, there is a measured change in excavation damage zone due to a low probability earthquake event. However, a quantitative study has yet to be performed considering extreme events. In this study, a two-dimensional model was developed in RS2, from Rocscience, a finite element package and compared to a previous repository seismic model. The model utilized a Voronoi joint network around the repository to represent a crystalline rock formation (host rock) and allow for excavation induced damage to evolve during construction. The host rock as well as the engineered barrier system were then subjected to glacial induced stress and earthquake loading. This model was then used to perform a statistical study using analysis of variance (ANOVA) to quantify the earthquake effects. The ANOVA analysis (significance level of 0.05) examined normal and shear stresses and displacements along the Voronoi joints after earthquake events of different seismic coefficients (model coefficients used to represent the peak ground acceleration as a fraction of the acceleration due to gravity), relative to the model with no earthquake events and no glacial loading. Glacial loading caused additional damage in the repository excavation damage zone and had statistically significant effect on joint normal stress. The seismic coefficients had no statistically significant effect on the joint parameters, although only the final state after the earthquake loading was investigated. Future research will examine the dynamic loading response during an earthquake.

DAMS AND EMBANKMENTS III & PIPELINES AND TRENCHLESS TECHNOLOGIES I

SESSION CHAIR: Tamer Elshimi

354 | Ground improvement by stone columns - A case study

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Stone columns have been widely used as a cost-effective, fast and environmentally friendly ground improvement method. Stone columns improve the load-bearing capacity, reduce settlement and mitigate liquefaction of soft subsoil under structures like liquid storage tanks, earthen embankments, raft foundations etc. This paper first presents the basics of the stone column technique and discusses the design considerations, applications, advantages and limitations of this method. Then a case study of stone column installation under oil tank foundations and auxiliary buildings for a bunker terminal project in the Middle East is elaborately explained. Geotechnical investigation data of the project site revealed subsurface conditions comprising of very loose to loose and medium silty sand with low SPT N values for the top 13 m depth in some boreholes. This necessitated ground improvement to meet the high bearing capacity requirement of 250 kPa and 300 kPa under marine gas oil tank, fuel oil tank and other structures and to achieve settlement criteria of a maximum uniform settlement of 50 mm and 100 mm during operation and hydrotest respectively. As the soil profile varied across the tanks, stone columns of 0.9 m dia. with a grid spacing of 2-3 m square and varying treatment, depths have been used. The design procedure, construction method and verification or confirmatory tests adopted for the successful delivery of the project is also covered in this study.

Keywords: Ground improvement, Stone columns, bearing capacity, oil tank.

426 | Local Factor of safety in variably-saturated embankments due to climate change using In-situ stress fem

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Climate change is expected to continue over this century and beyond with important impact on currently stable soil embankments. Soil response to precipitation pattern variation, due to climate change is directly related to pore water pressure and stress state changes. To accurately assess the behavior of embankments under changing climate, a deformation assessment using coupled hydro-mechanical analysis, with an appropriate elasto-plastic constitutive law may be required. However, priority in current engineering assessments is to identify the factor of safety against local, shallow or global failures, whereas deformation assessments are of a minor concern. In this research, the effect of climate change on the stability of embankments was quantified by estimating a field of Local Factor of Safety (LFS) using a coupled in-situ stress finite element analysis and variably unsaturated flow analysis. In this method, the effect of moisture content variation on the effective stress was taken into account using suction stress state. For a case study, the effects of climate change on the stability of a typical highway embankment consisting of sandy or silty soils in Niagara Falls, Ontario was considered. The study results demonstrate that the proposed simplified assessment approach is capable of identifying global and local failure zones without the use of advanced elasto-plastic simulations.

59 | Assessment of pipelines subjected to varying longitudinal soil displacement rates

PRESENTING AUTHOR: Prof. Ron Wong[1], Dr. Chee Wong[1]
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A number of oil and gas pipelines have been constructed across slopes in the province of Alberta, Canada. They were buried at shallow depths below the sloping surface. Due to complex terrains and geological formations, these slopes are active, continually moving in varying rates. Pipeline sections subjected to such permanent long-term ground deformations may yield because of large strain accumulation over time. It is of practical importance to quantify how such movement rates affect the integrity of the pipe so that an effective field monitoring and remediation program can be developed to maintain the integrity and prolong its operation. This paper develops semi-analytical solutions to

estimate the strains exerted on a pipe subjected to varying soil displacement rates. The effects of soil movement rates on the soil-pipe interaction are incorporated into the proposed solutions, which are not considered by the current guidelines for the designs of buried steel pipes (American Lifelines Alliance (ALA 2001) and Pipeline Research Council International (PRCI 2009)). These solutions will be used in a case study to assess the potential of yielding in the pipe with the given soil displacement rates that occurred in the slope. In this particular sloping site, the soil displacement rates of 10 – 50 mm/year were detected over 30 year.

73 | Mechanical Behavior of a buried steel pipe during compaction procedure

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A steel pipe (Grade X52) of 0.6 m in diameter and 5.2 m in length was buried in a rigid soil pit formed by three reinforced concrete walls and a curved masonry wall. The dimensions of the pit are 2.4 m (narrowest width) by 7.6 m (length) by 2.4 m height. The width at two ends of the pit is 3.8 m. The pipe was instrumented with strain gauges mounted externally at two pipe sections to measure both circumferential and longitudinal deformations. The steel pipe was laid at a vertical distance of 1.1 m from the base to minimize the boundary effects. The pipe rested on a layer of loosely compacted sand/gravel with thickness of 200 mm. Silty clay soil was used as backfill material, and compacted in layers. The final burial depth of the pipe is 0.6 m. The mechanical behaviour of the buried pipe was monitored through the compaction. It was observed that the pipe section deflects into a vertical ellipse at the initial compaction up to the pipe top level. This response is then reduced by further compaction of backfill above the pipe as the vertical deformation becomes dominant.

344 | Forecasting failure of water mains under climate variations: Stochastic Modeling Process

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Climate change has the potential to affect substantially the operational condition and lifespan of buried utilities, including pipelines transporting water, gas, and sewer. The

climate of Canada is known to vary spatially and temporally, and these variations can cause damage to buried infrastructures. Thus, climate variables can provide useful information related to the failure prediction of water mains. The physical mechanisms that negatively impact the condition of water mains and can lead to their failure are complex and not fully understood. This can lead to high uncertainty in forecasting the possible damage and the need to replace or repair water mains before major failures.
Although climate hazards have become a major concern to cities and municipalities in Canada, only a few studies have addressed the impact of climate variations and forecast their contributions to possible failures of water mains. In this paper, we present a spatiotemporal approach for failure forecasting of water mains at selected locations in the Cities of London (Ontario) and Quebec, Canada. The results show that the proposed model is able to reasonably forecast the failure of water mains up to nine months ahead under climate variations.

137 | Mitigating risks to shallow trenchless pipeline crossings using geophysics and test pitting

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Shallow linear infrastructure, like roads, rail and existing pipelines, commonly need to be crossed by new pipeline projects. For these relatively short and shallow crossings, pipelines can usually be installed using a range of available boring methods. Although the value of detailed engineering assessment often conducted for larger scale HDD crossings is not often perceived for these shallow crossings, they are not without risks associated with complex subsurface geology, largely pertaining to intersection of bedrock, coarse granular material or shallow groundwater. Here, we show how a combination of geophysical profiling and test pits can provide a cost-effective means to characterize shallow subsurface geology with minimal ground disturbance. We demonstrate this approach for a series of ten road and pipeline crossings spread over a 23-kilometre-long section of a proposed 42-inch natural gas pipeline in a previously glaciated area of Northeast British Columbia. A combination of seismic refraction and electrical resistivity tomography (ERT) profiles were acquired to non-invasively map the subsurface geology, from which select locations were proposed for targeted test pitting to ground truth results. At crossing locations where the combined investigation results identified potential risk with the preliminary borepath design (e.g., in and out of shallow bedrock), the results were then used

to optimize the depth profile, and to select the best-suited crossing configuration, boring method and tooling.

SEPTEMBER 16, 2020 - WEDNESDAY AM

CGS HERITAGE SESSION

SESSION CHAIR: JACQUES LOCAT

84 | Kemano Project – 70 years of development

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The Kemano hydroelectric facility came online in 1954 to provide electricity for the world's largest hydroelectric-powered aluminum smelter. This was the largest privately funded construction project in Canadian history. The Kemano tunnel and powerhouse had three phases of construction over a 70 year period. In the 1950s, the Nechako reservoir was created behind the 97 m high and 457 m wide Kenney dam. The dam reversed the flow of water from a 13000 km² area of Fraser River watershed toward the powerhouse. A 16 km long horseshoe-shaped tunnel with an 8 m span was blasted through the coastal mountains at an elevation between 790 and 830 m above sea level to carry water westward to a powerhouse built underneath Mount DuBose near sea level. In the early 1990s, construction started on a second tunnel using a 5.73 m diameter tunnel boring machine. Only the downstream portion of this tunnel was completed before the project was suspended by the provincial government. In 2007, Rio Tinto purchased Alcan, and subsequently spent billions of dollars to upgrade the smelter in Kitimat. To ensure long-term reliable electrical power, the second tunnel needed to be completed to provide a back-up to the original tunnel. The project consists of two phases. The first phase, completed in 2013, consisted of the construction of the interconnections between the new tunnel and the existing penstocks and a second surge shaft and tunnel adjacent to the second tunnel. The second and final phase involves refurbishing the existing 8.4 km of the tunnel and completion of 7.6 km of tunnel, with a new tunnel boring machine that was commissioned in 2018. Of note, the relationships and interactions with the First Nation communities have significantly evolved from the beginning of the project to the present.

98 | The Canadian Geotechnical Society's 1980s Canadian Geotechnical Heritage Book Project

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In the early 1980s, the Canadian Geotechnical Society began an initiative called the "Canadian Geotechnical Heritage Book Project". The project was to document the history of Canadian geotechnique through the eyes of Dr. Robert Legget and Dr. Robert Hardy, the two most prominent figures in the history, and more than 70 other individuals who were interviewed. Unfortunately the project was halted in 1986, but all information collected, including paper transcriptions of the interviews, was archived at the University of Alberta. Since then, a small portion of the information collected has been used, and is being used, for various research purposes. There is still a tremendous amount of additional primary source information available for researchers of the history of Canadian geotechnique.

446 | The evolution of direct simple shear testing

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Prior to Kenneth Roscoe's work at Cambridge University, the only available shear testing device was the Direct Shear (DS) test, which had a significant limitation in that it did not permit rotation of the principal axes during shearing. In this test, the sample was forced to fail along a specified failure surface between the upper and lower parts of the shear box. In 1953, Roscoe improved the direct shear test with the addition of hinged walls. This test facilitated rotation of the principal axes, enabled simple shear and did not force the soil to fail through a specified failure surface. This test has been termed the Simple Shear test. The Norwegian Geotechnical Institute (NGI) later modified the Roscoe 1953 shear test by using a cylindrical sample and a wire reinforced rubber membrane to constrain the sides. This test is termed the Direct Simple Shear Test (DSS). The Roscoe 1953 and the NGI 1966 test are still commonly used today. The key development since the 1960s has been the addition of cyclic loading capabilities. This has furnished the Cyclic Direct Simple Shear (CDSS) test a very important device for investigating the behaviour of soils subjected to seismic, wave and other dynamic load effects. The main controversy with respect to the efficacy of DSS

has focused around the ability of the test to impose uniform stresses throughout the sample and whether the test invokes plane strain conditions during shearing. The results of a detailed literature review related to the above-mentioned considerations are discussed in this paper.

493 | Paper and real pipelines of the Canadian Arctic

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Following the 1968 discovery of oil in Prudhoe Bay, Alaska, an increase in exploration in northern Canada generated widespread interest in pipelines southward across the Canadian arctic. Pipeline routes spanned the Yukon, Mackenzie Valley and the west coast of Hudson's Bay. Geotechnical issues associated with northern development were spurred leading to greater understandings in permafrost engineering and the impact of linear development on permafrost. In 1969, the Associate Committee on Geotechnical Research of the National Research Council of Canada (NRCC) organized a conference on permafrost problems related to mining and oil and gas production in the North. The conference was held at the University of Calgary. During the 1970s several large pipeline projects were initiated and eventually abandoned, including Beaufort Oil Pipeline project, Canadian Arctic Gas Study, Foothills Yukon, Foothills Dempster Lateral and Polar Gas (east and west). A significant amount of research was funded at the University of Alberta and the Geological Survey of Canada.

Most of this work ended gradually as a result of the Berger Inquiry report released in mid-1977, which recommended a ten-year moratorium on pipeline construction in the Mackenzie Valley, leading to alternative routes in the Yukon. Subsequent economic imperatives and discovery of hydrocarbon reserves in southern Canada essentially stranded the northern gas and oil resources.

The paper presents an overview of these early developments, including the enormous increase in engineering knowledge of permafrost engineering, pipeline-frozen soil interaction, slope stability in permafrost and other aspects. Full scale pipeline testing in Inuvik, Norman Wells, and Calgary are discussed as is a summary of ditching trials in the high Arctic that tested trenching principles that are still applied today.

494 | The Canadian Geotechnical Virtual Archives

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As ably summarized by the engineer and historian Henry Petroski, the degree to which a profession's history is known, remembered, preserved, and honoured influences how this profession is acknowledged and respected outside the confines of its own practice. The Canadian Geotechnical Society (CGS) has long recognized the importance of preserving its history. Through its Heritage Committee, the CGS actively maintains the Canadian Geotechnical Virtual Archives, which are part of the cgs.ca web site.

The paper presents an overview of the contents of the Virtual Archives, which holds records relating to the CGS from its formation to the present. This includes details of the society's history, profiles of past contributors and groups of contributors, and summaries of geotechnical projects of historic significance. These are freely available in the form of digitized articles, photographs and videos. It is believed that becoming familiar with these heritage items will give Canadian geotechnical professionals a sense of identity and pride in our profession.

504 | The Terzaghi, Peck and Casagrande historical libraries - a resource for the geotechnical profession

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NGI is the custodian of three historical libraries, the Terzaghi Library, the Peck Library and the Casagrande library. This collection of manuscripts, photographs, original technical drawings, artistic drawings, anecdotes, university courses, correspondence and project reports by four of the leaders of our profession is unique, from a geotechnical and a bibliographical point of view. The geo-libraries are today the largest collection of original manuscripts that documents the birth of a scientific subject. The paper tells the story of the libraries and takes the reader on a illustrated tour of the libraries. The libraries are above all a monument to the friendship, mutual respect and trust of the four geotechnical leaders. Originally (1967) a wall of 12 metres run of Terzaghi material from Vienna, the historical libraries are now both a large physical and digital repository forever available to our profession. In addition to their valuable technical content, the collections give insight into

Terzaghi, Peck and Casagrandes' personality and creativity, work habits and methods, new developments and accomplishments, relations with people, their sense of organisation (or disorganisation) and the activities they enjoyed. One can find, for example Terzaghi's "Notes on Construction (1912-13)" which cover almost the entire field of civil engineering and led to the invention of soil mechanics. The libraries are also treasures of inspiring quotes that many of us have not heard before or forgotten. As advanced insight, a short time in the libraries reveals that:

- Karl Terzaghi was a brilliant, fearless and enthusiastic man, a clear independent thinker.
- Ralph Peck was a conscientious, diplomatic, down-to-earth and caring gentleman.
- Arthur Casagrande was a gifted teacher and consultant with bold, “no-nonsense” ideas.
- Leo Casagrande was a pioneering educator and consultant, a man of substance with amiable personality.

SEPTEMBER 16, 2020 - WEDNESDAY AM

APPLICATION OF REMOTE SENSING AND MAPPING I & STRUCTURES FOUNDED ON CLAY SHALE I

SESSION CHAIR: JESSE MYSIOREK

288 | Automatic reflector-less surface deformation monitoring of a 21-lane highway during SEM Tunneling construction

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In current tunneling and other underground constructions, geotechnical instrumentation and monitoring has become a standard practice which allows for the instant evaluation of the construction impact to validate or adjust design/construction parameters as well as to protect infrastructure and public safety. Among various instruments, robotic total station (RTS) is one of the most effective tools capable of providing automatic, high precision and near-real time monitoring of ground and structure deformation. RTS is primarily known to operate in reflector mode in which the RTS is tracing optical prisms attached to the monitored objects while under some circumstances, installing and maintaining a sufficient number of prisms is not practical due to financial or logistic constraints.
This paper introduces a case study of utilizing RTS in reflector-less mode to monitor ground deformation during an on-going high-profile Sequential Excavation Method (SEM) tunneling project in Canada. The studied project requires continuous monitoring of nearly 500 points across 21 lanes of highway with a fast monitoring frequency, which makes it not practical to install prisms as monitoring points without having a significant impact on the highway traveling lanes or limiting the array of monitoring points. This paper briefly describes the project followed by the explanation of RTS workflow. Then focuses are placed on the design considerations of this unique reflector-less monitoring system and solutions to address challenges during its implementation and maintenance. Finally, selected monitoring results are presented with comparison to other supplemental instruments and RTS camera imaging. The paper is aimed to contribute to the literature on reporting the large-scale use of reflector-less monitoring technique in similar applications, which will become more common due to increasing tunneling activities in urban areas.

365 | Webequie First Nation supply road: Terrain analysis of the first Indigenous-led environmental assessment in Ontario

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Webequie First Nation, located approximately 500 km north of Thunder Bay, Ontario, is developing an all-season road between the community of Webequie and a proposed Ring of Fire mining development around Esker Camp near the Mukutei River, approximately 110 km to the east. The Webequie First Nation Supply Road (WSR) project is the first Indigenous-led environmental assessment in Ontario. Once completed, the WSR will offer year-round movement between the community and the future mine site and will facilitate economic opportunities for the community. This paper presents a description of the terrain analysis and mapping within the proposed route corridor, along with potential aggregate sources and stream crossings, that will guide the identification of an optimal route based on terrain and engineering considerations.

La Première Nation de Webequie, située à environ 500 km au nord de Thunder Bay, en Ontario, développe une route toutes saisons entre la communauté de Webequie et un projet de développement minier Ring of Fire autour d'Esker Camp près de la rivière Mukutei, à environ 110 km à l'est. Le projet Webequie First Nation Supply Road (WSR) est la première évaluation environnementale dirigée par des Autochtones en Ontario. Une fois terminé, le WSR offrira un mouvement à toute-l'année entre la communauté et le futur site minier et facilitera les opportunités économiques pour la communauté. Cet article présente une description de l'analyse et de la cartographie du terrain dans le corridor d'itinéraire proposé, ainsi que des sources d'agrégats potentiels et des traversées de cours d'eau, qui guideront l'identification d'un itinéraire optimal en fonction du terrain et des considérations d'ingénierie.

397 | Terrestrial laser scanning (TLS) deformation monitoring of a high-fill embankment in the Arctic

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The Inuvik-Tuktoyaktuk Highway (ITH) in Northwest Territories, Canada was built during winter on ice-rich continuous permafrost with no cuts in the ground to preserve the permafrost foundation. Several high-fill sections were required along the highway to meet vertical geometry specifications. Embankments in Arctic regions are susceptible to deformations due to thawing of the frozen fill material and permafrost foundation at the embankment toes. One high-fill section along ITH was reinforced with woven geotextiles to reduce slope movements. The reinforced section and an adjacent control section were instrumented to monitor slope movements. Terrestrial laser scanning (TLS) was conducted at the research site in June 2018 and June 2019. A real-time kinematic (RTK) survey system was used to measure ground control point (GCP) positions for georeferencing the TLS reconstructed point clouds. Embankment deformations were determined by point cloud comparison. TLS deformations were compared to instrumentation deformation data. This paper presents the methodology and results of the TLS deformation monitoring. Limitations of the technologies are discussed and recommendations for deformation monitoring using TLS are provided.

313 | Improving slope stability analyses by use of 3d fem for highway embankment over clayey soil

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In Quebec, highways are mostly constructed on clayey deposits. Embankments constructed on such compressible soft soils are further subjected to slope stability issues and require an in-depth understanding of the failure mechanism in order to choose the right analysis method.

Different methods such as the limit equilibrium method (LEM) and the finite element method (FEM) are commonly used to calculate the safety factor (FS) as the primary design

criteria. However, the latter is highly dependent on previous methods, approaches and assumptions.

2D slope stability analysis are widely used to solve geotechnical problems. However, application of 2D modeling sometimes forces the user to considerable simplification of the problem which impacts directly the safety factor. The main disadvantage in 2D analysis is that either the critical section must be defined, or in consequence several cross-sections must be analysed to provide a reasonable assessment of the 3D effect. Additionally, it is usually found that using a 2D analysis on slopes where 3D conditions prevail, will lead to an underestimation of the slope's safety factor.

Moreover, highways are sometimes constructed on highly fluctuated areas where 3D calculations are necessary in order to take the complexity of geometry and subsurface geology under consideration.

This study compares the results of 2D and 3D analyses using Midas GTS-NX, Soilworks and GeoStudio-SLOPE/W. The construction of a new highway alongside autoroute 50 in Gatineau Quebec will be used as a case study. A large segment of the new highway will be simulated on the 3D model using the construction stage model. The results obtained will be discussed in a detailed fashion and then compared with chosen critical sections that were evaluated for the same segment using a 2D analysis. A technical comparative discussion regarding the design procedures as well as the reasonable equilibrium between safety and economy will follow.

LANDSLIDES AND GEOHAZARDS III

SESSION CHAIR: TIEQUN FENG

341 | Prediction of ground motion parameters in 1D ground response analysis

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Several building codes recommend performing effective stress ground response analysis when a liquefiable stratum is identified. While total stress ground response analyses have been well verified against downhole array recordings and centrifuge test experiments, effective stress analyses have yet to be thoroughly validated. To this end, a database of potentially liquefiable sites instrumented with at least a pair of surface and at-depth accelerometers, that have recorded ground motions of varying amplitudes and pore pressure buildup has been compiled. A first step toward the validation of the effective stress model is to assess their response with respect to the expected behavior of liquefiable soils. The second step is to study the performance of such models in ground response analysis of sites contained in the database.

This paper first compares the pore pressure response as a function of shear strain against existing empirical correlations published in the literature representing the expected behavior of liquefiable soils. In the second part, the prediction of common ground motion intensity measures (IM) is investigated. IMs are used in various simplified seismic design procedures such as the assessment of liquefaction, seismic slope stability, structural response and the estimation of the damage potential of earthquakes. However, their assessment resulting from ground response analysis procedures has not been widely investigated to date. The uncertainty in the prediction of several IMs evaluated at the ground surface from each ground response model is thus quantified and compared. The selected IMs include the Arias Intensity (AI), significant durations (D5-95 & D25-75), number of equivalent loading cycles (Neq), cumulative absolute velocities (CAV & CAVSTD), shaking intensity rate (SIR), mean period (Tm), smoothed spectral predominant period (To) and predominant spectral period (Tp).

379 | Kinematic element method for slope stability

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Over the past century various approaches have been developed to handle slope stability, including the well-known ordinary method of slices that includes the Fellenius and Bishop solutions, as well as the more rigorous procedures due to Janbu, Spencer, and Morgenstern and Price (M&P).

In 1982, Gussmann introduced the kinematic element method (KEM) that easily accommodates varying non-circular failure surfaces based on non-associated plasticity to solve. KEM provides a systematic approach that rigorously accounts for the kinematics and statics of failure. It gives and provides an upper bound solution that can implicitly account for reversal in shear force direction due non-homogeneous ground conditions. Although quadrilateral elements are typically adopted to accommodate more realistic internal force distributions, one may use the methodology within the method of slices framework. The general algorithm can be presented as a matrix method or as a recursive procedure. Within the context of slope stability, the solution provides an optimized failure mechanism and the corresponding factor of safety.

This paper presents a version of the KEM based on the latter procedure and proposes an extension to elasto-plasticity that allows a simultaneous treatment of the kinematic and static problems. Examples are given to compare the KEM solutions to those provided by the Bishop and M&P strategies. The effect of restricting the interelement boundaries to vertical lines was found to overestimate the factors of safety and resulted in more rigid failure surfaces. The KEM as originally conceived by Gussmann (1982) provided upper bound solutions while those of KEM in terms of the method of slices were consistent with those based on limit equilibrium principles.

Gussmann, P. (1982). Kinematical Elements for Soils and Rocks. In Z. Eisenstein (Ed.), Fourth International Conference on Numerical Methods in Geomechanics. 1, pp. 47-52. Edmonton: University of Alberta Printing Services.

414 | Clay shear strength rate dependency and the available strength along earth slides rupture surfaces

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Earth slide movements are affected by the shear behavior of the material on their shear zone. In many cases, the earth slide shear zones are made of weak clay layers. Traditional geotechnical lab testing utilizes standard loading rates for determining the shear behavior of clay. When an earth slide movement creates field shear rates that are faster or slower than the typical laboratory test ranges, the available shear strength along the rupture surfaces can differ from the laboratory predicted strength. The effect of the clay shear strength rate dependency on observed behavior of earth slides founded on clay beds are examined in this paper. This paper demonstrates how some of the earth slides characteristics can be explained by considering the rate dependency of the shear strength of clay. This paper provides a review of available clay shear strength within an earth slide shear zone from pre-failure to during failure conditions. The pre-failure peak and residual shear strength rate are reviewed. The residual strength during failure and its dependency on the clay mineralogy, clay content, pore fluid chemistry, and stress history is discussed. In general, the lower shear rate, the smaller the available shear strength along a rupture surface. Both peak and residual shear strength reduce with slower shear rate before the failure. After full development of the rupture surface, the shear strength increases nonlinearly with the increase in shear rate. The nonlinear increase in the clay strength during failure is due to the clay viscosity shear thinning characteristics during the failure. The clay viscosity depends on the clay mineralogy, pore fluid chemistry, and liquidity index. By corelating the clay viscosity with the stress history, clay mineralogy, and clay content; an estimation of the available shear strength of clay beds are provided.

508 | Effects of structure on the mechanical behavior of loess: implications for flowslides in cemented soils

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Loess contains predominately silt-sized quartz grains that are bonded by various cementation agents, that is of significant interest to the understanding of the mechanical properties of lightly cemented soils. Loess is problematic upon wetting as its metastable

structure can rapidly transform from a cemented solid body to a fluidized material. The results of series of isotropically consolidated undrained tests (CIU) compare the large-strain behaviors of intact and reconstituted specimens, that show state-dependent flow instability due to the effect of structure. A constitutive understanding is gained using NorSand model by comparing the computed undrained behaviors of intact and reconstituted loess at the same state parameter. The results confirms the strong effect of structure on flow instability. The drained-to-undrained transition in the loading path of loess is simulated, and indicates a rapid reduction in strength under such a transition for loess, thereby the triggering mechanism of loess flowslides.

12 | Historical aerial photographs with digital photogrammetry to investigate the development of the Chin Coulee landslide

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The Chin Coulee landslide is situated on the northern slope of the Chin Coulee reservoir, adjacent to Alberta Highway 36. The landslide is approximately 350 m wide and up to 45 m deep. Its length is approximately 200 m long, with the toe of landslide located within the reservoir. The total landslide volume is estimated at approximately 2 million cubic meters. Highway 36 is located upslope from the crest of the landslide and it has been affected by landslide retrogression to the extent that realignment has been necessary to maintain the highway operational.

Alberta Transportation actively monitors the Chin Coulee landslide as part of its geohazard management plan. Resource allocation for geohazard management needs to meet public safety and highway operation requirements, as well as resource availability and the presence of other geohazards in the province. To that end, understanding the landside mechanisms, triggers and potential evolution are fundamental for defining the most cost/effective landslide management strategy. This paper presents the use of historic aerial photographs in combination with modern digital photogrammetry tools to investigate the development of the Chin Coulee landslide, and its evolution towards its current state. The authors have found that this technique makes use of important legacy information available in the province and enhances the current practices for landslide investigation.

GEOSYNTHETICS I

SESSION CHAIR: ANDREW BIDWELL

450 | Effect of contact variability on interface transmissivity and implications for mine waste covers and ponds

PRESENTING AUTHOR: Miss Farah Barakat[1]
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Studies have shown that the interface transmissivity between a geomembrane (GMB) and geosynthetic clay liner (GCL) is scale dependent and decreases with the wetted distance away from a hole in the geomembrane or hole in a wrinkle in the geomembrane. This has significance with respect to the leakage that can be expected, particularly at lower stress situations such as in covers and ponds. Based on the measured transmissivity in a series of tests conducted at different stress levels, the variability in transmissivity in tests for a contact area of 180 cm^2 provides statistical data defining the distribution of the transmissivity resulting from subtle variations in contact conditions at different stress levels. This paper examines the implications of this variability with respect to the leakage through a hole in a wrinkle in the geomembrane over a geosynthetic clay liner considering the effects of stress. It is shown that at overburden stresses of 10 and 25 kPa, when one considers the statistical distribution of transmissivity over a range of four orders of magnitude for an area of 180 cm^2 together with continuity of flow, then one can explain the observed decrease in transmissivity at a larger scale. Based on this, the effects on potential leakage through composite liners in mine waste covers and leakages from storage lagoons are reported.

337 | Innovative mechanically stabilized earth walls with geotextile geocells

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Structures reinforced with geosynthetics consist in increasing the mechanical performance of a soil (mainly shear resistance) by associating it with flexible geosynthetics inclusions. One of the important issues in the construction of geosynthetic reinforced walls is the supply of natural backfill materials with the required properties needed for the stability of the wall. Indeed, unlike geosynthetics that exhibit stable properties due to extensive quality controls during the manufacturing process, soil matrix will vary from a site to another and even from the beginning to the end of the excavation work. It influences the soil stability itself and also the soil-geosynthetic interface.
As it minimizes the influence of soil characteristics on the stability of the reinforced structure, M3S geotextile geocells make possible, in addition to the construction of reinforced structures with complex shapes, to reuse the soil material excavated on-site to build the wall, including those with very poor geotechnical characteristics.
This publication presents the M3S cellular system and its mechanical and functional characteristics. It also gives the main design steps to consider and the limits of the system.
Finally, examples of realization will be given with their associated environmental and social footprint reductions due to the use of onsite materials and the reduction of traffic.

399 | Multi-axial geogrid stabilized working platform for ringer crane operation

PRESENTING AUTHOR: Dr. Lois Schwarz[1]
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Design and construction of a geogrid stabilized working platform for use with a ringer crane to construct a petrochemical facility in the southern US was undertaken in 2016 and completed in 2017. The PTC-200 DS ringer crane was configured with a maximum bearing pressure of 192 kPa, a load spreader ring with outside and inside diameters 53 m and 33.2 m, respectively, and was rated the third largest ringer crane in the world. Stringent criteria for differential and total settlement needed to be met to ensure successful operation of the crane. Site soil conditions exhibited predominantly fat clays, oftentimes slickensided, and the occasional presence of sandy silt lenses and pockets. Original plans for the crane

bearing pad were to construct a deep foundation system composed of two hundred 457-mm square concrete piles and a 61-m diameter concrete pile cap. Alternatively, a geogrid stabilized working platform was designed to improve allowable bearing capacity of the soil and to decrease potential settlement while ultimately being less expensive than a concrete deep foundation system. Estimated settlement was based on a pseudo rectangular section of the annulus area and analyses were performed at four locations, center, corner, midpoint of short side, and midpoint of long side of the rectangular section. The geogrid mechanically stabilized working platform designed and constructed was 1829 mm thick and composed of five layers of multi-axial geogrid and crushed angular graded aggregate material. Estimated total cost savings of $3.1 million included savings from reusing the crushed stone at other site locations compared to the concrete foundation alternative and completing the project 32 days ahead of schedule. The success of the geogrid stabilized platform was further demonstrated when it withstood Hurricane Harvey in August 2017 without damage and the crane was back in operation the day after the storm passed.

GEOENVIRONMENTAL ENGINEERING III & SUSTAINABLE GEOTECHNICS I

SESSION CHAIR: CATHERINE MULLIGAN

116 | Thermodynamic-based model for the thermo-poro-elastoplastic behavior of saturated clay

PRESENTING AUTHOR: Mr. Mohammadhossein Sojoudi[1]
CO-AUTHOR: Dr. Biao Li[1]
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The thermo-poro-mechanical or thermo-hydro-mechanical (THM) coupling in clay related geomaterials is one of the most important issues in sustainable geotechnics. Clay soils have complex mineral composition and microstructure; thus, the study of thermo-poro-mechanical is complicated. Previous studies shed little light on the difference between a thermal plastic strain and thermally induced dehydration behaviors. In this study, we propose a thermodynamic-based constitutive model for describing the thermo-poro-elastoplastic behavior of saturated clay. The proposed model considers the effect of temperature variation, mechanical loading, and rate of loading on elastoplastic strains and dehydrations. The thermo-mechanical behavior is captured by using the thermodynamics laws and subloading surface plasticity. The hardening rule is established by using laws of physical conservation, energy dissipation and plastic flow. Dehydration behavior is considered using the laws of thermodynamics for chemical processes. A comparison between model predictions and experimental data for some clay soils with different geological origins is presented and a reasonable result is achieved.

Keywords: Thermodynamics, Thermo-elastoplastic model, Subloading surface, Clay bound water, Dehydration

143 | Formulation of a sustainable geopolymeric binder based on pulp mill fly ash for subgrade stabilization

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The present study was conducted to develop a sustainable inorganic geopolymeric binder for subgrade stabilization, based on a non-hazardous wood-based fly ash generated in the pulp manufacturing mills. The alkali-silicate activation method at ambient temperature (~22°C) was employed for synthesizing pulp mill fly ash (PFA)-based geopolymer, by using sodium hydroxide (SH) and sodium silicate (SS) compounds. Initially, the optimal content of virgin PFA required to achieve the desired strength for weak silty soil subgrade was identified based on 28-day unconfined compressive strength (UCS) analysis. Further, the optimum formulation of PFA geopolymer was determined in terms of the UCS variations with mainly considering the different influencing parameters such as activator to ash ratio, SH to SS ratio, and SH molarity. The compacted mixtures of soil and PFA, with varying proportions of SH and SS were subjected to UCS test after 7 days, 14 days and 28 days of curing. In order to evaluate the underlying mechanisms of stabilization in the soil and PFA-geopolymer systems, additional microstructural observation of untreated and treated soils was carried out using SEM-EDS, FTIR and XRD tools.

The experimental results demonstrated substantial strength improvement of subgrade with 20% virgin PFA; moreover, the strength increment was proportional to PFA content and extent of curing. The soil treated with PFA-geopolymer exhibited relatively higher strength when compared with virgin PFA-treated counterpart. The optimum conditions for achieving higher rate of PFA geopolmerization was determined to be 5 molar SH solution, with activator to ash ratio of 1:1, and SH to SS ratio of 1:1. The microstructural observations also revealed the formation of an inorganic PFA-based geopolymer network on the soil surface with high concentrations of calcium and silica, which resulted in the significant strength enhancement of subgrade.

206 | Developing a sustainable post-fire soil restoration technique using pulp mill fly ash

PRESENTING AUTHOR: Ms. Jaspreet Bring[1]
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Post-fire soils are vulnerable to higher rates of erosion and surface runoff primarily due to loss of protective surface cover combined with degradation of soil structure and increased water repellency. This study aims to develop a sustainable, eco-friendly and cost-effective strategy for post-fire soil restoration by utilizing a non-hazardous industrial waste product called pulp mill fly ash (PFA). Initially, this study will assess the impacts of wildfire severity on the critical forest soil properties located in the Okanagan region of British Columbia, by conducting comparative physico-chemical, mineralogical, and microstructural analysis of burnt and unburnt soils. Further, the feasibility of utilizing PFA for improving the mechanical and hydrological properties of burnt soil will be evaluated with various laboratory tests conducted on burnt soils treated with different PFA contents. The mechanical improvement will be determined in terms of variations in the soil aggregate stability, while the hydrological properties include soil water characteristics, infiltration rate and hydraulic conductivity. The underlying mechanisms which caused improvement following PFA treatment will be investigated through detailed microstructural analysis using characterization tools and techniques such as FTIR, SEM-EDS and XRD. The results revealed that PFA treatment improved soil aggregate stability by 6.4% and 14.9% with 5% and 10% PFA content, respectively, over 14 days of curing period. The optimum PFA content of 10% caused significant improvement of soil water holding capacity, as well as it reduced percentage of macropores and restored hydraulic characteristics. An increased aggregate stability in PFA treated soil suggested formation of new cementitious compounds predominantly consisting of calcium-silicate bridges, which was also revealed in microstructural analysis. Based on this study, PFA can be considered to be a potential candidate for simple, energy-efficient and environmentally-friendly treatment method to improve and restore fire-burnt soil properties to pre-fire levels.

343 | Assessment of a closed-loop geothermal system for seasonal freeze-back stabilization of permafrost

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Wastewater treatment lagoons in permafrost rich areas can be complicated and typically use frozen ground as a containment system for the waste and leachate, particularly where importing competent borrow material may be too costly. KGS Group has been working on developing the concept of using conventional closed loop geothermal systems in the sediments below the base of the lagoon to allow a natural winter air refrigerated solution of calcium chloride (anti-freeze) and water to be circulated below the lagoon to freeze the soil below the lagoon. This freeze-back of thawing permafrost below the lagoon base would extend the life of the lagoon. This concept could be implemented post initial construction of a lagoon using well-developed horizontal directional drilling techniques. Similar systems have been implemented for the addition of heat to the subsurface in the summer for winter heating. This paper assesses the effectiveness of the geothermal freeze back system using a heat transfer model developed in COMSOL Multiphysics, a finite element software. The model evaluates variable HDPE pipe spacings, pipe diameters and flow velocities with the circulation of the calcium chloride solution to temperatures as low as -30°C. Piping may be sized to have very low friction losses and therefore, low energy consumption for limited additional operational costs. The results of this assessment will be valuable in understanding the design and costs of a conventional geothermal freeze-back system for large developments over permafrost.

244 | Case Study - Challenges faced in Portlands Flood Protection and Enabling Infrastructure (PLFPEI) Toronto project

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This paper focuses on the main challenges faced during the installation of a full depth secant pile wall around the perimeter of the area of Work in Portlands Flood Protection and Enabling Infrastructure (PLFPEI) project. The secant pile wall is designed to facilitate excavation and construction of a naturalized river channel to protect against flooding. It consists of 2 components: structural and non-structural. The structural secant pile wall provides support during excavation and backfill operations within the area of Work while both components will serve as a groundwater cutoff wall.

Aside from equipment breakdown and maintenance, several obstacles caused significant delays during construction. For instance, given that the site is adjacent to Lake Ontario, multiple time-consuming measures were implemented to combat the high water infiltration rates. Concrete was placed using the tremie method instead of being free-falled. Sediments were building up at the bottom of the holes in certain locations at rates exceeding 1 m/hour which necessitated clean out procedures either with the drilling or the bailing bucket.

Additionally, the geologic conditions gave rise to certain problems. In fact, the varying bedrock levels lead to piles exceeding 45 m in length in order to reach the required 3-m socket into weathered shale. The deep piles posed a challenge for contractors in regard to the 0.35% verticality tolerance measured by the Jean-Lutz. Boulders and wood obstructions mostly from previous site use caused difficulties in advancing liners at certain sections. Also, since the construction extended during winter, the cold weather caused the winterization of the mobile batch plant and certain equipment including insulating the pump trucks.

The complexity of this project from conception to implementation has advanced the status quo of infrastructure projects in the region through the employment of numerous measures and techniques as highlighted in this paper.

OIL SANDS GEOTECHNOLOGY I

SESSION CHAIR: JOHN SOBKOWICZ

400 | Long-term consolidation of two new polymer treatments of oil sands fluid fine tailings

PRESENTING AUTHOR: Mr. Kwaku Amoako[1]

CO-AUTHORS: Dr. Ahlam Abdulnabi[1], Dr. Nicholas Beier[1], Dr. Paul Simms[2], Dr. Joao Soares[1], Mr. Kushbu Vandara[2], Mr. Daniel Moran[1]

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Total existing and legacy oil sands fluid fine tailings (FFT) in Alberta exceeds 1.2 billion m3, posing an environmental challenge for both reclamation efforts and physical stability. Thickening of FFT by adding polymer flocculants is one of the cost-effective treatment technologies used by operators to dewater FFT to limit those volumes. This paper examines the effects of two new polymers (cationic and neutral) on the consolidation behavior of FFT compared to A3338 polymer treatment. Seven large strain consolidation experiments were completed; two for each polymer type and one control sample of untreated FFT. Sedimentation, filtration and basic properties of untreated FFT and FFT treatments were also analyzed.

Results indicate that the neutral polymer increased the initial hydraulic conductivity of FFT by four orders of magnitude compared to the cationic and anionic polymers. At the end of self-weight consolidation, a demonstrably higher dewatering efficiency of the neutral polymer on FFT was observed relative to the cationic and anionic polymers determined by calculating the net water release of each polymer. At each load step, the hydraulic conductivity and compressibility of FFT treated using the neutral and cationic polymers were higher compared to the anionic polymer. Moreover, above a solids content of 30 %, the neutral polymer produced about a 40 % increase in the shear strength of treated FFT relative to the cationic polymer, which is attributed to the distinct structure the neutral polymer creates following treatment. The measured capillary suction time of the samples immediately after treatment indicates that dewatering FFT by suction is seven times faster when FFT is treated using the cationic polymer than the anionic polymer.

405 | Consolidation – Creep modelling of pilot's studies on deposition of flocculated fluid fine tailings

PRESENTING AUTHOR: Ms Narges Gheisari[1]
CO-AUTHORS: Dr Shunchao Qi[1], Prof Paul Simms[1]
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Pilot studies of flocculated fluid fine tailings (fFFT) deposits are modelled using coupled large strain consolidation – creep formulations embedded in the UNSATCON software. The creep formulation employed is based on theory developed by Vermeer, a hypothesis B type model that implies a strain rate dependency on the location of the compressibility curve. The pilots comprised deposits of tailings placed in 14 m tall x 2.75 m wide caissons. Here we present comparisons of data from tailings flocculated with a conventional anionic polymer. Simulations are presented for large strain consolidation only, as well as creep-consolidation, using reasonable ranges in the k-e function and the creep parameters. The use of a creep model improves fits to all measured properties (settlement and depth profiles of density and pore-water pressure), compared to the consolidation only results, though agreement in still not perfect. Using different groups of plausible parameter sets, the model was then used to extrapolate to full scale behavior. In general, use of creep model results in relatively small (~10%) increase in the overall settlement of the deposits, but a marked decrease in the rate of pore-water pressure dissipation. The significance of these results to implantation for full scale deposits are discussed, as are areas of uncertainty requiring further attention.

425 | 2D and axisymmetric large strain consolidation modelling for tailings applications

PRESENTING AUTHOR: Dr. Amin Esmaeilzadeh[1]
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A two-dimensional large strain consolidation model is presented. The model uses a piecewise linear formulation for large strain, which implies nodes that are associated with a constant mass of solids, whose positions are updated over time. Fluxes are calculated based on 2D gradients between adjacent nodes. Regions associated with each of these nodes to calculate fluxes only deform vertically, and can slip past each other. This appears to accommodate large strains without the need for remeshing due to mesh distortion, and appears to retain sufficient accuracy. The model is validated against other analytical and numerical solutions for axisymmetric and 2D consolidation. An example analysis of 2D

consolidation in a hypothetical tailings impoundment is shown. The analysis shows the formation of a beach, and how the variable water height may affect overall consolidation.

503 | Geotechnical Properties Determination to Evaluate Stability of Thickened Fluid Fine Tailing Deposits

PRESENTING AUTHOR: Alebachew Demoz[1]

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Terrestrial reclamation of fluid fine tailing (FFT) containment ponds starts with a necessary dewatering process. The dewatered FFT in its dedicated disposal site is then expected to develop in to stable landscape by self-weight consolidation. The feasibility of the supposition was investigated using shear strength and consolidation measurements of thickened FFT; cake.

Shear strength measurements were conducted under inundated and drained conditions. The cake gave a linear Mohr-Coulomb failure envelope with 1.2kPa cohesive strength and 6º friction angle. This indicates that the load bearing capacity of thickened FFT deposits is too low to support landscaping machinery.

The cake hydraulic conductivity was very low and similar to that of active clays. The coefficient of consolidation for the cake was nearly constant and had a mean value of 0.099 m2.s-1, also similar to active clays. The void ratio–effective stress–hydraulic conductivity power law relations constitutive constants were used as input to predict settlement using a finite-strain 1D model software. Model outputs indicate that consolidation by self-weight of cake, or thickened FFT deposit is extremely slow to create reclamation ready deposits. Both the shear strength and consolidation properties suggest that options that will increase the shear strength and hydraulic conductivity of thickened FFT have to be integrated in the process prior to placing them at final disposal sites. Amending the thickened FFT with coarse tailings can simultaneously increase the shear strength and hydraulic conductivity of thickened FFT and is likely the sole solution. The advantages of this method referred to as co-disposal thus far was not demonstrated because the coarse material was added into slurry (viscous) FFT, rather than thickened (plastic consistency) FFT reducing its impact. There are reports which raise the limitations of discharging treated FFT and this study goes farther by determining the geotechnical parameters.

90 | Evaluation of oil sands tailings using Ultrasonic Pulse Velocity Method

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CO-AUTHORS: Dr Paul Simms[1], Dr Giovanni Cascante[2]
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The Alberta oil sands mining and extraction processes in Northern Alberta yield vast volumes of tailings which are mainly consisted of water, fine clay particles, sand, chemicals, and bitumen. The disposal of this mixture in the tailings pond is one of the main reasons causing gravity segregation to occur. During this process, the stable suspension also known as the fluid fine tailings (FFT), is formed, which requires many years to consolidate. Thus, land reclamation becomes a huge environmental issue. Therefore, a proper understanding of the transformation occurs in density and structuration of mine tailings may be important to better plan the operation of deposition in the tailings ponds such that reclamation can be done when these ponds are no longer in use. Thus, this paper reports on the initial results of an experimental program designed to monitor changes in density and structure in FFT using ultrasonic waves. The experiments include not only the evaluation of wave velocities (compressional and shear) but also the changes in wave attenuation as a function of time.

SEPTEMBER 16, 2020 - WEDNESDAY PM

SOIL MECHANICS AND FOUNDATIONS VI

Session Chair: Leanne McLaren

181 | A case for a higher geotechnical resistance factor - piles driven to bedrock

PRESENTING AUTHOR: Mr. Michael Snow[1]
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Static pile load tests (SPLTs) have been carried out in conjunction with high-strain dynamic pile testing (PDA) at three different sites to investigate the pile capacity in support of the structural design of two buildings and a bridge. Conducting the pile load testing was considered an investment to achieve more cost-effective foundation designs for current and future projects. The Canadian Highway Bridge Design Code and the National Building Code of Canada permit higher geotechnical resistance factors when static or dynamic pile load tests are conducted to reduce the geotechnical uncertainty. In each case the owners found value in undertaking the load tests in order to be able to use higher geotechnical resistance factors as outlined in the Canadian Highway Bridge Design Code and the National Building Code of Canada.

In eastern Ontario a very common deep foundation type is the use of driven steel piles, either H-piles or pipe piles, driven to refusal on bedrock. In some cases, the site conditions require pile lengths that can easily be over 25 m, representing a material cost of the overall structure. For three case histories presented, the authors proposed and were retained to complete pile load tests to support a 50 percent increase in the factored Ultimate Limit States (ULS) axial geotechnical pile capacity. In all three cases both dynamic (PDA) and static load tests were completed, and the results supported much higher pile capacities than originally anticipated otherwise.

In view of the results of the SPLT and PDA tests, the paper also discusses the appropriateness of the current geotechnical resistance factors for piles driven to refusal on sound bedrock where in all the cases undertaken the structural capacity of the pile was the limiting factor.

360 | A study on pile setup of driven steel pipe in Edmonton till

PRESENTING AUTHOR: Mr. Jason Ni[1]

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As one of the major deep foundation type, driven steel pile (DSP) is widely used in all construction projects in Canada. Especially in rural northern Alberta areas where concrete supply is not accessible in a cost-effective manner, the DSP foundation is highly preferred by heavy industrial development such as oil and gas related facilities.

For driven steel pile set in the fine-grained soils, a significant pile-soil setup (pile capacity gain) is expected due to excessive pore water pressure dissipation after the pile installations. In the field, pile appeared to have a much lower capacity at the end of the installation compared to long-term performance. In a fast-paced construction environment, the time cost to wait and verify the pile long-term capacity is not desired. To proceed with the upper structure construction without any delay, a reasonable prediction of the DSP setup is required. However, a very limited study has been done for the rate of pore water pressure dissipation in clayey soils.

This study is aimed to provide a case study of the pile setup effect of DSP set in Edmonton Clay Till by using the finite element method compared to the field observation data. A numerical model is being built to allow foundation engineer to assess the pile setup behavior with available soil testing results and reasonable assumptions.

378 | Comment améliorer les études géotechniques avec les banques de données des puits

PRESENTING AUTHOR: Robert Chapuis[1]
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Il est important pour les ingénieurs en géotechnique et les entrepreneurs de connaître les conditions d'eau souterraine pour toute excavation temporaire ou permanente. Les informations souhaitées incluent les valeurs de la conductivité hydraulique, les débits de pompage anticipés, les rabattements anticipés, les risques d'instabilité mécanique. Cependant, les informations recueillies sont souvent limitées. L'étude géotechnique d'un projet est limitée généralement à quelques forages dans l'emprise du projet. Les informations tirées de cette étude locale peuvent être complétées par des informations publiques tirées des banques de données des puits. Ces banques renferment de nombreuses données trop peu exploitées en géotechnique. L'article fournit des exemples de données statistiques, relativement faciles à extraire, sur les débits de pompage dans les puits au voisinage d'un futur projet. Il donne aussi des informations sur la performance relative de diverses techniques de forage des puits, une performance qui varie selon le type de roc aquifère. On montre ainsi l'utilité des banques publiques de données sur les puits pour les professionnels et surtout les entrepreneurs qui doivent planifier, installer et opérer des systèmes d'assèchement des excavations.

328 | Experimental study on the critical height of an unsupported vertical cut

PRESENTING AUTHOR: Mr. Gregory Brennan[1]
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Construction of buried infrastructure, e.g. pipelines, storm drains, power transmission cables, etc., is commonly initiated by excavation or trenching. Excavation or trenching is inherently dangerous; therefore, it is important to adhere to guidelines to help prevent collapse and mitigate injuries or damage to adjacent properties. This is especially true for unsupported vertical cuts. Most excavation or trenching operations involve soils above the water table where the soil type and the influence of matric suction (i.e. negative pore-water pressure) are often overlooked in geotechnical engineering practice. In this study, laboratory tests are conducted to investigate the stability of an unsupported vertical cut in the vadose zone using a specially designed large-scale soil tank (B × L × H = 1.5 m × 2 m × 2.4 m) while taking into account the influence of matric suction. The soil tank is filled with

engineered sand and has provisions to simulate both saturated and unsaturated conditions by controlling the level of water. The experimentally determined maximum depth of an unsupported vertical cut (i.e. critical height) is compared with that obtained using a simple-to-apply, semi-empirical mathematical model. Additionally, a detailed description of the soil tank is presented.

SOIL MECHANICS AND FOUNDATIONS VII

SESSION CHAIR: ERTAN OZMEN

406 | Insights on threshold fines content

PRESENTING AUTHOR: Dr. Carmine Polito[2]
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As increasing amounts of non-plastic silt are added to a sand, its classification transitions from sand to silty sand to sandy silt and eventually to silt. This transition leads to a fundamental change in the soil's behavior from sand-like to silt-like with a corresponding increase in compressibility and decrease in both shear strength and resistance to liquefaction. Numerous studies have shown that this change in behavior occurs over a relatively narrow range of silt contents. This range is referred to by several names in the literature, including threshold fines content (TFC). The TFC represents the silt content at which the soil begins to transform from a sand matrix, in which the silt particles are entirely contained in the voids between the sand grains, to a silt matrix that contains isolated sand grains. Below the TFC, the soil behaves essentially as a sand; above the TFC the soil behaves essentially as a silt.

While the concept and importance of the TFC has been increasingly recognized over the last 20 years, several aspects of it have not been widely discussed in the literature. This paper will focus on four of these aspects: the existence of both an upper-bound and a lower-bound TFC for a given soil, the range and distribution of TFC upper- and lower-bound values for natural soils, the effect of relative density on the TFC, and the behavior of soils with fines contents between the upper-bound and lower -bound TFC.

447 | Deep foundation design and optimisation: A case study

PRESENTING AUTHOR: Ms Raluca Opris[1]
CO-AUTHORS: Ms Bintou Keïta[1], Dr Michel Küntz[1]
[1]*WSP, Montreal, Canada*

As part of a foundation design for a structure supporting a new fire protection system at the Norcan Oil Terminal, a geotechnical investigation campaign satisfying the needs of the project was carried out. Following the campaign that included different sampling and testing methods (drilling, field vane test and CPT), the interpretation of field and laboratory data results was undertaken and allowed the design of deep foundations. The dimensioning of the piles supporting the fire protection structure was carried out and optimized based on the structural loading cases and ground conditions. Pile loading tests were also carried out which validated the design. All the steps taken, validation of the calculations using in situ tests and the dimensioning methods used are presented.

470 | Simple techniques for numerical modeling of temporary excavation support systems in unsaturated soils

PRESENTING AUTHOR: Mrs. Maha Saleh[1]
CO-AUTHOR: Professor Sai Vanapalli[1]
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Excavation support systems are often located above the ground water table (GWT) where the soil is typically in an unsaturated state. The presence of capillary suction within the vadose zone (i.e. above the GWT) contributes towards an increase in the soil shear strength and stiffness. However, current design procedures ignore the contribution of capillary suction and assume saturated soil conditions. This is because reliable prediction of the mechanical behavior of unsaturated soils is challenging. However, extending saturated soil mechanics principles result in an erroneous design for excavation support systems, especially in semi-arid and arid regions, where the GWT is typically at a greater depth. In this paper, a simple numerical technique is proposed to investigate the performance of cantilever diaphragm walls in unsaturated soils. The only information required in addition to the conventional saturated soil properties is the soil water characteristic curve. Numerical analysis is carried out with SIGMA/W to determine deformations and wall straining actions. The results of the present study suggest that ignoring capillary suction results in a conservative design. In addition, estimates of deformations, forces and moments are erroneous. This study is of interest for practicing engineers as it provides a

simple yet reliable approach for the rational design of excavation support systems extending mechanics of unsaturated soils.

134 | Analysis of strip plates on elastic foundation using generalized sub-grade model

PRESENTING AUTHOR: Ms. Amlesu Tewoldebrhan[1]

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A concrete plate supported directly by the soil continuum is a very common construction form. The response of the plate when it carries external load is influenced by the soil, and the response of the soil is also influenced by the action of the plate under the load. Thus, developing a
sub-grade model for soil-structure interaction problem is essential in order to predict the response of both components of the system and arrive at an optimum design.

Many sub-grade models have been developed in order to improve on the inherent lack of shear interaction among the individual springs found on the long-enduring model of Winkler. These models still have shortcomings with the nature of simplifying assumptions they make to ease the mathematical equation. Recently a generalized model is presented for a sub-grade idealized as an elastic layer overlying a rigid base. In contrast to previous works no stresses, strains or displacements are neglected a priori.

The objective of this work is implementing, verifying and calibrating this improved continuum-based generalized sub-grade model in the analysis of strip plates on an elastic foundation. The governing differential equation of a strip plate on elastic foundation is formulated. Then, closed form particular solutions, when using Winkler type and Kerr equivalent Pasternak models, are obtained by considering different boundary conditions of long and short length of a strip plate, under different loading conditions. Microsoft excel programs are written for the computation of deflection, moment and shear force. The sub-grade models will be calibrated using Finite Element based Plaxis 2D software. Lastly, numerical illustration is provided using these models in comparison with Plaxis 2D model for long and short strip plates subjected to selected symmetrical loading conditions. Thus, the findings of the calibrated models can be used in routine analysis of strip plate on elastic foundation

SITE IMPROVEMENT TECHNIQUES I & GEOPHYSICAL METHODS I

SESSION CHAIR: ROCKY WANG

384 | Impact of lead and sodium carbonate on consolidation and hydraulic properties of clayey sand

PRESENTING AUTHOR: Mr. Adel Ahmadihosseini[3]

CO-AUTHORS: Mr. Ashkan HosseinZadeh Namadi[1], Dr. Mahmoud Hassanlourad[1], Mr. Amin Hasani Motlagh[2], Mr. Pouya Alipanahi[2], Dr. Hamed Sadeghi[2]

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Various in-situ techniques are used to treat heavy metal pollution including solidification/stabilization (S/S) with chemical binders which results in a solidified matrix and hence structurally stable soils. This study describes the impact of different amounts of various binders on shear strength behavior of contaminated loess. The contamination substance was chosen based on the fact that industrialization have increased the concentration of lead in natural environment; therefore, lead nitrate as soluble lead compound is used in this study. In order to solidify or stabilize the soil, different chemical binders are added to the contaminated soil. The binders used in this study include ordinary portland cement, pulverized fly ash, lime, rice husk ash, activated carbon and zeolite. Different amount of each binder will be used to evaluate their influence on shear strength of stabilized lead-contaminated loess. Shear behavior and shear strength properties will be obtained through conducting two series of triaxial compression and direct shear tests. The influence of each binders on shear strength characteristics of lead contaminated loess will be interpreted and discussed. In the end, suggestions for future research in this field are presented.

230 | Predicting soil strength through electrical resistivity measurements in clay

PRESENTING AUTHOR: Mr. Tommy Kam[1]
CO-AUTHORS: Dr. Wing Shun Kwan[1], Dr. Mark Tufenkjian[1]
[1]*California State University, Los Angeles, United States of America*

This paper presents an experimental study that investigates the effects of stress history and mineralogy on the use of electrical resistivity to predict soil strength. Employing electrical resistivity as a geophysical parameter has shown advantages when surveying soil properties of seafloor soft soils because of the potential for rapid coverage rates and non-contact ability. Recent experimental studies show that the electrical resistivity, ρ, is promising in predicting the undrained shear strength, Su, for a given soil type under the same conditions (e.g., pore fluid and stress history). When employing ρ in surveying seabed sediments, the effects of natural variability in the soil, such as different stress histories and mineral compositions, need to be addressed. This study utilizes a special-made triaxial setup that can measure the electrical resistance, R, at any stage of a consolidated undrained test on reconstituted clay samples, which is used to calculate the electrical resistivity of the clay samples. The reconstituted clay samples are mixed with two different types of minerals, kaolin and bentonite, at desired soil ratios, resulting in a range of plasticity index (PI) values. Multiple triaxial tests are performed on each batch of specimens with varying stress histories (represented by the overconsolidation ratio, OCR). The results provide a correlation of Su relating to ρ, PI, and OCR, which is useful in geotechnical engineering applications where the determination of soil strength using geophysical methods is an option.

249 | Adding value to projects with Geophysical Ground Investigation: A review of three project case histories

PRESENTING AUTHOR: Miss Michelle Watson[1]
CO-AUTHORS: Mr James Collins[1], Mr Damon Sunderland[2]
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This paper seeks to contribute to the available industry literature on guidance for planning geophysical investigations to minimize ground risk and cost while maximizing value for the project. This paper reviews the successes and challenges of five case histories where geophysical ground investigations have been employed on buildings and infrastructure projects. Based on the lessons learnt a preliminary framework for planning geophysical investigations to minimize ground risk and cost while maximizing value is proposed.

Geophysical techniques are commonly employed as part of modern day ground investigation campaigns. While geophysics is not a substitute for boreholes or other intrusive testing, it is a powerful complimentary tool. An effectively planned geophysical investigation has the potential to optimize time, cost, environmental impact and ground risk on projects. However, the value of a geophysical investigation can be compromised due to poor timing of the investigation and/or poor interaction between the key parties including the geotechnical engineer or engineering geologist, client and specialist geophysical sub-contractor.

Based on real project case studies from around the world including Canada, Australia and Hong Kong which have utilized a variety of geophysical investigation techniques this paper presents successes, challenges, limitations and lessons learnt. Informed by the project case histories a preliminary framework for planning geophysical investigations is proposed. The framework covers the lifespan of project from concept to construction. It suggests the ideal timing of geophysical investigations and identifies key moments for co-ordination between stakeholders.

The authors hope that this paper will encourage practitioners to take a big picture approach when including geophysics in a ground investigation campaign and will result in investigations being targeted, cost-saving and value-adding for projects.

OFFSHORE AND NEARSHORE GEOTECHNICAL ISSUES I

SESSION CHAIR: LIJUN DENG

331 | Mechanism of wave-induced liquefaction around suction caissons

Dr Amin Barari[1],
PRESENTING AUTHOR: Mr Amir Moghaddam
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Development of excess pore-water pressure within seabed caused by the waves propagating on the surface of sea may threaten the safety of an offshore foundation. Very few studies have considered effect of wave specifications on residual wave-induced liquefaction around caissons. In this study, a comprehensive elasto-plastic soil model for large liquefaction-induced shear deformation of sand is adopted to capture changes of pore water pressure and effective stresses within the sandy seabed. The caisson is expected to behave under the linear elastic law and considered as a single-phase medium. OpenSees, the FEM framework initially programmed for soil-structure interaction under seismic loadings, is used for the problem of Wave-Foundation-Seabed Interaction (WFSI). Biot's consolidation theory, linear wave theory and the advanced soil model are eventually combined to simulate the soil response accounting for the hydrodynamic pressure of wave imposed on the surface of seabed in the presence of an offshore foundation. This finite element numerical model is validated by a well-documented centrifuge experimental model, upon which the gravitational analysis is conducted on whole domain before performing the dynamic analysis.
It is demonstrated from numerical results that caisson's skirt tip is a potential zone for early development of liquefaction due to static shear-stress concentration beneath it which acts together with contact pressure to develop 3D hydraulic gradients in the vicinity of caissons which are all found to be prominent in assessing a WFSI problem. It was either identified that inclusion of skirts interrupts the dissipation pattern of accumulated pore-pressure because of longer drainage path which is another scope of the current study.

71 | Reliability assessment of drag embedment anchors in layered seabed, clay over sand

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Drag embedment anchors combined with catenary mooring systems are widely used for temporary and permeant station keeping of the offshore floating facilities. By growing exploration and production of offshore reserves, the number of mooring failure incidents in floating facilities has been increased. This implies the significance of the reliability assessment of the mooring system components and particularly drag embedment anchors as one of the key elements. The currently used anchor design codes consider only homogeneous seabed soil conditions. It is publicly accepted that the presence of the layered seabed may significantly affect the ultimate holding capacity of anchors. Therefore, it is expected that layered seabed condition affects the reliability indexes of these anchors as well. However, there are only a few published studies that have investigated homogeneous seabed soil conditions ignoring the effect of layered soil strata. In this study, the reliability of drag embedment anchors was comprehensively investigated in the layered seabed (clay over sand). An advanced calculation tool was developed to obtain the holding capacity of the anchors by combining a series of iterative limit state and kinematic analysis. Time domain dynamic mooring analysis was conducted by assuming a semisubmersible platform to obtain the dynamic line tensions. The uncertainties of the environmental loads, metocean variables, seabed soil properties were incorporated into a first-order reliability analysis (FORM) to obtain the failure probabilities. A probabilistic model established for determination of holding the capacity for nominated drag anchor families. The study revealed a significant effect of the layered soil condition in reliability assessment by lowering the magnitude of reliability indexes. The improvement of the recommendations provided by design codes by incorporation of the complex seabed condition was found necessary for a safer and cost-effective anchor design.

274 | Seismic responses of monopile in sands under scour conditions

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Monopile-supported offshore wind turbines are vulnerable to both scour and earthquakes in seismically active regions. Scour changes not only the damping and natural periods of the monopile-soil system but also the seismic and hydrodynamic loads on the pile. In general practice, the estimated maximum scour depth is often used for the design of the marine foundations. Nevertheless, unlike the pile static capacities, the highest seismic demand of pile may not be associated with the maximum scour depth employed in the routine design. Such combined effects of scour and earthquakes on the monopile are not well understood, particularly for a live-bed condition involving a changeable scour depth. This study aims to fill this gap through parametric analyses considering various scour depths and seismic inputs. An open-source finite element model was developed following the dynamic-beam-on-nonlinear-Winkler-foundation method via OpenSees, where pile-water interactions were represented by hydrodynamic added masses. Moreover, pile static lateral responses under various scour depths were analyzed in OpenSees using the conventional nonlinear Winkler foundation method. Through the parametric analyses, scour effects on both the static and seismic responses of the monopile in soft clays were investigated, and the critical scour depths corresponding to the peak static and seismic demands were obtained. In the end, recommendations for selecting proper scour depths were made for the design of the monopile under static and seismic loading.

POSTERS

173 | A new disposal method of ultra-fine tailings

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The ultra-fine tailings have the characteristics of poor water permeability, long consolidation time, low mechanical strength, and are difficult to dissipate excess pore water pressure. These characteristics lead to problems of dam construction difficulty, poor drainage of embankment, high water content of deposited tailings and low dam bearing capacity. This paper introduces a new method of chemical pretreatment combined with physical treatment of ultra-fine tailings. By adding flocculant, the fine particles in tailings can be combined into coarse particles to accelerate the setting speed and pre dehydrate the ulter-fine tailings. When the solid concentration is up to 20%, the pre dehydrated tailings are filled into a special pore size geofabriform bag made of geotextile. The bag is different size and is preset drainage body inside which can reduce the seepage path and increase the permeability coefficient of the whole bag. Drainage board is laid on the external surface of the geofabriform bag, and vibration load is applied on the drainage board to accelerate the dewatering and consolidation of ulter-fine tailings in the bag. The cost of this method is acceptable. Engineering application indicated that this method has easy site application and the ultra-fine tailings can be disposed in situ.

369 | Système de gestion des connaissances appliquées en géotechniques : étude de cas

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La gestion des connaissances est un concept né dans les années 90. L'un des principaux objectifs de cette discipline est l'utilisation des pratiques et technologies de l'organisation pour bénéficier des connaissances. Les systèmes de gestion des connaissances se réfèrent à tout type de système informatique qui stocke, traite et récupère des données, quelle que soit leur nature, améliorant ainsi la collaboration, la localisation des ressources de connaissances et, finalement, l'ensemble du processus d'acquisition, de traitement et d'exploitation. En outre, ces systèmes de gestion peuvent également être utilisés pour encourager et superviser les collaborateurs à adopter de bonnes pratiques. Ils permettent

aussi de gérer les connaissances utilisées pour connecter les personnes et l'organisation selon les principes de la taxonomie et de l'ontologie. La mise en œuvre d'un système de gestion des connaissances fiable améliore la prise de décision et augmente la productivité organisationnelle. Cette étude de cas reflète le travail de recherche mené au sein du laboratoire de mécanique des roches et géologie appliquée de l'Université de Sherbrooke et porte principalement sur la mise en place d'un outil de système de gestion de connaissances appliquées en géotechnique basée sur une application web afin de répondre aux exigences d'ergonomie et de faciliter la gestion des données. Ce type de système basé sur le web transforme les données brutes accumulées par une organisation en connaissances utiles en collectant des données dans une base de données centrale, en les contextualisant et en les rendant facilement consultables afin que les utilisateurs puissent trouver eux-mêmes les connaissances dont ils ont besoin et ainsi préparer les données pour appliquer des algorithmes d'intelligence artificielle dans des projets de recherche en géotechnique.

Mots-clés : connaissances, outil, système de gestion de connaissances, géotechnique, données, intelligence artificielle.

225 | Community surficial geology and geohazards map series, Fort McPherson, Northwest Territories, Canada

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In many northern Canadian communities, buildings are supported in or on permafrost. Permafrost degradation due to climate warming can impact these building foundations, as well as nearby slopes whose stability often depends on remaining frozen. Community mapping can therefore be a useful strategy in land-use planning.
Two series of maps, describing community surficial geology and geohazards, including permafrost-related geohazards, were compiled with the assistance and support of Ecology North, the Hamlet of Fort McPherson, and the Rat River Development Corporation Ltd., as one of several proposed adaptations to climate change in Fort McPherson that required geotechnical engineering and permafrost expertise. Additional maps were developed to demonstrate changes in slope vegetation (trees and shrubs) over several decades to correlate with areas of slope movements and development. Another map presented a visual slope retrogression analysis and recommended setbacks.

The map series were designed to be desktop-level maps that would accomplish the following tasks:

- Help the community better understand the soils, rock and permafrost conditions around them, including geohazards related to those conditions;
- Provide a tool to assist land managers with land use and development: to determine the preferred areas for building and avoid areas unsuitable for the future development. Using the maps, it will be possible to avoid areas with high ice content and/or organic soils, issues with water on site and thaw settlement, as well as slope instabilities; and
- Provide a baseline reference for monitoring potential permafrost degradation or large-scale changes in the permafrost conditions and/or slope stability, resulting from climate change and/or human-induced impact.

278 | Wellbore stability of highly deviated well intervals for large-diameter boreholes

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The development of steeply dipping narrow vein ore bodies by using traditional mining techniques is always a challenge and leads to a large stripping ratio for the mining to be economic efficient and high safety risk. The Sustainable Mining by Drilling (SMD) method is proposed to overcome the difficulties in narrow vein mining. In this concept, the dipping narrow vein ore body will be crushed and transported to the ground in the process of the directional drilling. The stability of the wellbores during and after drilling is a critical issue for the safety of narrow vein mining, especially for the hanging wall in highly deviated intervals. In this study, the in-situ stress and other rock mechanics information were collected on the mining site. Then, the wellbore stability was evaluated by using different wellbore failure criteria. The designed maximum depth was 250m; the maximum wellbore diameter was 1.3m; the maximum wellbore inclination was 45 degrees. The results of the wellbore failure criteria were compared. A discrete element method (DEM) simulation was conducted. The DEM simulation result presented a microscope evaluation of the process of rock failure occurrence. Coupling the analytical result and the simulation result, the mud weight for the drilling was optimized as a solution to the highly deviated well interval stability. The risk of wellbore failure was then reduced.

182 | Backfill analysis and parametric evaluation of the cement binder on cured strength and curing time

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A new innovative method named Sustainable Mining by Drilling method (SMD) is used for mining in which the ore is highly dipped stranded and it is not economic to mine by a conventional method. The SMD method is based on a two-pass drilling procedure using a high torque, high thrust drill rig that is custom modified for the mining equipment. For the first drilling pass, a pilot hole is drilled along the dip of the vein. This hole is directionally steered using downhole geophysical imaging tools to follow a trajectory that is halfway between the hanging wall and footwall contacts of the vein. In the second drilling pass, the pilot hole is opened to the full width of the vein using a large diameter hole opener that follows the trajectory of the pilot hole. The holes will be drilled in primary and secondary sequencing. Primary holes are drilled in the intact rock and secondary holes are drilled between the primary holes. Primary holes need to be backfilled using cemented tailing backfill, while secondary holes do not. In this paper, the mineralogy and grain size distribution tests of tailings are conducted. The procedures and mixture for fabricating the backfilling material for the SMD project are introduced. Two recipes were tested: 100% Portland cement and a combination of 80% Portland cement and 20% fly ash, respectively. During the curing time (28 days in total) of the backfilling material, its increase in strength over time is tested and analyzed at 7 days, 14 days, and 28 days after the casting. At each curing stage, density and unconfined compressive strength (UCS) tests are performed. The relationships between backfill strength and tailing grain size distribution, curing time and the backfill material recipe are proposed based on the experimental results.

104 | Experimental investigation of the soil-water retention of a glacial till from northern Quebec

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The shear strength characteristics are essential part of the hydro-mechanical behavior of unsaturated soils. It is well-known fact that the shear strength of unsaturated soil is related to the hydraulic retention behavior of soils through the soil water retention curve (SWRC).

It is believed that the SWRC is highly dependent on the particle size and formation of particles. Consequently, the particle size distribution may affect the overall hydro-mechanical response of unsaturated soils. despite their significant application in geotechnical engineering, the unsaturated shear strength of man-made fine materials such as mine-tailings is less understood. In this study, the conventional direct shear testing procedure is used to assess the unsaturated shear strength characteristic of mine-tailing using the suction stress characteristic framework (SSCF). The characterization of the hydro-mechanical behavior of the mine-tailings is complemented with the determination of the SWRC in an oedometer apparatus with control of matric suction. the experimental data from direct shear tests are compared with the predicted values obtained from SWRC using SSCF. The results indicated that having fine materials does not necessarily dictates residual shear strength similar to clayey soils and SWRC are required to be modified in order to properly model such behavior.

393 | Analytical solutions for dynamic consolidation of soft clay ground under different loading modes

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Intermittent dynamic traffic loading is often applied to the soft clay ground in the long-term operation of rail transit. Through literature review, there are still some divergences in what types of loading modes can be used to simulate traffic loading and how loading modes affect the consolidation behavior. So far, there is no reasonable equation in the local code to evaluate the deformation of ground under long-term traffic loading. Therefore, it is important to forecast dynamic consolidation of soft clay ground under the different loading modes. In this study, three loading modes of sinusoidal loading, triangular loading and rectangular intermittent loading was selected. Based on the theory of Terzaghi one-dimensional consolidation, analytic solutions for consolidation of the single-layered ground subjected to sinusoidal loading, triangular loading and rectangular intermittent loading, respectively, have been investigated. Series separation variable method was applied to the solution due to the assumptions of an isotropic elastic material for the ground. Research showed that vibration frequency and stress level played an important role in the pore pressure and the rate of consolidation. To accurately predict the long-term deformation of multi-layer ground under different vibration frequencies and stress levels, the finite element method was used, and different loading modes were obtained by programming of subroutine. The development of deformation and excess pore pressure was also analyzed

during dynamic consolidation of multi-layer ground under the different loading modes. Finally, based on simulation results, the empirical formula considering the vibration frequency and stress level was proposed to predict the long-term deformation for different loading modes. By comparative analysis of case study, it was found that the error between the calculated result and the measured settlement value can be controlled within 10%, which demonstrated this formula can be applied well in engineering practice.

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