www.geotechnicalnews.com

Volume 35 • Number 2 • June 2017

GEOTECHNICAL news

The six-pack of soft tailings capping methods

Illustration: Derrill Shuttleworth

RST Instruments Ltd. offers 2 Wireless Data Collection Systems to quickly get you connected to your data: **RSTAR** and **DT LINK**. Both systems offer **minimum per channel cost, extra long battery life** and **long distance data transmission.**

WIRELESS DATA COLLECTION

for Geotechnical Monitoring Instrumentation

FULLY AUTOMATED COLLECTION (REMOTELY)

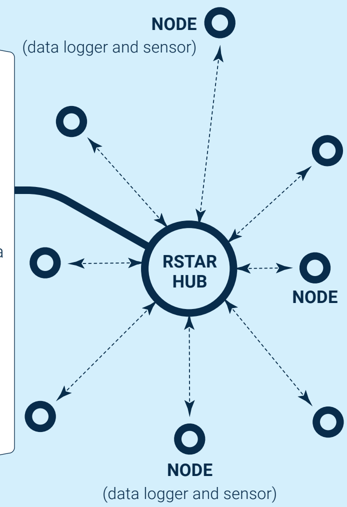
An RSTAR System uses data loggers (nodes) at the sensor level, deployed in a star topology from an active RSTAR Hub containing an RST flexDAQ Data Logger.

rstar
ARRAY RADIO SERIES

FEATURES

Up to 10 years of battery life from 1 lithium 'D' cell.
Up to 14 km range from Hub to Node in open country. (depending on antenna type)
Up to 255 nodes per RSTAR Hub.
Based on 900 MHz , 868 MHz and 2.4 GHz spread spectrum band. (country dependent)

The RSTAR Hub shown left contains a flexDAQ Data Logger System with an antenna and battery. Collected data is saved to the flexDAQ memory where users can access it remotely, either on-site or off-site.



>>> Watch the video for both systems at: www.rstinstruments.com/Wireless-Data-Collection.html <<<

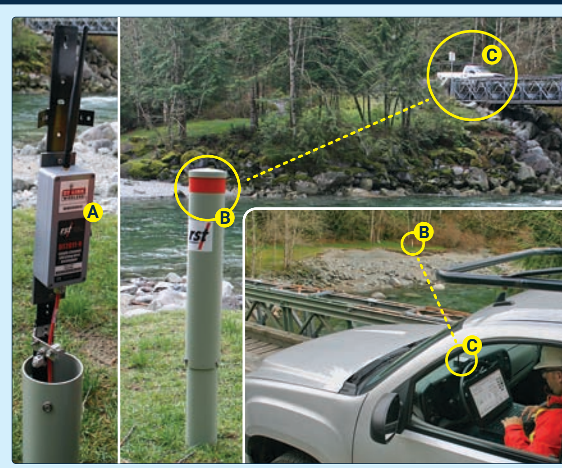
SEMI-AUTOMATED COLLECTION (ON-SITE)

DT LINK is an on-site wireless connection to RST data loggers for quick data collection. Ideal for hard to access areas where the data logger is within line of sight.

DT LINK WIRELESS

FEATURES

Safely & easily collect data from data loggers that are in areas with poor access, trespass issues and hazardous obstacles.
Years of battery life from 1 lithium 'D' cell.
Range up to 800 m (900 MHz) and up to 500 m (2.4 GHz).
Collect data in seconds with a laptop connected to DT LINK HUB.



Pictured: (A) DT LINK WIRELESS data logger, connected to a vibrating wire piezometer and housed in a (B) protective enclosure, has its data collected from a laptop connected to the (C) DT LINK HUB - all within seconds from the convenience of your vehicle.

DT SERIES
DATA LOGGERS

RST's "DT Series" Data Loggers accommodate the RSTAR and DT LINK WIRELESS Systems. Compatible sensor types include:

Vibrating Wire, Potentiometers, MEMS Tilt Sensors, Strain Gauge (full bridge) Sensors, Digitally Bussed Sensors, 4-20 mA Sensors, and Thermistors.

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- Strain Gages
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- Settlement Sensors
- Pressure Cells
- DeAerators
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- Cables

- Load Cells
- Concrete Stress Cells
- B/H Deformation Gages
- Stressmeters
- Inclinometers
- Tiltmeters
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- Readouts
- Terminal Boxes
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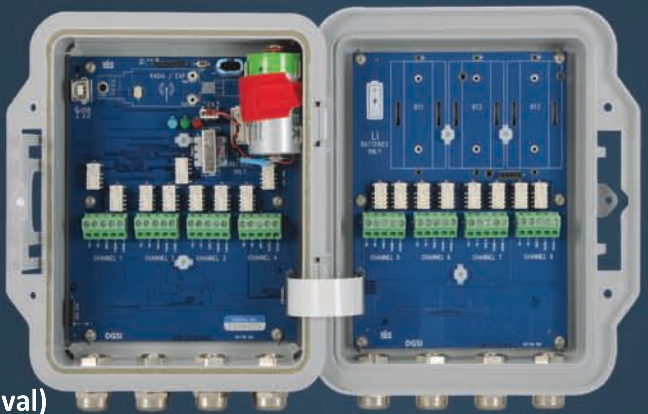
V-Logger Series

Slope Indicator proudly introduces the V-Logger Series, our latest VW data logger product.

This flexible 4 or 8-channel data logger is IP 68 rated, CE certified, and has a battery life of up to 10 years. The optional radio uses the much less congested 860-930 MHz bands, which allows for better connectivity and longer range. Seamlessly connect to cellular modems and solar panels for fully remote stations.

- **Four or Eight Channel Vibrating Wire Loggers**
- **Extended Battery Life**
- **Expandable up to four D-cell lithium batteries**
- **Optional rechargeable lithium-ion polymer pack**
- **Expanded Memory**
- **40x more accurate than our previous loggers**
- **Designed to work with Sensemetrics' THREAD Mesh Network**
- **Integrated 860-930 MHz radio option (pending FCC / IC approval)**



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NX NOVA METRIX

Dharma Wijewickreme, President of Canadian Geotechnical Society

Message from the President

As we march towards a well-deserved warm summer, I would like to use this President's Message to refocus our attention on a familiar topic that is invariably of direct interest to the CGS membership. As professionals, it is important for us to continuously care for the teaching and training of qualified people and promote research and innovation. The other aspect is the need to generate and disseminate factual, impartial, and reliable information for consumption by all concerned. While academia - by way of the job description - is contributing to these fronts, the tremendous counterpart role that industry has in this regard cannot be overstated. I believe that improving interactions and collaborations between academia and industry on a wider format is needed to support this cause. It would be of value to increase the participation of industry personnel in teaching and training, for example, by delivering guest lectures in the university classrooms and during site visits; reciprocally, more opportunities should be created for the academics to get exposed to industry real-life problems and to work on applied outcome research and technology solutions. The power of industry support to lever government funding, and in turn, enhance the industry investment multiplier with respect to research is another fact that needs to be kept in mind, and the list of potential interactions can go on. I believe that this is the right time for an expanded and renewed conversation on this topic, and the CGS can play a vital role in facilitating and advancing this dialogue through our annual CGS Conference, meetings in local Sections, and other types of activity. The Society's strong reputation and healthy financial stature provide an ideal environment to develop and launch new targeted initiatives in support of these. Let us have a conversation on this topic, and I invite you to engage by writing to us at *admin@cgs.ca*. Our CGS team is ready to receive your thoughts and ideas that will pave the way moving forward.

Now, let me report on some other important news. By the time you read this article, **Dr. Vaughan Griffiths**, Colorado School of Mines, will have completed his **Cross Canada Lecture Tour (CCLT)**. It is exciting to note that the always well-attended CCLT is becoming so popular amongst our membership. In the last round, fifteen of our Local Sections indicated that they would like to host the CCLT, leading to a case where for one of the first time in our history, we were not able to include some of our larger

Local Sections in the Tour. Shortly, we will also be announcing the details about the 2017 Fall CCLT. This will be our 100th CCLT - a significant milestone event that all of us should be proud of!

To complement the CCLT, we now have added the brand-new **CGS Colloquium Lecture Series**. This Lecture Series opportunity, created in partnership with the **Canadian Foundation for Geotechnique**, is offered to the most recent Canadian Geotechnical Colloquium Speaker to cover travel expenses to deliver the Colloquium lecture across Canada, with a particular focus on engaging students. If not fully, at least a part of the Colloquium tours by **Jasmin Raymond** and **Greg Siemens** should have been well completed by the time you read this message.

This was a banner year for the CGS in terms of our members receiving awards from the **Engineering Institute of Canada (EIC)**. Three of our members (**Michel Aubertin**, **Jean Hutchinson**, and **Bryan Watts**) received prestigious EIC Medals, with five others (**Bruno Bussière**, **Richard Chalaturnyk**, **Paul Dittrich**, **Jocelyn Grozic**, and **Catherine Mulligan**) each receiving an EIC Fellowship. The details related to these awards can be found elsewhere in this magazine.

The organizational work for **GeoOttawa 2017**, the 70th CGS Conference to be held in Ottawa from October 1-4, 2017, is progressing well with some 750 abstracts accepted. Thanks are due to **Mamadou Fall** and his team for their great effort on this front. Please visit the conference website (*www.geoottawa2017.ca/*) and consider joining your colleagues in Ottawa.

In spite of some challenges in lining up personnel to work on the technical aspects, we are working hard to have the Errata for the 4th edition of the **Canadian Foundation Engineering Manual (CFEM)** made available this Fall. In tandem, our focus is also to have the English and French versions of the next CFEM Canadian Foundation Engineering Manual finalized and made available at the earliest opportunity. If you are interested in contributing to this important activity, please contact us at *admin@cgs.ca*.

The strength of the CGS is a result of the tremendous volunteer effort that is put in by our membership. Therefore, I would like to use every opportunity to thank our CGS volunteers involved in the Executive, Board, Sections, Divisions, Committees, and external representations. Of course, it is important to acknowledge the contributions from our CGS National office: **Michel Aubertin**, **Wayne Gibson**, and **Lisa McJunkin**; the time and effort put in by these professionals by working often in the background are tremendous. I also would like to take a moment to thank our CGS Corporate Sponsors: **DownUnder Geotechnical; Geo-Slope International; GKM Consultants; Golder Associates; Insitu Contractors; Klohn Crippen Berger; Knight Piésold Consulting; MEG Consulting; Mobile Augers and Research; Naviq Consulting; Reinforced Earth; Rocscience; Stantec; Thurber Engineering; Trek Geotechnical; SoilVision Systems** and **Advanced Construction Techniques**.

As I indicated in my previous messages, member engagement and involvement is one of the most important keys to our success. So, please take a moment to read this magazine, visit our website (*www.cgs.ca*) and offer your thoughts and input. We encourage and welcome your feedback!

Provided by Dharma Wijewickreme
CGS President 2017 - 2018

Message du président

Alors que nous avançons vers un été bien mérité, j'aimerais utiliser ce message du président pour remettre l'accent sur un sujet familier qui, invariablement, intéresse directement les membres de la SCG. À titre de professionnels, il est important pour nous de veiller continuellement à l'enseignement et la formation de personnes qualifiées ainsi qu'à la promotion de la recherche et de l'innovation. Un autre aspect consiste en la nécessité de produire et de diffuser de l'information factuelle, impartiale et fiable à des fins d'utilisation par les personnes concernées. Bien que le corps professoral universitaire, conformément à son mandat, contribue directement à ces aspects, le rôle majeur de l'industrie à cet égard ne peut pas être surestimé. Je crois qu'il faut améliorer les interactions et la collaboration entre le milieu universitaire et l'industrie dans un format élargi pour appuyer cette cause. Il serait utile d'augmenter la participation des professionnels de l'industrie dans l'enseignement et la formation, en donnant par exemple des conférences dans des classes universitaires et durant des visites de site. Réciproquement, plus d'occasions devraient être créées pour que le milieu universitaire soit exposé aux problèmes industriels réels et travaille sur la recherche et le développement de résultats pratiques et de solutions technologiques. L'apport de l'industrie permettant d'obtenir du financement gouvernemental, et en retour, l'effet multiplicateur sur les investissements industriels pour la recherche est un autre élément qu'on doit garder à l'esprit; cette liste des interactions possibles pourrait être allongée. Je crois que c'est le bon moment pour élargir et renouveler la conversation sur ce sujet. La SCG peut jouer un rôle vital en facilitant et en faisant progresser ce dialogue par le biais de sa conférence annuelle, des réunions dans ses sections locales et d'autres types d'activités. La solide réputation et la situation financière saine de la Société offrent un milieu idéal pour concevoir et lancer de nouvelles initiatives ciblées afin d'appuyer cette démarche. Ayons une conversation sur ce sujet; je vous invite à participer en nous écrivant à l'adresse admin@cgs.ca. L'équipe de la SCG est prête à recevoir vos réflexions et idées qui ouvriront la voie de l'avenir.

Maintenant, permettez-moi de vous rapporter certaines autres nouvelles importantes. Lorsque vous lirez ce message, le **Dr Vaughan Griffiths**, de la Colorado School of Mines, aura terminé sa **Tournée de conférences transcanadienne** (**TCT**). Il est intéressant de noter que la toujours très populaire TCT le devient encore plus auprès de nos membres. Pour cette dernière Tournée, 15 de nos sections locales avaient indiqué vouloir accueillir la TCT. Par conséquent – et pour une des premières fois de notre histoire – nous n'avons pas pu inclure certaines de nos plus grandes sections locales dans la Tournée. Nous aurons bientôt des informations sur la TCT de l'automne 2017. Il s'agira de notre 100^{e} TCT, un évènement marquant dont nous devrions tous être fiers!

En complément de la TCT, nous avons maintenant ajouté la toute nouvelle **Série de conférences du Colloquium de la SCG**. Cette série de conférences, créée en partenariat avec la Fondation canadienne de géotechnique, est offerte au plus récent conférencier du Colloquium canadien de géotechnique pour couvrir ses frais de déplacement afin de présenter le Colloquium ailleurs au Canada, en se concentrant particulièrement sur la participation d'étudiants. Lorsque vous lirez ce message, les tournées du Colloquium de **Jasmin Raymond** et **Greg Siemens** devraient être en partie ou entièrement terminées.

Cela a été une année faste pour la SCG en matière de prix de **l'Institut canadien des ingénieurs** (**ICI**) reçus par ses membres. Trois de nos membres (**Michel Aubertin**, **Jean Hutchinson** et **Bryan Watts**) ont reçu de prestigieuses médailles de l'ICI, et cinq autres (**Bruno Bussière**, **Richard Chalaturnyk**, **Paul Dittrich**, **Jocelyn Grozic** et **Catherine Mulligan**) ont obtenu un titre de Fellow de l'ICI.

Vous trouverez les renseignements concernant ces prix dans un autre article de ce magazine.

L'organisation de **GéoOttawa 2017**, la 70^{e} conférence de la SCG, qui aura lieu à Ottawa du 1er au 4 octobre 2017, progresse bien avec l'acceptation de 750 résumés. Nous remercions **Mamadou Fall** et son équipe pour leurs énormes efforts. Veuillez visiter le site Web de la conférence (*www.geoottawa2017.ca/index.php?lang=fr/*) et pensez à vous inscrire et ainsi joindre à vos collègues à Ottawa.

Malgré certains défis pour mobiliser des membres afin de contribuer aux aspects techniques, nous travaillons fort pour que l'erratum de la quatrième édition du **Manuel canadien d'ingénierie des fondations** (**MCIF**) soit disponible cet automne. Dans un même temps, nous nous efforçons également de faire avancer les prochaines versions anglaise et française du MCIF pour de les rendre disponibles le plus tôt possible. Si vous désirez contribuer à cette activité importante, veuillez nous écrire à l'adresse *admin@cgs.ca*.

La force de la SCG réside dans le travail bénévole remarquable effectué par nos membres. Par conséquent, je tiens à profiter de chaque occasion pour remercier les bénévoles de la SCG qui font partie du Comité exécutif, du Conseil, des sections, des divisions, des comités et qui la représentent à l'externe. Bien entendu, il est important de reconnaître les contributions du Bureau national de la SCG : **Michel Aubertin**, **Wayne Gibson** et **Lisa McJunkin**; le temps et les efforts investis par ces professionnels qui travaillent souvent en arrière-plan sont exceptionnels. J'aimerais également prendre un moment pour remercier les commanditaires de la SCG: **DownUnder Geotechnical; Geo-Slope International; GKM Consultants; Golder Associates; Insitu Contractors; Klohn Crippen Berger; Knight Piésold Consulting; MEG Consulting; Mobile Augers and Research; Naviq Consulting; Reinforced Earth; Rocscience; Stantec; Thurber Engineering; Trek Geotechnical; SoilVision Systems** et **Advanced Construction Techniques**.

Comme je l'ai mentionné dans mes messages précédents, l'engagement et la participation des membres sont les plus importantes clés de notre succès. Veuillez donc prendre un moment pour lire ce magazine, visiter notre site Web (*http://www.cgs.ca/*) et nous faire part de vos idées et commentaires. Nous apprécions votre rétroaction et vous encourageons à nous la transmettre.

Fourni par Dharma Wijewickreme
SCG Président 2017-2018

From the Society

Members in the News

CGS Members Awarded 2017 EIC Medals and Fellowships

The CGS is very pleased to report that eight members were among the recipients of The Engineering Institute of Canada's 2017 Medals and Fellowships. These CGS members received three of the six EIC Medals, and five of the 20 EIC Fellowships.

CGS members who received 2017 EIC Medals are:

- **Michel Aubertin**, CGS Past President (2009-2010), current CGS

70TH CANADIAN GEOTECHNICAL CONFERENCE
70E CONFÉRENCE GÉOTECHNIQUE CANADIENNE

GEO OTTAWA 2017

October 1-4 / 1-4 octobre
Ottawa, Ontario
www.geoottawa2017.ca

Join us in Ottawa this October for the Canadian Geotechnical Society's 70th annual conference. In 2017 we are collaborating with the International Association of Hydrogeologists (IAH/CNC) to also present the 12th Joint CGS/IAH-CNC Groundwater Conference.

*The GeoOttawa 2017 theme **70 Years of Canadian Geotechnics and Geoscience** will build on the extensive contributions of geotechnical and hydrogeological practitioners to Canada's built form since the Canadian Geotechnical Society was founded 70 years ago.*

GeoOttawa 2017 conference program highlights will include:

R.M. Hardy Address presented by Dr. Richard Bathurst (Royal Military College)
Darcy Lecture presented by Dr. Kamini Singha (Colorado School of Mines)
Comprehensive Industry Trade Show with over 70 exhibitors
Over 750 delegates and more than 350 technical and special presentations over three days!

TENTATIVE TECHNICAL SESSIONS

PRIMARY GEOTECHNICAL
- Soil Mechanics and Foundations
- Rock Mechanics and Engineering Geology
- GeoHazards and Landslides
- Mining Geotechnics and Hydrogeology
- Geoenvironmental Engineering
- Transportation Geotechnics
- Geosynthetics
- Cold Regions
- Sustainable Geotechnics
- Professional Practice

SPECIAL GEOTECHNICAL
- Tunnelling and Deep Excavations
- Geohazards in Linear Infrastructure
- Remote Sensing
- Innovative Foundation Systems
- Foundations for Renewable Energy
- Trenchless Technology
- Risk Management in Geotechnical Projects
- Reliability Analysis for Geotechnical Design
- Radioactive Waste Management
- Shallow Geothermal Energy Exchange
- Seismicity and Sensitive Clay

PRIMARY HYDROGEOLOGICAL
- General Hydrogeology
- Source Water Protection (including implementation of policy)
- Groundwater and the Ecosystem
- Groundwater and Climate Change
- Groundwater Resources and Management
- Fractured Rock
- Hydraulic Fracturing
- Application of Geophysics to Hydrogeology in Fractured Rock
- Groundwater Contamination by Human Activities
- Quantitative Assessment and Performance of Contaminant Remediation
- Professional Practice
- Public Consultation of Groundwater Issues

SPECIAL HYDROGEOLOGICAL
- Mining
- Cold Regions
- Radioactive Waste Management
- Shallow Geothermal Energy Exchange

The conference will be held at the Shaw Centre in downtown Ottawa, Ontario. Come and enjoy Canada's 150th birthday in our nation's capital this fall!

Please see the conference web site at www.geoottawa2017.ca for detailed conference information and to register online. Be sure to register before July 31, 2017 to take advantage of early pricing discounts!

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Executive Director, and recently retired Professor at École Polytechnique, Montréal, QC – Julian C. Smith Medal "for achievement in the development of Canada"

- **Bryan Watts**, CGS Past President (2011-2012) and Chairman, Klohn Crippen Berger, Vancouver, BC – K.Y. Lo Medal "for significant engineering contributions at the international level"
- **D. Jean Hutchinson**, Professor and Chair of the Department of Geological Sciences and Engineering, Queen's University, Kingston, ON – Canadian Pacific Railway Medal "for many years of leadership and service by members of the Societies within the Institute at the regional, branch and section levels"

CGS members who were awarded 2017 EIC Fellowships include:

- **Bruno Bussière** – Université du Québec en Abitibi-Témiscamingue, Rouyn-Noranda, QC
- **Richard Chalaturnyk** – University of Alberta, Edmonton, AB
- **Paul Dittrich** – Golder Associates, Oakville, ON
- **Jocelyn Grozic** – University of Calgary, Calgary, AB
- **Catherine Mulligan** – Concordia University, Montréal, QC

2017 Medal and Fellowship recipients were celebrated at the EIC Gala on April 1st in Gatineau, QC.

Membres de la SCG honorés par l'ICI

La SCG est heureuse d'annoncer que huit de ses membres ont reçu des prix de l'Institut canadien des Ingénieurs en 2017. Des membres de la SCG ont obtenu trois des six médailles de l'ICI, et cinq des vingt titres de Fellow. Les membres honorés par l'ICI en 2017 sont :

- **Michel Aubertin**, Ancien Président de la SCG (2009-2010), actuel Directeur général de la SCG, et Professeur récemment retraité de l' École Polytechnique de Montréal, QC : Médaille Julian C. Smith "pour ses réalisations pour le développement du Canada"
- **Bryan Watts**, Ancien Président de la SCG (2011-2012) and Président de Klohn Crippen Berger, Vancouver, CB : Médaille K.Y. Lo "pour des contributions importantes en ingénierie à l'échelle internationale"
- **D. Jean Hutchinson**, Professeur et directrice, Department of Geological Sciences and Engineering, Queen's University, Kingston, ON : Médaille Canadian Pacific Railway "pour plusieurs années de leadership et de services aux sociétés membres de l'ICI aux niveaux régional ou des sections locales"

Les membres de la SCG qui ont reçu le titre de Fellow de l'ICI en 2017 sont:

- **Bruno Bussière** – Université du Québec en Abitibi-Témiscamingue, Rouyn-Noranda, QC
- **Richard Chalaturnyk** – University of Alberta, Edmonton, AB
- **Paul Dittrich** – Golder Associates, Oakville, ON
- **Jocelyn Grozic** – University of Calgary, Calgary, AB
- **Catherine Mulligan** – Concordia University, Montréal, QC

Les récipiendaires des prix 2017 de l'ICI ont été célébrés lors d'une cérémonie tenue le 1er avril 2017, à Gatineau, QC.

Canadian Foundation for Geotechnique

Canadian Foundation for Geotechnique Funding Initiatives – Present and Future

The Canadian Foundation for Geotechnique provides funding for numerous activities that are intended to benefit the Canadian Geotechnical Society and its members. Through the generous donations of CGS members, the geotechnical consulting industry, local chapters and CGS Divisions, and the prudent management of these funds by past and current members of the Foundation, the Foundation is coming into a position where it anticipates an ability to fund new initiatives as well as increase funding for some existing awards and prizes.

Current Awards

The largest funding commitment of the Foundation is the two Cross Canada Lecture tours each year, which are funded entirely by sponsorship from geotechnical businesses. The total annual budget for these two tours is $20,000.

Student Awards	Previous Value	New Value
1st prize Undergraduate - Individual	$ 750.00	$1,000.00
2nd prize Undergraduate - Individual	$ 500.00	$ 750.00
1st prize Undergraduate - group (4)	$ 500.00	$ 700.00
2nd prize Undergraduate - group (4)	$ 250.00	$ 400.00
1st prize Graduate Student Award	$1,000.00	$1,250.00
2nd prize Graduate Student Award	$ 750.00	$ 900.00
CGS Colloquium	$5,000.00	$5,000.00
M Bozozuk National Graduate Scholarship	$5,000.00	$5,000.00

In addition to the CCLT, the Foundation funds scholarships and prizes given to students and members of the geotechnical community. The Table below shows the current and new value of awards and prizes that the CFG funds.

The Foundation also funds the striking of the **Legget Medal** which is presented annually. The Legget Medal is the most prestigious award of the Canadian Geotechnical Society. The Foundation also funds numerous plaques and certificates for awards and prizes.

New Funding Initiatives

After 2 years of consultations with CGS executive and CFG members, the Foundation developed a list of approximately 15 potential new initiatives to consider. The list has been distilled down to a short list of 3 new initiatives to fund or further develop for funding. A brief synopsis of these initiatives is provided below.

1. The CFG was keen to see if there was interest in initiating a "Best Paper" award at the CGS Annual Conference. After much deliberation, it was decided to settle on the "Best Case History" theme. The GeoVancouver 2016 organizing committee enthusiastically accepted the challenge to adjudicate the conference papers and selected one paper for this new award. The CFG funds a framed certificate for the authors, and it is hoped that Conference organizing committees will adjudicate the award in the future.
2. A new graduate student award is being developed aimed specifically at Masters level students. Currently the CFG **Michael Bozozuk Graduate Student Scholarship** is generally awarded to PhD students. Making awards at the Masters level is challenging due to the shorter duration of the students' program, and the time for them to show their skills and to be adjudicated for the award. Consequently, this may be initiated as a prize, rather than a scholarship. Details will be resolved with the Education Committee and it is hoped that an announcement on the initiation of the award will be made at the 70th CGS Conference in Ottawa this fall. The CFG has committed to funding this award at a level of $5,000 per year.
3. The CGS executive has initiated a **CGS Colloquium Lecture Series**, which will be co-funded by the CGS and the CFG. This involves the Colloquium recipient visiting various cities (and possibly having it broadcast to other locations), similar to the Cross Canada Lecture Series. The event is intended to have a particular focus on engaging students, so it may be held as a university-based event (also open to CGS members, of course), to promote the profession to potential new members in the engineering student body. This will provide an opportunity to both showcase Canada's outstanding young Colloquium recipients as well as provide an opportunity for students to interact with members of the local chapters. It is anticipated that the program will start small, and grow with time.

Initiatives de financement actuelles et futures de la Fondation canadienne de géotechnique

La Fondation canadienne de géotechnique (FCG) offre du financement pour de nombreuses activités au bénéfice de la Société canadienne de géotechnique (SCG) et à ses membres. Grâce aux généreux dons de membres de la SCG, de l'industrie des services-conseils en géotechnique, des sections locales et des divisions de la SCG ainsi qu'à la gestion prudente de ces fonds par des membres anciens et actuels de la Fondation, la FCG anticipe pouvoir financer de nouvelles initiatives ainsi qu'augmenter le financement de certains prix existants.

Prix actuels

Le plus important engagement de financement de la FCG est la Tournée de conférences transcanadiennes (TCT) qui a lieu deux fois par année; celles-ci sont entièrement financées par des commandites d'entreprises géotechniques. Le budget annuel total de ces deux évènements est de 20 000 $.

En plus de la TCT, la FCG finance des bourses et prix remis à des étudiants et membres de la communauté géotechnique. Le tableau ci-dessous présente la valeur actuelle et nouvelle des prix que la FCG finance.

Prix pour les étudiants	Valeur actuelle	Nouvelle valeur
1er prix – Meilleur rapport d'un étudiant de premier cycle	750,00 $	1 000.00 $
2e prix – Meilleur rapport d'un étudiant de premier cycle	500,00 $	750,00 $
1er prix – Meilleur rapport d'étudiants (4) de premier cycle	500,00 $	700,00 $
2e prix – Meilleur rapport d'étudiants (4) de premier cycle	250,00 $	400,00 $
1er Prix de l'étudiant gradué	1 000,00 $	1 250,00 $
2e Prix de l'étudiant gradué	750,00 $	900,00 $
Colloquium de la SCG	5 000,00 $	5 000.00 $
Bourse nationale pour études supérieures Michael Bozozuk	5 000,00 $	5 000,00 $

La FCG finance également la frappe de la **Médaille Legget** qui est décernée chaque année. La médaille Legget est le prix le plus prestigieux de la Société canadienne de géotechnique. La FCG finance aussi de nombreuses plaques et de nombreux certificats remis en prix.

Nouvelles initiatives de financement

Après avoir consulté le Comité exécutif de la SCG et les membres de la Fondation durant deux ans, la FCG a établi une liste d'environ 15 nouvelles initiatives possibles à envisager. Cette liste a été épurée afin d'arriver à une courte liste de trois nouvelles initiatives à financer ou à développer à des fins de financement. Voici un résumé de ces initiatives.

4. La FCG tenait à voir s'il y avait un intérêt pour créer un « Prix pour le meilleur article » à la conférence annuelle de la SCG. Après de longues discussions, il a été décidé de s'entendre sur le thème des « études de cas ». Le comité organisateur de GéoVancouver 2016 a accepté avec enthousiasme le défi de juger les articles de la conférence et d'en sélectionner un pour ce nouveau prix. La FCG finance un certificat encadré pour les auteurs, et l'on espère que les comités organisateurs des Conférences à venir sélectionneront aussi un lauréat pour ce prix.
5. Un nouveau prix pour étudiant gradué visant particulièrement les étudiants à la maîtrise est créé. Actuellement, **la Bourse FCG pour études supérieures Michael Bozozuk** est habituellement remise à des étudiants au doctorat. Octroyer une bourse au niveau de la maîtrise est un défi, car le programme d'étude dure moins longtemps et le délai pour que les étudiants démontrent leurs compétences et soient jugés est court. Par conséquent, la possibilité de remettre un prix plutôt qu'une bourse d'étude sera évaluée. Le Comité sur l'éducation règlera les détails, et l'on espère qu'une annonce sur la création de ce prix sera faite à la 70e Conférence de la SCG à Ottawa cet automne. La FCG s'est engagée à accorder un financement de 5 000 $ par année pour ce prix.
6. Le Comité exécutif de la SCG a lancé une **« Série de conférences du Colloquium de la SCG »**, qui sera cofinancée par la SCG et la FCG. Cette initiative vise à ce que le conférencier du Colloquium puisse visiter différentes villes (et que sa conférence soit possiblement diffusée à d'autres endroits), similairement à la Tournée de conférences transcanadienne. Elle vise particulièrement à faire participer des étudiants. Les présentations pourraient donc avoir lieu dans le cadre d'un évènement universitaire (aussi ouvert aux membres de la SCG) pour promouvoir la profession auprès de possibles nouveaux membres et étudiants en ingénierie. Ceci donnera l'occasion à de jeunes conférenciers canadiens exceptionnels, sélectionnés pour le Colloquium, de présenter leurs travaux en plus de permettre aux étudiants d'interagir avec des membres des sections locales. On prévoit que le programme commencera modestement et prendra de l'expansion avec le temps.

Upcoming Conferences and Seminars

70th Canadian Geotechnical Conference and the 12th Joint CGS/IAH-CNC Groundwater Conference
October 1 to 4, 2017
Ottawa, Ontario
www.geoottawa2017.ca

Response to the **GeoOttawa 2017** call for abstracts was excellent, with over 750 abstracts accepted. As this is the 70th Canadian Geotechnical Conference and the 12th Joint CGS/IAH-CNC Groundwater Conference, abstracts were submitted under either the Geotechnical or Hydrogeological themes. GeoOttawa 2017 will also be recognizing the Best Case Study Papers and the Best Student Papers with awards. Up to three case study papers will be recognized at the conference and the lead authors of the Best Case Study Paper will come from consulting or industry (not academia).

The conference program will include daily plenary sessions, featuring keynote speakers of interest to all delegates, followed by technical and specialty, as well as poster sessions, to meet the diverse needs of attendees. Confirmed speakers currently include: **Dr. Richard Bathurst** (R. M. Hardy Lecture), **Dr. Kamini Singha** (Darcy Lecture), **Dr. Greg Brooks** (CGS Lecture), and **Dr. Michael Hendry** (CGS colloquium). Details on our confirmed speakers and their talks are available on the conference website. In addition to the oral and poster presentations, the conference's technical program will include local technical tours, short courses, and industry presentations by our exhibitors. There will be 75 booths at the trade show and over 20 confirmed sponsoring companies showcased before, during, and after the conference. An exciting addition to this year's conference will be the

Wednesday lunch presentation of the Canadian Geotechnical Achievements Project that the CGS National Office has been busy organizing.

GeoOttawa 2017 will be held at the **Shaw Centre** in downtown Ottawa. This spectacular facility is one of Canada's premier conference venues and recently received a top three ranking by the International Association of Congress Centres. We have arranged accommodation for conference delegates at four surrounding hotels: **The Westin Ottawa**, **The Lord Elgin**, **Novotel**, and **Les Suites**. All hotels are just a short walk away from the Shaw Centre. Further information and online reservation links for each location can be found on the GeoOttawa 2017 website.

This is the 70th Annual CGS conference and Ottawa will also be the epicentre of Canada's 150th birthday celebration, so this is one conference you don't want to miss! Join us October 1 – 4, 2017 at the Shaw Centre!

Please address any questions to the Conference Chair: **Mamadou Fall** at *mfall@uottawa.ca*

Submitted by Mamadou Fall
Conference Chair – GeoOttawa 2017

70e conférence de canadienne de géotechnique et la 12e conférence conjointe SCG/AIH-SNC sur les eaux souterraines 1 – 4 octobre 2017 Ottawa, Ontario

La réponse à l'appel de résumés de **GéoOttawa 2017** a été excellente, avec l'acceptation de plus de 750 résumés. Comme il s'agit de la 70e conférence canadienne de géotechnique et de la 12e conférence conjointe SCG/AIH-SNC sur les eaux souterraines, des résumés ont été soumis sous le thème de la géotechnique ou de l'hydrogéologie. GéoOttawa 2017 reconnaîtra également les meilleures histoires de cas et le meilleur article d'un étudiant en octroyant des prix pour ceux-ci. Jusqu'à trois histoires de cas seront reconnues à la conférence, et leurs auteurs principaux proviendront de sociétés d'experts-conseils ou de l'industrie (pas du milieu universitaire).

Le programme de la conférence comprendra des séances plénières quotidiennes, présentant des conférenciers qui intéresseront tous les délégués, suivies de sessions techniques et spécialisées, ainsi que de sessions de présentation d'affiches, pour répondre aux besoins diversifiés des participants. Voici les conférenciers actuellement confirmés : **Dr Richard Bathurst** (Conférence R. M. Hardy), **Dr Kamini Singha** (Conférence Darcy), **Dr Greg Brooks** (Conférence de la SCG) et **Dr Michael Hendry** (Colloquium de la SCG). Les renseignements sur nos conférenciers confirmés et leurs conférences sont affichés sur le site Web de la conférence.
En plus des présentations orales et d'affiches, le programme technique de la conférence comprendra des visites techniques locales, des cours intensifs et des présentations de l'industrie de nos exposants. Il y a aura 75 stands au salon professionnel, et plus de 20 commanditaires confirmés seront présentés avant, pendant et après la conférence. Un ajout prometteur à la conférence de cette année sera la présentation du Projet sur les réalisations géotechniques canadiennes que le Bureau national de la SCG s'est affairé à organiser et qui aura lieu le mercredi midi.

La conférence GéoOttawa 2017 aura lieu au **Centre Shaw**, au centre-ville d'Ottawa. Cet établissement spectaculaire est l'un des principaux lieux de conférence au Canada et a récemment été classé parmi les trois premiers par l'International Association of Congress Centres. Nous avons pris des dispositions pour que les délégués de la conférence soient hébergés dans quatre hôtels à proximité: le **Westin Ottawa**, le **Lord Elgin**, le **Novotel**, et **Les Suites**. Ces hôtels se trouvent tous à une courte distance à pieds du Centre Shaw. De plus amples renseignements sur chaque hôtel et des liens pour y réserver une chambre en ligne se trouvent sur le site Web de GéoOttawa 2017.

Il s'agit de la 70e conférence annuelle de la SCG, et Ottawa sera également l'épicentre des célébrations du 150e anniversaire du Canada; c'est donc un rendez-vous à ne pas manquer! Joignez-vous à nous du 1er au 4 octobre 2017 au Centre Shaw.

Veuillez adresser toute question au président de la conférence, **Mamadou Fall**, à *mfall@uottawa.ca*.

Soumis par Mamadou Fall
Président de la conférence – GéoOttawa 2017

Division News
Engineering Geology Division

Soliciting Input for an Engineering Geology Monograph

As discussed at the highly successful GeoVancouver Engineering Geology Division Executive meeting, the CGS Engineering Geology Division will be pursuing the publication of an **Engineering Geology Monograph** based on the Canadian experience. We would like to solicit input in terms of the content to include as well as suggestions for topics, etc. It is envisioned that the monograph will capture the history, significant events, innovations and contributions of Canadians to the field of engineering geology. We would to have as many people as possible to contribute to this active, living archive. As such, we are soliciting the CGS membership (and beyond) for their ideas in terms of topics, articles, papers, historical perspectives and people to include. If you would like to contribute to the monograph, please contact me, **Nicholas Vlachopoulos**, at *vlach@rmc.ca* or at (613) 541-6000 x 6398. We require any and all feedback as it can become available.

Soliciting Input for GeoOttawa Workshop/Specialty Conference

After a very successful joint session with the **Professional Practice Com-**

mittee in Vancouver, we are in the preliminary stages of determining if there is enough interest in co-sponsoring a workshop or speciality session with the **Rock Mechanics Division** and/or the **Education Committee** (two different sessions). I would welcome your input as to the type of workshop or speciality session that would be of interest to you as well any suggested speakers. I will then contact the appropriate conference organizers to schedule the sessions. Please contact me, **Nicholas Vlachopoulos**, at *vlach@rmc.ca* or at (613) 541-6000 x 6398

Submitted by Nicholas Vlachopoulos
Division Chair – Engineering Geology Division

Committee News
Heritage Committee

Canadian Geotechnical Society Virtual Archives

There are rich but rarely used resources in Canada that consist of files containing historical information on geotechnical laboratory and field research, geotechnical investigations, work of committees and geotechnical expertise. Ways to identify and use these resources have been developed by the Heritage Committee of the Canadian Geotechnical Society in the form of virtual archives on the CGS web site, where the location and content of accessible historical geotechnical material are given.

CGS members and others are invited to submit candidate material for consideration. The submission should give the location of the material, a description of its nature and content, its historical significance and the conditions under which it can be accessed. Do not submit physical archival material as the Society has no space to store it, however electronic copies of photographs or materials are welcome.

Your contribution to the CGS Virtual Archives web page should be sent to the Chair of the Heritage Committee, **Heinrich Heinz**, P.Eng. at *hheinz@thurber.ca.*

Editor

Don Lewycky, P.Eng
Tel.: 780-478-4156
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Introduction by Richard Guthrie, Editor

Spring 2017

Field season is fast approaching as I write this. Many of us will be out spending a summer looking at Geohazards, designing mitigation and trying to better prepare our communities, environment, and industries against the potential impacts of a geologically and geomorphologically dynamic earth. Much has happened in the world in the last few months. Many of us have been watching the drama of the Oroville Dam unfold in the western US. At the same time, the US political drama between policy and science has being simultaneously unfolding. New developments will require geotechnical knowledge and the application of geotechnical engineering. It behooves all of us, regardless of politics, to continue to learn, develop and apply our knowledge and experience for the betterment of society.''

At least part of our jobs lay in understanding the tools and technologies available to us. For this reason, we present an article on Structure from Motion, a relatively new photogrammetric technique that is being used to provide better kinematic, geologic, and geomorphologic interpretations based on both newly acquired imagery (air photographs, digital hand-held cameras, and UAVs) and historical air photographs. I hope you find it interesting.

Next issue, despite the unfolding drama to the south, we will provide information about, and access to, a free Canadian tool that integrates downscaled models from GCMs (global climate change models) into hydrologic studies used to guide communities, dams, and culvert sizing (among other things).

Letters

I received and excellent letter from Dick Jackson of Ontario who added some missing details to the article I wrote last quarter. An edited version of his letter is here (please note that any errors are mine, not Dick's):

Thanks Dick for the feedback and the important historical update! For those of you who haven't seen Logan's initial sketches, I've included them below the letter:

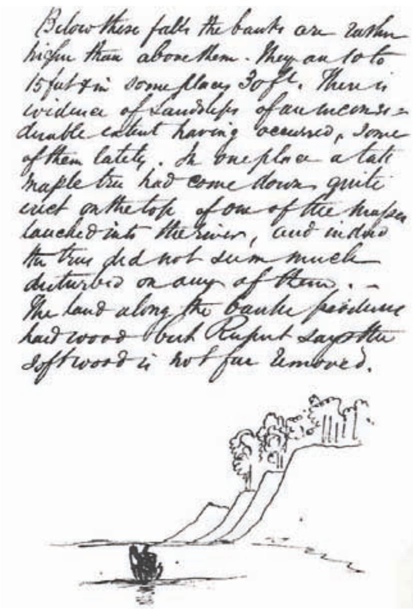
April 02, 2017

Dear Rick:

I read your Geohazards article in Geotech News with interest. I have long been interested in the history of the applied earth sciences and worked with Frank Patton to get his early papers archived by the CGS. Your article was fascinating in many aspects. A few points:

- Logan, in 1842, made the first known descriptions of failures in what is now recognized as Leda Clays and in a field book he sketched a major landslide (Legget, 1979).
- You didn't mention two events that most profoundly affected practice in Europe and here – the Vaiont landslide disaster and the Aberfan coal-mine tailings disaster – both in the 1960s. It was because of Vaiont that BC Hydro had Frank Patton develop the prototype Westbay system to monitor the Downie landslide above the Revelstoke dam.
- In mentioning Terzaghi, you might have mentioned how he believed that ALL graduate civil engineers should have been taught 'geology for engineers'. He advocated a two-semester course combined with field trips taught by "a geologist who appreciates the requirements of engineers and an engineer who has learned from personal experience that geology is indispensable in the practice of his profession''.
- It is worth noting that so many of the great geotechnical engineers are most interested in geology. Here at the University of Waterloo, my close colleague Maurice Dusseault was allowed to substitute structural geology for structural engineering while studying at the University of Alberta for his BSc in civil engineering. Morganstern is another with strong geological interests. Terzaghi, of course, was the model. He even married a geologist, which I believe is probably the best advice.
- I appreciate your celebration of John Clague, Steve Evans and Oldrich Hungr. But also remember it was Fredlund and his followers who put unsaturated zone soil mechanics on the map and Soil Vision in Saskatoon and Geo-Slope in Calgary that have produced such useful software. It was Hodges and Freeze who did the first simulations back in the 1980s of slope failure.

Regards, Dick Jackson
Geofirma Engineering Ltd.,
Heidelberg, Ontario


Below these falls the banks are rather higher than above them. They are 10 to 15 feet & in some places 30 ft. There is evidence of landslips of an inconsiderable extent having occurred, some of them lately. In one place a tall maple tree had come down quite erect on the top of one of the masses launched into the river, and indeed the tree did not seem much disturbed on any of them. The land along the banks posesses hard wood but Rupert says the softwood is not far removed.

Announcing

7th Canadian Geohazards Conference – Geohazards 7: Engineering Resiliency In A Changing Climate http://www.geohazards7.ca/

The Canadian Geotechnical Society (CGS) is pleased to announce the 7th Canadian Geohazards Conference – Geohazards 7 – to be held June 3-6, 2018 at the Coast Canmore Hotel & Conference Centre in Canmore, Alberta. The CGS's Geohazards conferences are the premiere forums in Canada for the sharing and dissemination of scientific and engineering knowledge related to geohazard assessment and risk management.

Canmore is ideally situated for hosting Geohazards 7. It is located within easy travel distance from the Calgary International Airport, and is less than a 30-minute drive from Banff National Park. Heavy rainfall in June 2013 resulted in the worst floods in Alberta's history. Landslides, debris floods and debris flows cut off highway and rail access to Banff and Canmore, and many homes constructed on alluvial fans were destroyed. Municipal governments, the Province and the engineering and geoscience community have since carried out aggressive programs to quantify geohazard risk, increase public awareness of hazards, and are constructing mitigation measures to reduce future risk. Canmore is a terrific venue to showcase the results of some of these initiatives, which will feature in the conference program and fieldtrip.

This conference will be of interest to engineering and geoscience students and consultants, industry, and government agency representatives who are involved in planning, approval, construction and operation of infrastructure and residential development in areas prone to geohazards. The conference will touch on the full gamut of hazards and risks associated with floods, debris flows, landslides, snow avalanche, earthquakes, volcanic eruptions, degrading permafrost and more. Arming participants with greater awareness of methods for quantifying geohazard magnitude and frequency for risk assessment and mitigation design, quantifying uncertainty in a changing climate, and communicating with the public about geohazard issues, are key objectives of the conference.

Closing Notes

If you have a paper or project related to Geohazards that you think would be interesting to GN readers, please send me note at *Richard.Guthrie@stantec.com.* Have a safe and productive field season. We'll see you in September.

Structure from motion and landslides: The 2010 Mt Meager collapse from slope deformation to debris avalanche deposit mapping

Gioachino Roberti, Brent Ward, Benjamin Van Wyk de Vries, Luigi Perotti

Topographic reconstruction is a fundamental operation in geotechnical and geomorphological studies. In recent years, three-dimensional surface reconstruction has been revolutionized by the development of Structure from Motion (SfM) photogrammetry. The SfM technique allows rapid base map production from any set of overlapping photographs. Surface information can be retrieved from these images without the need of camera calibration, ground control points, or any other external information.

We present herein, the application of SfM to the study of the 2010 Mount Meager debris avalanche. We used SfM to produce base maps for a large scale (1:1000) geomorphic study of the debris avalanche deposit, to produce a post-event DEM of the collapse scar and generate sequential DEMs to track the deformation of the Mt Meager flank pre-collapse. In the study of the deposit and the collapse scar we processed oblique helicopter digital photos taken with a standard SLR camera. For the observations of the flank prior to the collapse, we used digitized historical vertical aerial photos. We processed both oblique photos and vertical historical aerial photos with the commercial SfM software package PhotoScan. SfM is a powerful tool for geologists and geomorphologists and quickly becoming standard technique in interpretive geoscience.

Structure from Motion

Originally, Structure from Motion (SfM) refers to the computing vision problem of reconstructing the geometry of an object (Structure) from a moving sensor (Motion). With the use of SfM, the three-dimensional geometry of scenes and objects can be retrieved from sequential two-dimensional images by measuring geometric differences between images. In geoscience, SfM refers to a composite workflow of Structure from Motion and Multi View Stereo (MVS) algorithms. The SfM process matches features between images, estimates the camera position and parameters, and delivers a sparse point cloud in generic x, y, z object coordinates. The MVS increases the number of matches to generate a denser point cloud. The point cloud can be then georeferenced by adding ground control points (GCP) and interpolated to generate digital elevation models (DEM).

The use of SfM does not require specialized personnel or expensive software, making three-dimensional modelling accessible to everyone. This technique is broadly applied from the hand-sample reconstruction to outcrop modelling and medium scale topography generation. SfM-derived DEMs have been proven to be of comparable quality to Lidar DEMs. While SfM is most often used with imagery taken from a hand-held camera or unmanned aircraft vehicles (UAV)few studies have explored the application with historical aerial photos. Limitations exist related to the automated workflow where errors are difficult to identify and control, however, recent work has focused on assessing and reducing such errors allowing broader acceptance of SfM

SfM allows for a rapid and high-resolution cartographic production effective in the assessment of natural disasters. For landslides it can be used to generate post-event topography, to get sequential DEMs of slow moving landslides, or to perform kinematic analysis of joints and discontinuity sets.

There are many open source and commercial SfM packages available. We used PhotoScan to reconstruct the 2010 Mt Meager landslide deposit, landslide scar and the slope distress of the flank prior to the collapse. Photoscan includes, in a single package, the whole workflow from image matching to orthophoto and DEM extraction, allowing point cloud and mesh editing. Its efficiency, straightforward workflow, and a user-friendly interface has made Photoscan successful with a wide scientific literature to prove its reliability and precision.

The 2010 Mt Meager landslide

In 2010 the south flank of Mt Meager (British Columbia, Canada) failed catastrophically (Figure 1) generating the largest (~50 Mm3) landslide in Canadian history (Guthrie et al., 2012). The collapse evolved as four structurally controlled sub-failures that retrogressed from the base of the flank to the peak of the mountain (Roberti et al., in press.). The rock mass fractured forming a rapid debris avalanche that reached peak velocity of 90 m/s, ran up to 270 m on the valley sides and travelled 12.7 km damming Capricorn Creek for 19 h and partially damming Lillooet River for 2 h.

SfM-derived base maps were used for detailed descriptions of the deposit and revealing the separation of a water-rich frontal debris flow and a water-poor, less mobile debris avalanche core in the landslide event. The SfM analysis of historical aerial photos over Meager Peak allowed the description of the ongoing slow deformation on the flank responding to glacier pulsations at its base. We calculated the volume of the collapse and the geometry of the sub-failures by

Figure 1. Photograph of the main collapse of Mt Meager. Note helicopter for scale (photograph courtesy of R. Guthrie).

comparing the 2006 and the post-event DEMs. Glacial retreat in the years preceding the collapse, in addition to faulting, deformation, and smaller failures, were all evident in the lower flank from SfM analysis.

Details of the volume and mechanics of the 2010 Mt Meager landslide are expected to be released shortly in an upcoming paper in Landslides (Roberti et al., in press). At this point we can say that we improved on the original volume estimate of Guthrie, et al. (2012), that the landslide is somewhat larger than previously supposed, and that, using SfM, we were able to make a more precise description of both causal mechanisms and the mechanics of the collapse.

2010 debris avalanche deposit

For the geomorphological study of the 2010 Mt Meager landslide deposit we took pictures from a low-level helicopter traverse with a digital Canon SLR camera. We processed 712 images, where poor quality images were excluded (blurred, overexposed) and, when necessary, the helicopter skids masked out. The resulting orthophoto and DEM have a resolution of 8 cm/pixel and 0.34 m/pixel (point density at 0.64 pts/sq m), respectively. GCP planimetric coordinates were retrieved from a 0.5 m GeoEye orthophoto while vertical information was from a 25 m resolution British Columbia Terrain Resource Inventory Mapping (TRIM) DEM of 18.3 m average accuracy.

The precise distribution of different debris avalanche facies was mapped at 1:1000 scale (Figure 2) and deposits related to different water contents phases were recognized (Roberti et al., 2017). The deposits were correlated water-rich and water-poor phases. The water-rich phase superelevated and left relatively thin scattered distal deposits. The water-poor phase was confined to the valley bottom and stopped rapidly leaving thick hummocky deposits.

1948-2006: The deformation before the collapse

We documented more than a half-century of geomorphological evolution of the south flank of Mt Meager from historical aerial photos, orthophotos and DEMs. A rich archive of historical vertical aerial photos is available at the Geography Department Library at UBC (University of British Columbia). The study area was captured in 1948, 1964, 1973, 1981, 1990, 2006. We digitized the aerial photos and processed them with PhotoScan to reconstruct the diachronic evolution of the three-dimensional geometry of the flank. The frames were scanned at 800 dpi with a standard A3 scanner, orienting the strip flight direction parallel to the CCD array of the scanner. To georeference the models, planimetric coordinates were retrieved from SPOT-10 m resolution imagery while the vertical information was obtained from the 25 m BC TRIM DEM.

To test the precision of the cartographic products, we took control points from a Lidar DEM acquired during summer of 2015. The 2006 and the post-collapse DEMs were compared using a pixel-wise difference, and calculating the volume of the failed mass. It was also possible to calculate the volume and the geometry of the sub-failures, interpolating the superficial faults between the two DEMs. The error in the volume calculation was assessed by comparing the two surfaces outside of the collapse scar, where no change was expected and calculating the same relative error for the volume estimate.

In addition, we mapped the extent of the glacier tongue at the base of the failed slope on each orthophoto. Uncertainties in this exercise related to inherent errors in the base map, to the manual tracing of the glacier perimeter, and difficulty of distinguishing between ice, snow and snow-covered ice. We used the inherent pixel precision of the orthophotos to buffer the perimeter of the glaciers. The precision of the glacier area was calculated as the root of the squared sum of the buffered areas.

An interpretation of the 2006 topography is shown in Figure 3.

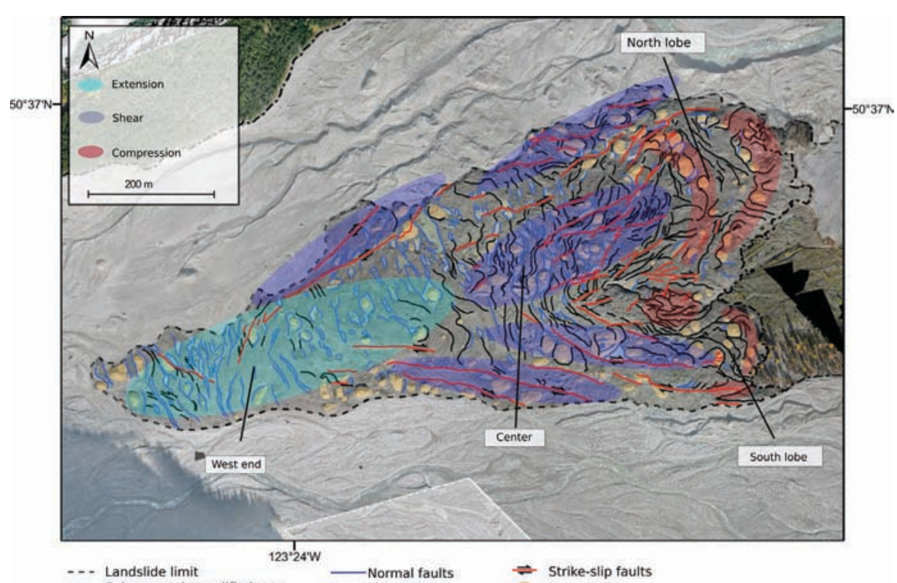


Figure 2. Detail of the 2010 Mt Meager debris avalanche deposit. High resolution mapping allowed the identification of different stress regimes: extension (light blue) at the west corner; shear (purple) in the central part and at the sides; and compression (red) at the front and between the two lobes. Modified from (Roberti et al., 2017).

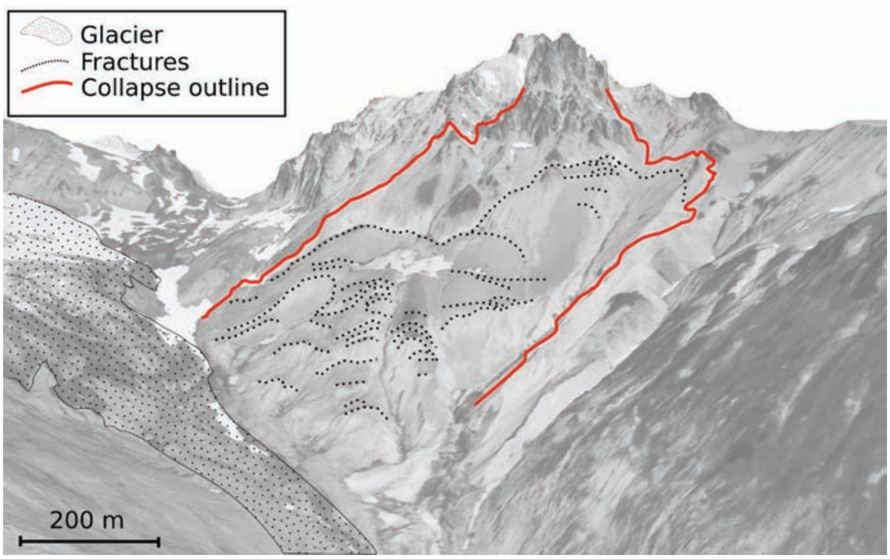


Figure 3. SfM-derived 3D view of Mt Meager before the 2010 collapse. Fractures are evidenced: they indicate active deformation of the slope prior the collapse. Modified from (Delcamp et al., 2016).

Georeferencing and cartography accuracy

The standard procedure in georeferencing digital geospatial data is to use coordinates from a source with higher accuracy. Commonly, GCP coordinates are measured in the field during a differential GNSS survey. In our case, it was not feasible to acquire GNSS points in the field and the coordinates used for georeferencing the SfM models were retrieved from the available Canada imagery and DEMs. The accuracy of the coordinates used (10 m planimetric and 18.3 m vertical) in the georeferencing process was lower than the potential accuracy of the SfM products (0.8 cm for the deposit images and 0.5 m -1 m for the historic photos). The pixel precision of the models depends on the photo quality, the original images pixel size and the matching algorithm. The final cartographic accuracy depends on the geographic/cartographic coordinate source used in the georeferencing process. During georeferencing other errors might be introduced when GCPs have lower accuracy than the three-dimensional matching. When the GCPs have higher accuracy than the bundle adjustment, they might improve the model quality. When GCPs are lacking and/or they are not reliable, the models might be just scaled for relative volume and area calculations.

The ability of SfM to build three-dimensional geometries with relative object coordinates gives the user the opportunity of making quick maps that do not necessarily require GCP surveys. Observations can be done in relatively-scaled object-coordinates without ground control. Careful evaluation of the models is nevertheless required, especially when GCPs are not used, to reduce erroneous reconstructed areas and wrongly projected points.

Summary

Structure from Motion (SfM) is a versatile photogrammetric tool that allows for rapid and high quality cartographic production. SfM can reconstruct the three-dimensional geometry of objects and surfaces in relative coordinates without the need for camera calibration parameters, or GCPs. Geometries and camera parameters can be retrieved during bundle adjustments from the redundancy of images. SfM can process newly acquired overlapping images as well as digitized historical vertical aerial photos. Measurements can be done with geographic coordinates or relative object coordinates without the need for precise GCPs. SfM is becoming a mature technology and a standard tool for geoscience and can be effectively applied to the study of historic landslides deformation to document ongoing motion or to map freshly emplaced deposits.

The use of SfM in the detailed study of the 2010 Mt Meager landslide deposit, allowed a precise volume calculation and documentation of the slow deformation preceding the collapse. The 2010 Mt Meager landslide separated into a water-rich and a water-poor rheology phases with different run-out, characteristics and deposits. The slope prior the collapse was actively deforming and a glacier below the flank was retreating.

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Overture

47th episode of the Grout Line and for this issue a European experience with the use of Multiple Port Sleeved Pipes (or TAM) in soil grouting. The authors Ing. Andrea Pettinaroli (*a.pettinaroli@stap-engineering.eu)*, Dr. Mario Ruggiero (*m.ruggiero@sireg.it*) and Ing. Gabriele Balconi (*g.balconi@sireg.it*) prepared this article about a successful compensation grouting project carried out in Warsaw, Poland.

A case history of compensation grouting with the TAM application in an urban area in Warsaw, Poland

Andrea Pettinaroli, Mario Ruggiero, Gabriele Balconi

Grouting is a technique used for modifying the behaviour of a mass of soil or rock by injecting cementitious or chemical mixes. Different processes of execution may lead to different results, and the choice is a function of the objective of the treatment and of the type of ground. More than fifty years ago, the introduction of sleeved pipes also known as TAM (Tube A Manchette) brought a lot of advantages to this technology; it allowed for widening of the use of the grouting, leading in many cases to more easily reach the purpose and to savings in time and cost. The use of non- metallic pipes is nowadays highly diffused because the variety of pipe materials available, such as plastics and composites, allows for optimization of the costs of the tubes as a function of the kind and importance of the work. The TAM pipe technology is used both in soil and rock.

Figure 1. DURVINIL grouting tubes with raised sleeves (left) and with flush sleeves (right).

The TAM pipe is a tube, normally made of plastic, perforated at a regular distance, with rubber sleeves mounted on the holes to prevent the flow-back of the mixtures inside the pipe. For standard applications the pipe's outer diameter ranges usually from one to two inches (Fig.1).

After identifying the area to be treated and method of treatment required it is necessary to proceed with the realization of the pre-drilled and cased holes where the pipe will be inserted, by a conventional drilling rig. The sleeved pipe is installed and sealed into the hole by means of a suitable plastic cement mixture (sheath) in granular soils, or alternatively through the use of geotextile bags in rocky soil acting as packers. The sealing prevents the injection mixture from raising up along the borehole and penetrating in the area of influence of the single sleeve.

Once the annular space around the pipe is sealed, the pressure injection is carried out through a single valve with a double packer (mechanical or hydraulic with expansion joint). The injection mixture opens the valve and spreads the grout into the surrounding soil. After grouting, the valve closes, preventing the injected material from returning into the pipe. Once the pipe has been washed inside, the valves are ready to be used eventually for other subsequent grouting operations.

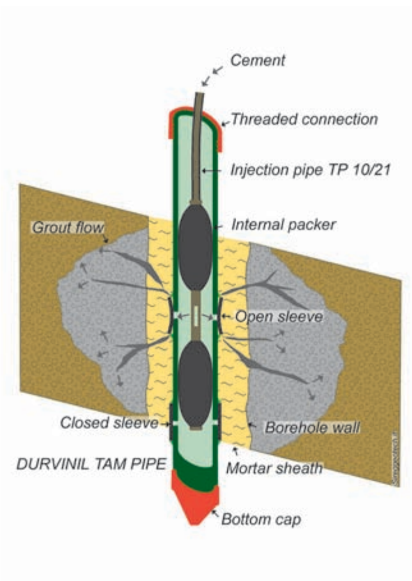

Figure 2. Grouting injection through a sleeved grouting pipe.

There are many advantages to this method. One of them is that the injection can be carried out in more than one stage and, if necessary, using different cement based mixtures.

One of the typically employed grouting processes is **Permeation grouting**, which consists of filling the natural voids in the soil with a mixture, substituting the in-situ fluid (normally air or water). The result is a reduction of the hydraulic conductivity and an increase in the mechanical characteristic of the soil. Cements, chemical mixtures and resins reinforce the soil structure, improving the strength and the elastic modulus of the treated ground. The granular composition of the soil also plays a fundamental role in the success of the permeation grouting: the finer the dimension of the soil grains and the higher the dis-uniformity degree ($U= D_{60}/D_{10}$), the lower the volume of the voids. So basically it is important that in the first phase of the grouting design, a detailed investigation campaign including soil coring is planned, in order to obtain the granulometric sieve from samples of the soil layers where the treatment shall be carried out.

On the other hand, the capability of a grout mix to permeate the soil is a function of its composition. The rheology study of the mixtures allows for definition of this parameter.

In order to achieve a good permeation grouting homogeneity, cement mixes are stabilized by adding a filler (for example bentonite) that helps to maintain in suspension the cement grains. The use of fillers normally increases the viscosity of the mixture; the use of polymeric-based additives allows viscosity and stability to reach optimal values.

As a matter of fact, an accurate set of preliminary tests has to be foreseen before starting permeation grouting work, in order to define the correct mixture to be used for the grout and to provide the benchmark values of its rheological parameters. The latter will be considered during the on-site work in progress controls. The use of sleeved pipes brings a series of advantages to permeation grouting:

- it allows for the injection of the proper grout quantities, in a controlled way, in the different zones of the soil mass to be treated;
- for each sleeve it is possible to record the operative parameters (pressure and flow rate) during the injection process, obtaining the “story” of each grouting and allowing the evaluation of the parameters for the following steps;
- it is possible, if necessary, to inject additional quantities of grout in further stages;
- it allows for the injection of different kinds of mixtures from the same sleeve, for example following an order of growing penetrability.

The use of sleeved pipes, often coupled with a polypropylene bag (Fig.3), allows for the reduction of the number of drillings required. This way the injection process is faster, without any influence on the type of mixture to be injected and/or on the parameters to be used.

Grouting is not only required to improve the mechanical characteristics. It has also been used in the reduction of the mechanical prop-

Figure 3. High tenacity polypropilene bags.

erties of the rock/soil for specific purposes: for example a treatment of fissured rock with highly deformable resin using sleeved pipes allowed for excavation with blasting of a highway tunnel close to a rock mass containing inflammable gas. The energy of the blast was dissipated by the shell of deformable treated rock that surrounded the tunnel excavation profile, avoiding the propagation of the vibration waves and the upsetting of the dangerous zone in proximity to the site (Wolf E., Collini R., Balossi Restelli A. – Attraversamento di una tratta della galleria Capo Calavà (Autostrada Messina Palermo) in presenza di gas tossici in pressione – Gallerie e grandi opere sotterranee n.°8, March 1979)

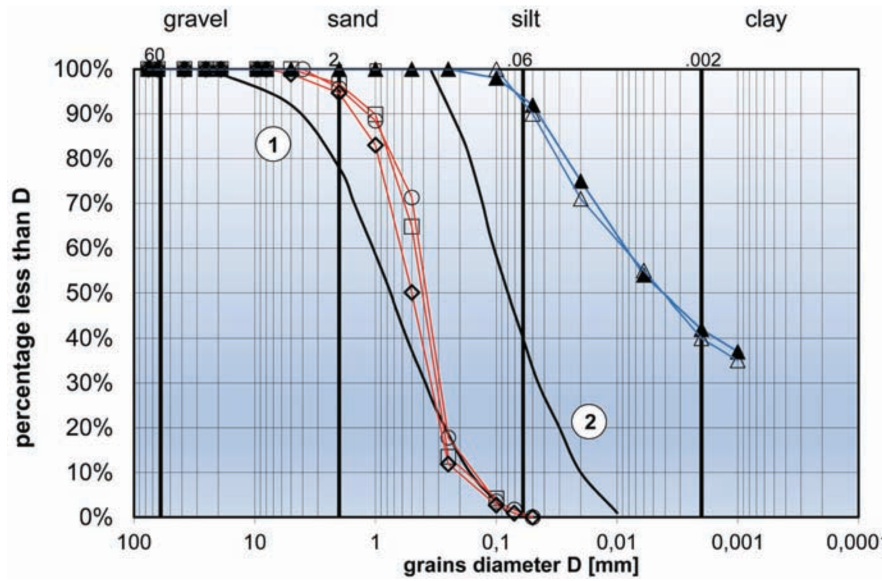

Figure 5.The granulometric distribution of the soil.

Warsaw Metro compensation grouting

The new Warsaw Metro Line 2 ends east of Vistula river. The last station C15 is near a shopping center. The latter is connected to the Metro Station by an underground pedestrian passage that runs very close to the shallow foundation of one of the building's façades. During the execution of the provisional lateral sheet wall diaphragm, the vibration de-tensioned the sandy layer under the foundation of the structure, causing remarkable settlements on some pillars, up to about 50 mm (Fig. 4).

The investigation showed the presence of a superficial layer composed of an almost monogranular sand in the foundation level, from 3 m to 12 m of depth under the campaign level (see res curves in the chart of the following fig. 5), followed by a stiff clay layer at -12 m u.c.l. (blue curves).
CPT tests were carried out both in the area of the disturbance and in the sector of the building façade where the diaphragm wall was not constructed, putting in evidence the weakening caused by the works.

It was then necessary to re-compact the soil under the building foundations in the zone of the damage, and to uplift the involved plinths in order to reduce the differential settlements between the adjacent parts of the structure. Moreover, preventive treatment was necessary in order to reinforce the soil foundation of the plinths in the sectors where the sheet wall was yet to be executed.

The treatment was carried out injecting in the first stage a cement grout, with ratio C/W=0,4 stabilized with bentonite and the aid of a stabilizer additive, and in the second stage silica grout. The consumption of cement mix has been prevalent in the decompressed zone for achieving the re-compaction effect. In the natural sandy soil a lower quantity of cement was integrated by the silica grout that achieved the requested improvement of the ground by permeating the latter with a smooth effect on the structures, as hereafter described.

The treatments were carried out by grouting the sands for a thickness of about 9 meters (down to the clayey layer) under the foundations, composed by concrete plinths at the base of the pillars, connected by beams.

Two lines of PVC sleeved pipes were installed along the external alignment of the building (fig.6), while two other rows were installed working from the

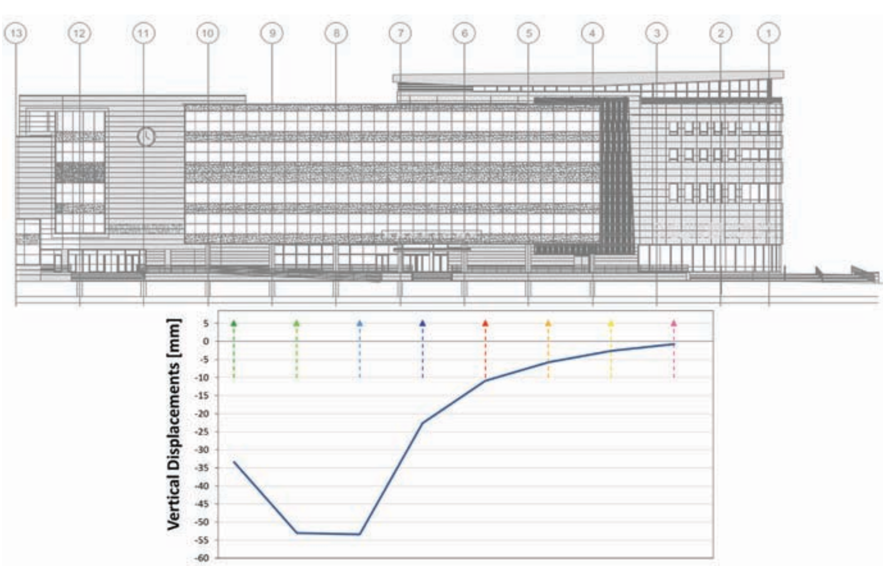

Figure 4. Pillars' settlements before the grouting work.

Figure 6. Two rows of TAM outside the structure, installed from a lowered existing level.

Figure 7. Drilling works from the underground parking inside the building.

underground floor, in narrow spaces (the average height was 2,30 m) (Fig. 7).

The structures were controlled by an automatic topographic monitoring system (Fig.8); optical prisms were placed in correspondence of each pillar.

The grouting scheme was studied in order to gradually uplift the structure's pillars; in some cases even the specific order of the sleeves to be injected was indicated. On the first day, a set of holes was drilled and the sheath injection executed. On the following day, the first stage of the injection, using cement grout, was carried out. The monitored points were regularly checked. The operative parameters were recorded in real time and the pressure and volumes evaluated at the end of each working day. In some cases, the data analysis involved rescheduling the grouting sequence of the following days. The continuous and constant monitoring and recording of the grouting parameters influenced the timing and scheduling of the project. On several occasions the weekly scheduling was modified based on the results obtained day by day. In some cases, the weekly programming was modified based on the data and results obtained on a specific day.

The chart of figure 9 shows the evolution of the vertical displacements measured during the works. Firstly the grouting with cement mix gradually uplifted the pillars nr. 8 and 9.

Figure 8. Topographic monitoring system.

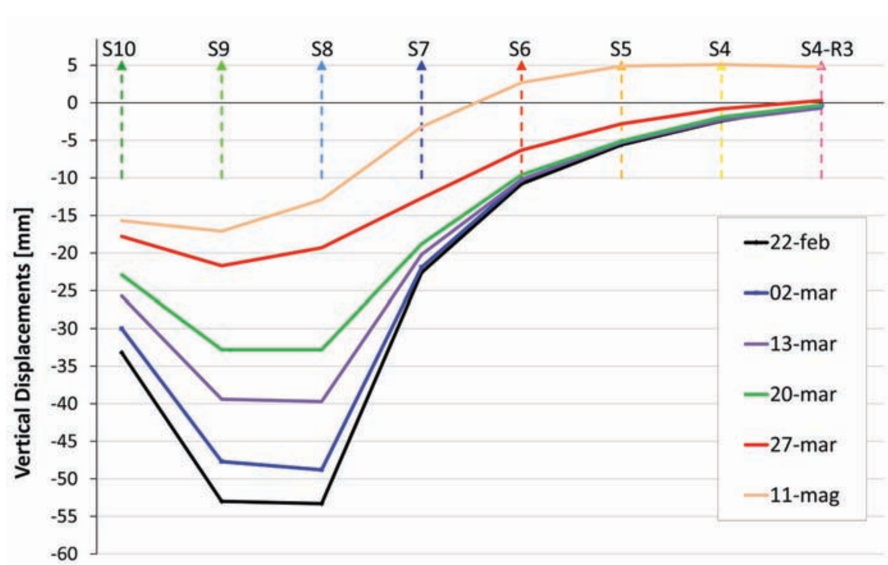

Figure 9. Pillars' displacements during the grouting works.

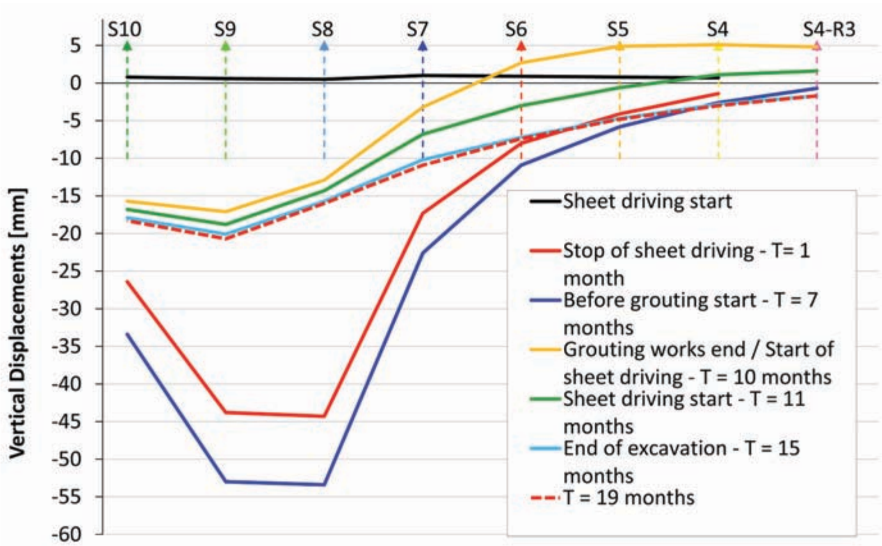

Figure 10. Pillars' displacements during the time.

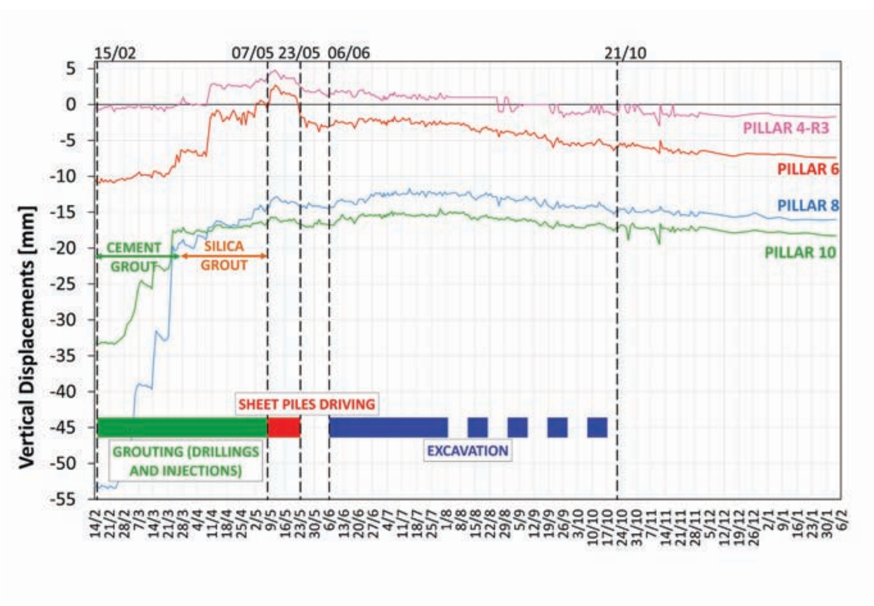

Figure 11. Pillars nr. 10, 6, 8 and 4R3 displacements during all the working phases.

Few holes required an additional second stage of cement grouting. When the differential settlements between the pillars were strongly reduced, the silica grout was injected, working gradually along the area to be treated. The effect of this injection stage is shown by the yellow line in (Fig.10); an average uplift of about 5 mm was induced.

At the end of the treatment, the sheet wall execution was also completed in the area in front of pillars nr. 6 to nr. 3.

The sheet elements were now driven into the ground without vibration. The green curve in the following figure 11 evidences the effect of this work on the structure. Settlements of about 5 mm were measured in the zone besides the activities, while pillars nr. 8 and 9, showed a very reduced settlement (less than 1.5 mm) after the compaction grouting works.

Finally, the excavation between the driven sheet walls and the following

Figure 12. Warsaw worksite.

Figure 13. Warsaw worksite (2).

reinforced concrete lining cast was carried out in the following 4 months.

Low residual settlements were measured, varying from 1.5 mm to 3 mm, in the range expected by the structural designers. The effect of the treatment, together with the different execution methods used, definitely allowed for reduction of the sensitivity of the structure during the driving of the sheet piles. This was confirmed by the very slight displacement produced during the final excavation stage.

The success of this project confirms once more the flexibility of the TAM grouting technology that, along with the use of real time monitoring and recording, allows the technical optimization of the scheduling.

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In conclusion, a final reminder, only a few weeks away:

- 5 short courses:
  Compaction Grouting
  Jet-grouting (1/2 day)
  Compensation Grouting
  Diaphragm wall
  Deep mixing (1/2 day)
- 5 Key Note Lectures
  Rick Marshall, CHST- Grouting, Deep Mixing and Diaphragm Walls: Achieving success through safety.
  Jim Warner P.E. Fellow and Life Member ASCE- Reflections from 65 years in the grouting industry.
  Dave Paul, USACE – Mosul Dam, International cooperation for remediation of dam safety issues.
  Prof. Alessandro Flora- The future of Jet-grouting- A European perspective.
  Donald Bruce, PhD, C.Eng.- Remedial cutoff walls for dams: great leap and Wolf Creek.
- 130 technical presentations

More details at *www.groutingconference.org.*

An opportunity not to be missed, to stay updated on Grouting, Deep Mixing and Diaphragm Walls, to network with colleagues and friends and, why not, enjoy the beauty of Hawaii!

Aloha!

And see you there, I hope!

As usual, I make the same request, asking you to send me your grouting comments or grouting stories or case histories. My coordinates remain:

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Ciao! Cheers!

The impact of shear strength, density, and settlement on capping and reclaiming soft tailings deposits

Gord McKenna, Brent Mooder, Bill Burton, Andy Jamieson, Derrill Shuttleworth

Soft tailings are operationally challenging and expensive to stabilize, cap, and reclaim to agreed land uses. This article highlights recent work (see McKenna et al 2016) on the role of shear strength, density, and settlement on capping soft tailings, with examples from Athabasca oil sands mining.

To extend this work beyond oil sands, the authors are collecting additional data from the literature on capping tailings at metal and coal mines, dredge spoils, sewage lagoons, soft industrial wastes, and embankments on soft ground. If you have strength and density data, and especially capping experience you can share, please contact us.

What are soft tailings?

Soft tailings (Figure 1) are the residues separated during ore processing that, due to their low strength and bearing capacity, are difficult to stabilize, cap, and reclaim (Jakubick et al 2003). Many metal and coal mines have a few hectares of soft tailings that are capped using soft-ground techniques (Figure 2). Other mines, especially oil sands mines, have many square kilometres of deep soft tailings deposits, necessitating a more holistic approach to tailings management.

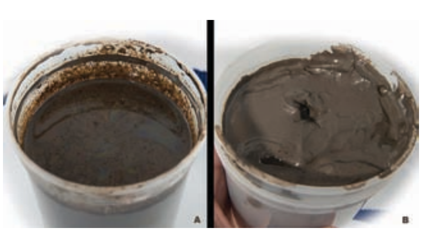

Figure 1. Two oil sands soft tailings. A: Untreated fluid fine tailings; B: Fly ash amended thickened tailings.

Figure 2. Soft-ground techniques employed at Wismut Uranium Mines, Germany.

Oil sands soft tailings are generally underconsolidated clay-rich tailings. They may be deposits formed by fines segregated from tailings sand slurry during hydraulic placement, or they may be deposits of reprocessed fine tailings. Typical geotechnical moisture contents are 40 to 250%, which corresponds to solids contents of 30 to 70%. They have peak undrained shear strengths that are less than 25 kPa with sensitivities of 2 to 13; many have strengths comparable to soft foods (McKenna et al 2017). Soft tailings with shear strengths less than 5 kPa are sometimes referred to as fluid tailings.

For soft tailings with low permeabilities, deep deposits are expected to take decades to centuries to consolidate. In the oil sands, post-reclamation settlements of 10 to 50% of the original tailings thickness may be expected, due to the combination of self-weight and the weight of a cap.

Successful reclamation

Successful tailings reclamation requires clear, achievable goals and performance objectives. The goal is clear in oil sands: regulatory approvals require oil sands operators to construct reclaimed landforms that are capable of supporting a self-sustaining, locally common boreal forest (which includes

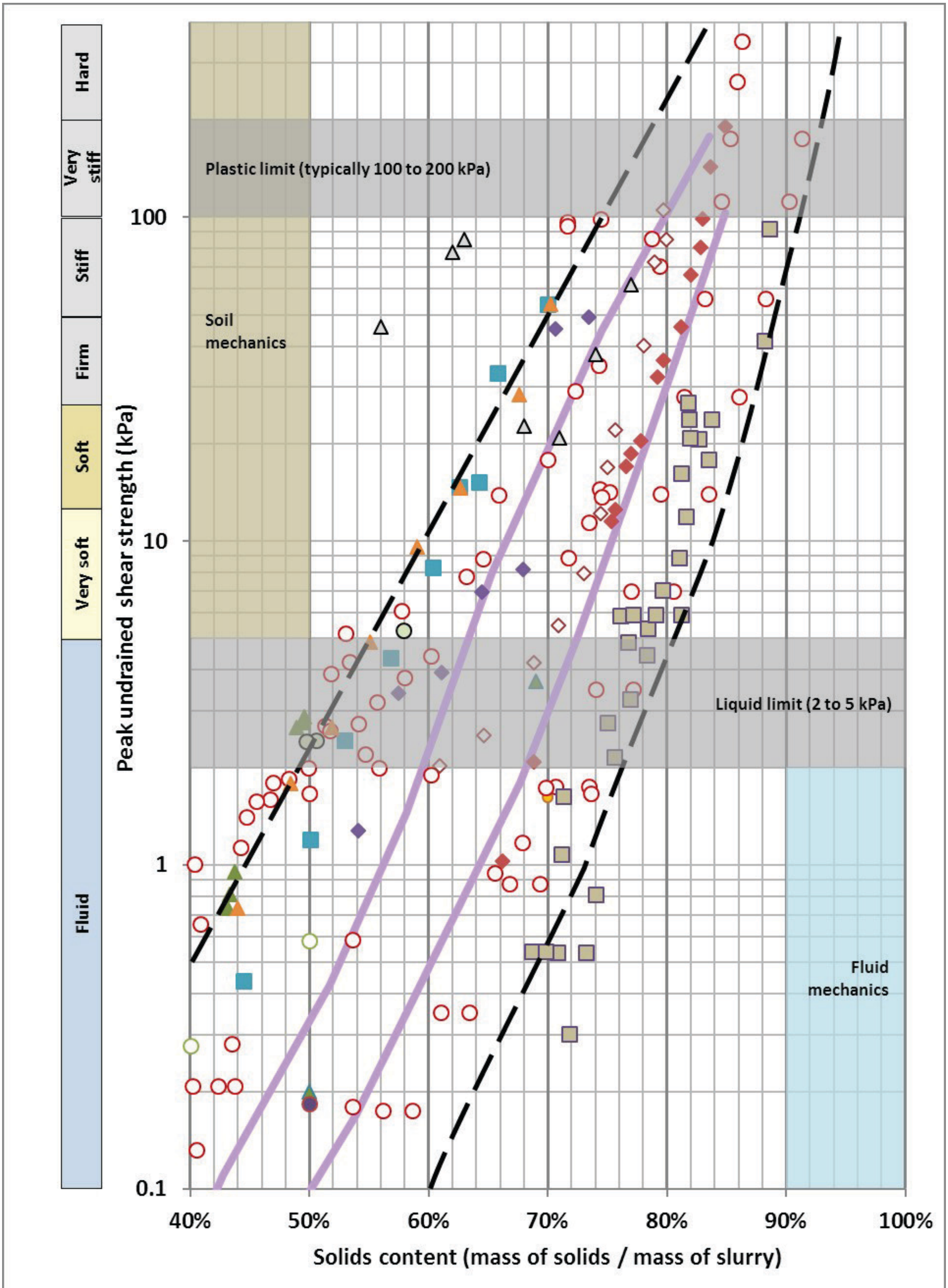

Figure 4. Shear strength and solids content of oil sands fine tailings.

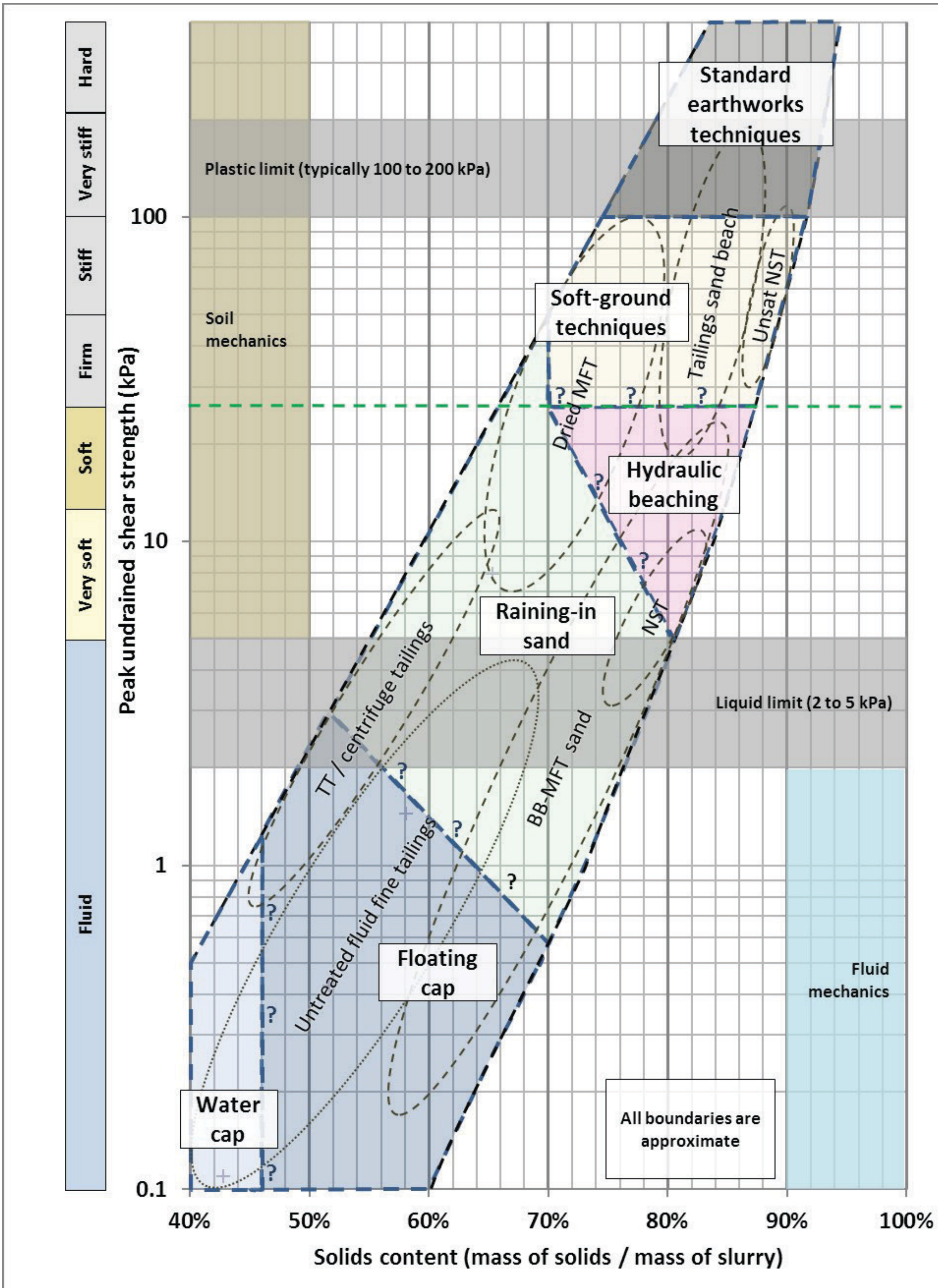

Figure 5. Capping technologies for oil sands soft tailings.

uplands, wetlands, and lakes). Mines declare specific reclamation objectives and design criteria to support this and other goals (eg Ansah-Sam et al 2016).

To build useful post-mining landscapes, designers need to ensure that each soft tailings deposit can be reclaimed to safely support uplands, wetlands, and lakes and that provide sufficient water quantity and quality to support downstream needs. Excessive post-reclamation settlement can lead to enlargement of lakes and wetlands, upsetting the water balance, affecting water quality, and changing the land use mix. Figure 3 shows some recent examples of oil sands soft tailings reclamation projects designed to accommodate settlement.

The strength and density of oil sands tailings

Figure 4 shows the relationship between density and shear strength of oil sands tailings using publicly available data. As might be expected, the

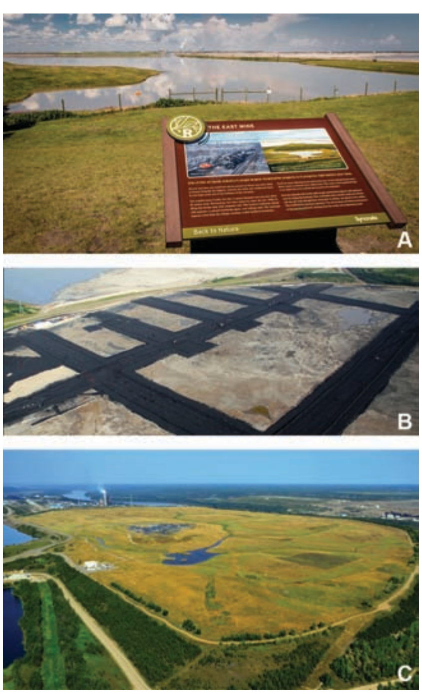

Figure 3. Oil sands soft tailings reclamation. A: water-capped tailings at Syncrude; B: Floating coke-capped tailings at Suncor; C: Hydraulic beach capped tailings at Suncor.

shear strength increases exponentially with density. For comparison, the light purple lines show the relationship between liquidity index for natural sensitive clays (as explored in the 1960s by Houston and Mitchell) with similar Atterberg limits to oil sands fine tailings: liquid limit=60%; plastic limit=20%.

Most of oil sands soft tailings R&D and commercial operations are focused on increasing densities and strengths through chemical and mechanical treatment. Much of the variation in the strengths in Figure 4 is due to the impact of chemical amendments – typically coagulants and flocculants. Some scatter is due to the wide range of clay contents.

The six-pack of soft tailings capping methods

Figures 5 and 6 present six ways that soft tailings are capped:

- *A water cap* can be used to reclaim tailings to a lake. As tailings are pumped to a newly mined out pit, the shorelines and outlet are constructed, then water is pumped in to flood the deposit. The initial water cap is designed to be deep enough to prevent lake currents from resuspending the tailings at the mudline and help kickstart a productive ecosystem (see CEMA 2012). Syncrude's Base Mine Lake is a full-scale prototype water-capped tailings end pit lake (see Figure 3A).
- A low-density *floating cap* can be employed where the underlying tailings are denser than the cap. Suncor has successfully capped fluid tailings using its low-density petroleum coke (similar to coal) placed by small equipment onto a reinforced geofabric rolled out on a frost layer in the winter (see Figure 3B).
- *Raining-in* tailings sand in thin lifts over soft tailings is an option where the tailings are a little stronger and denser. Floating barges, connected with winches and cables to the shore or guided by dynamic position systems, lay out very thin (sometimes less than 5 cm) lifts of sand by spraying the sand slurry through the water column, to allow it to gently come to rest on the mudline. A common technique for capping natural harbour, lake, and river sediments, raining-in has been piloted in the oil sands on low-density untreated tailings. Unlike natural sediments, untreated oil sands tailings does not consolidate between these lift placements, and hence does not increase in density or strength. Mixing or inversion (where the denser cap plunges to the base of the soft tailings) are risks. Treated oil sands tailings are likely more amenable to the raining-in technique.
- *Hydraulic beaching* of tailings sand is used where the soft tailings deposit is stronger and denser. A cap is placed hydraulically from the dyke using open-pipe discharge (or with spigots or a discharge spoon) forming a thick layer over the underlying soft tailings. Beaching has been successful at commercial scale on several soft deposits that have similar or higher density to that of the capping layer (see Figure 3C). Beaching has been unsuccessful where the capping slurry is denser than the soft tailings – the capping material reports to the bottom of the deposit (known elsewhere as the *displacement technique*).
- *Soft-ground techniques* involving mechanical placement of mine waste or tailings sand with small earthworks equipment and geogrid can be employed where shear strengths are greater than 25 kPa (see Figure 2). Small dozers and 25 to 40 T trucks are carefully employed to place fill, often in 1 m lifts. Trucks are kept away from the face – they dump, then the dozer pushes the fill over the crest, onto the geogrid. For moderately dense soft tailings, soft-

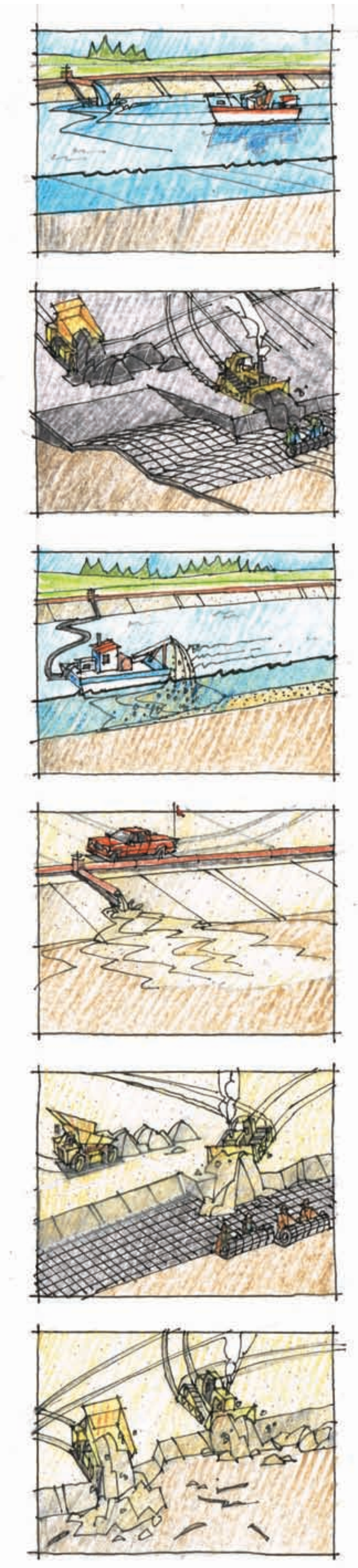

Figure 6. The six-pack of soft tailings capping methods.

ground techniques are sometimes employed where strengths are a little less than 25 kPa – deformations are usually large and a stabilizing "bow wave" in the tailings forms ahead of the advancing lift. Operators "chase the wave" from all sides to the centre of the deposit.

- *Standard earthworks techniques* using mining equipment is an option where strengths are more than about 100 kPa or where there is a thick enough mechanically or hydraulically placed cap. This is the realm of traditional mine reclamation: D9 dozers and 100 tonne trucks working to place capping lifts on firm to stiff tailings. Given the high bearing pressures of most haultrucks (approximately equal to their tire pressures of 400 to 700 kPa), even stronger tailings would be needed for direct trafficability of the tailings surface. The ultimate bearing capacity of soft tailings is roughly five times its undrained shear strength.

The capping boundaries in Figure 5 are approximate and will vary with the sensitivity of the tailings and the acceptable level of risk. The boundaries will continue to be refined as additional commercial-scale experience is gathered. The boundaries will also vary for different types of tailings in different industries.

Techniques to improve tailings to make capping easier

There are a number of techniques employed to make soft-tailings capping easier by increasing the density and strength, each with its own benefits and challenges at mining scales.

Tailings processing for density

Commonly, mines employ tailings processes that make denser, stronger tailings. These processes can allow water and reagents to be recovered quickly and can reduce containment requirements and risks of spills. Many processes target pumpable tailings, some of which result in deposits that are soft, difficult to cap, and prone to large settlements.

Crust management

Allowing or enhancing a dried tailings crust aids trafficability of amphibious and light vehicles and provides workers access on foot. However, a crust on its own doesn't provide trafficability required to support mining equipment because dozer tracks and haultruck tires can punch through into underlying soft tailings. Similarly, embankment stability does not benefit much from a thin tailings crust. Crust management can be important but by itself is seldom the full answer.

Frost

In cold regions, thick frost greatly aids foot and light vehicle trafficability, and when thick enough, can allow D6 dozers to traffic soft tailings deposits. Ice-bridge guidelines are used to roughly estimate trafficability of frozen soft tailings. Haultrucks and larger dozers are heavy enough to crack and break through the frost and can become mired or sink.

Adding cement and flyash

Cement or flyash amendments can increase tailings strengths dramatically. The amount of amendment controls the shear strength; concrete-like strengths can be achieved. Such treatment remains in the pilot stage in oil sands largely due to cost and logistics for the existing large and deep deposits. Treating tailings during discharge (at end of pipe) is being studied. Costs and geoenvironmental impacts of these amendments are key parts of these studies.

Dewatering with wickdrains

Wickdrains (vertical band drains) are used to accelerate consolidation of natural soils for heavy-civil projects and tailings deposits some metal mines by shortening drainage paths. For oil sands, they require installation at close spacing (1 to 2 m) due to the low permeability of the tailings. Large-scale field testing is ongoing in oil sands tailings (eg Wells and Caldwell 2009). Wickdrains can speed

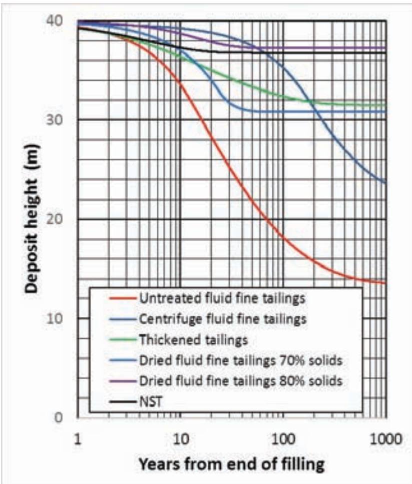

Figure 7. Oil sands soft tailings settlement based on large-strain consolidation modeling.

consolidation but do little to enhance the strength at the mudline unless there is a sand cover.

Post-reclamation settlement of oil sands tailings

Settlement of soft tailings deposits can be a significant design issue. Figure 7 presents modelled consolidation settlement for oil sand tailings deposited into a 40 m deep mined-out pit. These large settlements are typically accommodated by water capping the soft tailings to become a lake – the water cap becomes thicker as the tailings mudline settles. But if settlements are small (less than a few metres), they can be managed with design of the outlet and hummocky topography to preclude large areas of open water forming.

Small settlements are associated with firm to stiff tailings deposited at their final density or that largely reach their final density before reclamation. These technologies include dried fine tailings, cement-amended tailings, filtered tailings, non-segregating tailings, and co-mixing tailings and overburden, all of which are under development (see CTMC 2012). Most are capital- and energy-intensive. There is optimism that firm to stiff tailings can be produced economically with enough strength and density to allow capping and reclamation with limited post-reclamation settlement.

Matching tailings management to landscape performance objectives

By considering both operational and landscape performance objectives in tailings management, mine operators can meet their short-term mining business needs, reduce their long-term liability, and create a legacy of landscapes with value to future generations. Integrating mining and reclamation goals and objectives improves business performance and reduces environmental risk. Understanding the links between tailings deposit strength, density, and settlement to the declared reclaimed landscape performance objectives is a critical component in tailings R&D, tailings management, and landform design.

Further reading (most available online, or call for a copy)

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In 1982 members of the Canadian Geotechnical Society conceived the idea of a book recording the development of geotechnical engineering in Canada. Since a number of the early practitioners were still living at the time, foremost among them Bob Hardy d Bob Legget, the approach was intended to create "a living history ... through the eyes and recollections of living engineers, to show the humanity that underlies the development of major geotechnical projects in Canada."

As this book is now out-of-print, we will be publishing excerpts from it over the next few editions of Geotechnical News. Ultimately, a pdf copy will be available.

Geotechnical Engineering in Canada An Historial Overview

Cyril E. Leonoff

Born in Leeds, Quebec, Samuel Fortier (1855-1933) graduated in civil engineering from McGill University in 1885 and later received a masters's degree from this university. In October 1896 Fortier read a paper, "The Storage of Water in Earthen Reservoirs," before the Canadian Society of Civil Engineers, which earned for its author the Gzowski Medal, the senior technical award of the society. In it he anticipated the factors that would be considered by a modern soil mechanics engineer: "An intimate knowledge gained from a close study and carefully made tests of the physical ... and mechanical ... properties of the materials ... the size and weight of the grains, the amount of air-space they enclose, the percentages of air and water contained in these open spaces, and the effects produced by moisture, heat and frost, as well as the action of such forces as gravity, capillarity and evaporation [and] the mode of compacting reservoir embankments." Fortier further recognized that "the proper widths and slopes to adopt in the building of earthen dams cannot as yet be determined by mathematical calculations [but] the dimensions in each particular case must be left to the good judgment, practical skill and the knowledge gained from experimental tests, of the designing engineer."

Fortier is less well known in Canada than in the Western United States, to which he emigrated and gained repute as a water works and agricultural irrigation engineer in Colorado, Montana, and California.

In 1897 civil engineer Robert Brewster Stanton, who had thirty years' experience in the Rocky Mountain region from Canada to Mexico, read a paper before the British Institution of Civil Engineers on the great landslides that had occurred on the Thompson River near present-day Ashcroft; British Columbia, at the time of construction of the Canadian Pacific Railway in the 1880s.

Within a distance of some five miles there were several large landslides, six crossing the railway line, as well as a number of smaller slips. Twenty miles farther down the river, at a point opposite Spences Bridge, there was a similar large slide. Three of the slides were of giant proportions. The largest, the 100 million-ton Great North Slide of October 1881, actually blocked the river for 44 hours, causing a huge flood. Stanton, after careful observations, attributed the slides to irrigation of the silt terraces above the river, which when saturated lost strength and collapsed into the river. More recent soil mechanics examination has indicated that the silt is finely layered with clay and that the seat of shearing may have been in the clay. As both transcontinental rail lines CP and CN still traverse these slides, there is yet some local manifestation of slide action on a smaller scale.

The failure of the Transcona Grain Elevator, built in the glacial Lake Agassiz basin near Winnipeg, Manitoba is a classic case of shear failure of a heavy structure on a raft foundation, built on a thick layer of soft saturated clay. Filling of the bins of the million-bushel-elevator began in September 1913. When 875,000 bushels of wheat were stored, a vertical one-foot settlement was noted within an hour, then the structure began to tilt to the west, and within 24 hours came to rest at an angle of 26° 53' from the vertical. The west side was 29 feet below and the east side 5 feet above original grade. The rigid monolithic structure, built on a two-foot-thick reinforced-concrete raft, showed little damage other than a few surficial cracks. The elevator was righted and underpinned by the Foundation Company of Canada on piers sunk 54 feet to the limestone bedrock.

A later study in 1952, carried out jointly by the Division of Building Research, National Council of Canada and the University of Manitoba, confirmed an ultimate bearing capacity of 6,200 pounds per square foot, which correlated very closely with the theoretical value based on a soil mechanics analysis.

Two Canadian cases of recorded long-term building settlements, erected before the science of soil mechanics was applied to building foundations, are also noteworthy.

Construction of the CPR Empress Hotel at James Bay, Victoria began in 1904 on a site reclaimed from the sea. Marine clay underlies the building to a thickness ranging from a few feet to more than 100 feet. The building was constructed on a foundation of 1,853 timber piles, each about 50 feet long. Observations began in 1912, after settlements were first noticed, and have continued ever since. By 1971 the differential settlement across the building north to south amounted to some 30 inches, although this was not noticed by the casual visitor.

After 50 years of service, the owners were faced with the decision whether to extend the life of the elegant structure or to replace it with a modern building. On the basis of a comprehensive study, R.M. Hardy concluded that the rate of settlement was decreasing and would be within acceptable limits. As a result, in a multi-million dollar program, the building was rehabilitated under the appropriate name Operation Teacup.

The Victoria Memorial Museum (National Museum of Canada) building in Ottawa, a massive four-storey structure, 400 feet long and 150 feet wide, with heavy sandstone bearing walls, rested on spread footings. Since completion of the building in 1910, footing loads, which varied from 12 to 4 tons per square foot, caused a differential settlement in 40 years of more than 1 1/2 feet.

Unlike the Empress Hotel, the building showed distress from the start and was completed with much difficulty. Basement and ground floors and the exterior walls, supported on both exterior and interior footings, showed severe distortion and cracking. The upper storeys, carried on plate girders spanning the exterior walls, suffered less differential settlement. By 1916 a tower at the front of the building was out of plumb by more than a foot and the upper portion had to be removed to prevent complete failure.

In the early 1950s, borings and studies of the museum by DBR/NRC revealed that the building was underlain by 50 feet of sensitive, compressible marine (Leda) clay, which graded into clayey silt, sand, and glacial till at in creasing depth, with bedrock at 132 feet.

Birth of Soil Mechanics

Prior to the 20th century, any textbook on foundation and earthwork engineering divided soil into several categories – gravel, course and fine sand, silt, and soft or stiff clay. Various allowable bearing values, based on empirical equations or rules, were assigned to these different materials. But only one variable, the type of soil, was considered. Equally important mechanical properties of the soil, such as density, water content, and compressibility were ignored.

In those early ears, the foundation design of buildings or of structures involving deep excavation or tunneling was based on primitive geological surveys of the materials located beneath the construction site. Foundation on bedrock was preferred. But where bedrock could not be reached, over soft soils the bearing load was spread out by use of spread footings or rafts, often with disappointing results, as we have seen with the Victoroa Memorial Museum and the Transcona Grain Elevator.

When in doubt, pile foundations were the rule. At the beginning of the 19th century, empirical pile formulas were developed, with the bearing capacity of each pile computed on the basis of the work performed by the hammer in driving the pile into the ground, the depth of the pile's penetration, and the resistance of the soil. While helpful, these formulas did not preclude the possibility of an entire group of piles settling. If the pile tips were located above clay soil, excessive settlement often took place as a result of the gradual consolidation of the clay soil beneath the piles, as we have noted with the Empress Hotel.

The mechanics of landslides were not understood, and rational methods for evaluating the safety of slopes with respect to sliding were unknown. The only analytical tools at the disposal of civil engineers were the theories of earth pressure on retaining walls, and the natural angle of response at which a soil mass would remain stable, as enunciated by C.A. Couloumb in 1776 and W.J.M. Rankine in 1856. However, because of their simplified assumptions on the behaviour of soil, these theories had little practical usefulness outside of the classroom.

Humankind had been constructing earth dams for at least 2,000 years usually for the purpose of creating water storage reservoirs. Yet the height of such construction was limited to about 100 feet before collapse. Dam failures were widely reported in the engineering literature, when the mechanics of seepage, pore-water pressure, and piping in cohesive soils were still undiscovered. Few engineers had the perspicacity of Samuel Fortier, and systematic methods for compacting the soils used to construct the dam remained undeveloped.

Early in the 20th century, three major engineering failures precipitated the first modem soil studies. These were the great landslides in the deep cuts made to bring the Panama Canal through the Continental Divide, the catastrophic slides on the Swedish state railways, and the outward movements of the massive pile-supported quay walls in the construction of the

Kiel Canal between the North and Baltic seas. In 1913, the situation in Panama, as well as continuing dam failures and building settlements, led the American Society of Civil Engineers to appoint a committee to look into these matters. The committee stressed "the importance of expressing the properties of soils by numerical values." Similar realizations came in Europe.

Seldom has one man dominated a discipline as did Karl (Charles) Terzaghi (1883-1963) in the field of soil mechanics. An Austrian, he studied mechanical engineering and geology, receiving a mechanical engineering degree in 1904, and later a doctor of technical sciences, from the Technical University of Graz. For six years preceding World War I, he worked on a variety of engineering and construction projects in the Alps, in Croatia, and in northern Russia, where he was able to absorb the practical side of civil engineering. In particular, problems which arose in constructing the foundations of a large building in St. Petersburg, where he had opportunity to observe "the incompetence of the engineering profession in the field of earthwork engineering," piqued his interest and set Terzaghi on his life mission to find a rational basis for predicting the performance of soils in earthwork and foundation engineering.

At this time, the United States Reclamation Service was doing pioneering work on a large number of dams and irrigation works in the Western States under a wide range of geologic conditions. With the agreement of the director, Terzaghi spent two years in America studying case histories of these projects. But he returned home at the end of 1913 disillusioned, because he had failed to find the "missing link," the correlation between the performance of a foundation and the geologic characteristics of its site.

At the beginning of World War I, Terzaghi enlisted in the air force of the Austrian army. However, in 1916 he was posted by the Ministry of Foreign Affairs to Constantinople, Turkey, to lecture on foundations at the Imperial School of Engineers the present Technical University of Istanbul (The Ottoman Empire sided with the Central Powers and the institution was under German influence). There Terzaghi began a study of all German, French, and English literature on the subject. At the end of the war, the victorious Allied Powers occupied Constantinople and the teaching staff, including Terzaghi, were summarily dismissed.

At this nethermost point in his career, Terzaghi felt humiliated, depressed, and without any means of support. He had "no urge whatsoever to teach" inasmuch as he was "too deeply preoccupied with [his] own ignorance." Soon enough though, he was offered an appointment at Robert College-now Bogazici University in Istanbul, an English-speaking school founded by American missionaries. In a flash of inspiration, Terzaghi visualized what was needed to obtain a rational approach to the problems involved in earthwork and foundation engineering. Progress depended on the development of testing equipment which could provide a quantitative measure of the properties of the soils involved. On two sheets of paper he listed a number of possible ways to test soils, made sketches of the equipment needed, and suggested how the results could be interpreted. Terzaghi had finally made his fundamental discovery: "Engineering geology cannot become a reliable tool in the hands of earthwork engineers unless and until we acquire the capacity to assign to each material of the earth numerical values."

Within a few weeks of beginning work at Robert College, Terzaghi had set up a small laboratory in the engineering building. During the week the lab's lights were to be seen burning well into the night. Weekends were spent on expeditionary field trips along the Bosporus and the Marmara Sea. Having scant funds, Terzaghi had begun seven years of "strenuous experimentation" with soils, using borrowed measuring devices and apparatus built with odds and ends scrounged from the college dump. His first earth-pressure apparatus was made from empty cigar boxes, and his loading devices consisted of empty oil cans filled with Sand. In Terzaghi's first aAmerican article, "Old Earth-Pressure Theories and New Test Results," published in 1920 in Engineering News-Record in which he discarded the theories of Coulumb and Rankine, he described the small-scale experiments that established the relationships between earth pressure and the lateral deformation or yielding of mass of soil. Earth pressure against retaining walls, braced cuts, and anchored bulkheads, as well as arching over tunnels and around shafts, are dependent on this relationship. In 1925, with the publication of Terzaghi's first book, Erdbaumechanik, the science of soil mechanics emerged from is academic womb.

From the fall of 1925 until October of 1929, Karl Terzaghi spent his second period in the United States, this time at the Massachusetts Institute of Technology, where numerous new buildings were undergoing large and continuous settlements. While at MIT he codified the equipment needed for soil testing. There he made the acquaintance of Dr. Arthur Casagrande (1902-1981), who was to become his principal associate throughout the second half of Terzaghi's career. Like Terzaghi, Casagrande was a native Austrian. He had graduated from the Technical University in Vienna before coming to the United States in 1926 with no real prospect of work. He gained n interview at MIT< met Terzaghi and immediately began to work for him. In 1934 Casagrande moved on to Harvard University becoming Professor of Soil Mechanics and Foundation Engineering.