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Volume 32 • Number 2 • June 2014

GEOTECHNICAL news

- US Highway 2 was proactively detoured prior to a major slope failure based on a monitoring program
- Thesis Abstracts 2014

innovation

DIGITAL MEMS INCLINOMETER SYSTEM

in MEMS Digital Inclinometer Systems

How the best just got better.

For measuring any lateral movement down in the earth, via inclinometer casing, the Digital MEMS Inclinometer System from RST Instruments Ltd. was the first, and is still the best, Digital MEMS Inclinometer System available.

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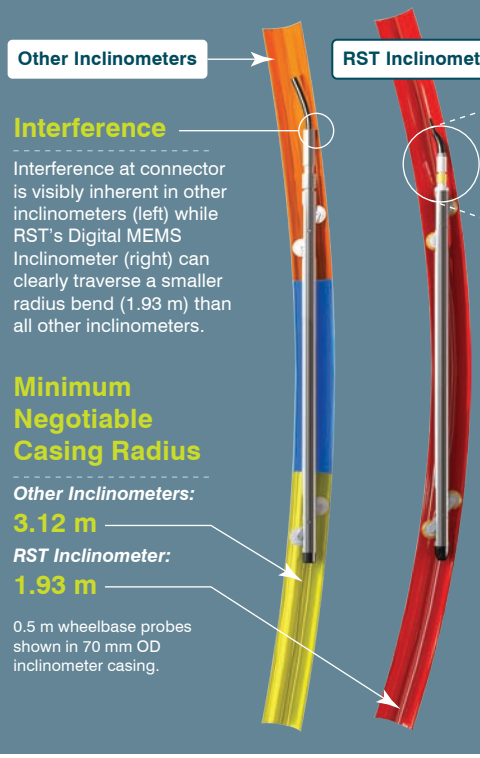
OTHER INCLINOMETERS VS. RST



Interference

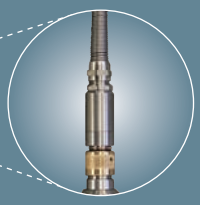
Interference at connector is visibly inherent in other inclinometers (left) while RST's Digital MEMS Inclinometer (right) can clearly traverse a smaller radius bend (1.93 m) than all other inclinometers.

Minimum Negotiable Casing Radius

Other Inclinometers:
3.12 m

RST Inclinometer:
1.93 m

0.5 m wheelbase probes shown in 70 mm OD inclinometer casing.



RST's newly developed connector is by far the industry leader for the least amount of connector interference.

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Above, the RST Digital MEMS Inclinometer Probe with industry leading system accuracy of ±2 mm per 25 m, is shown connected to the cable.

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SYSTEM INCLUDES:

MEMS Digital Inclinometer probe, cable system, reel with battery power, and an Ultra-Rugged Field PC that functions as a wireless readout, analysis, and data storage device. Includes all accessories, as shown at left. Please contact the RST sales team for complete details.

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digital inclinometer analysis software

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CONTENTS

GEOTECHNICAL INSTRUMENTATION NEWS

Performance observations of MEMS ShapeAccelArray (SAA) deformation sensors **23**
Derrick Dasenbrock

Advances in geotechnical data management and, visualization **27**
Robert Bachus

THE GROUT LINE

A grouting industry review **30**
Sam Bandimere

WASTE GEOTECHNICS

UQAT-Polytechnique establishes a unique Research Institute on Mines and the Environment **33**
Vivian Giang

DEPARTMENTS

CGS News **9**
Geotechnical Instrumentation News **23**
The Grout Line **29**
Waste Geotechnics **33**
Geosynthetics **35**
Thesis Abstracts **40**

Cover *US Highway 2 was proactively detoured prior to a major slope failure based on a monitoring program. (Photo by Derrick Dasenbrock).*

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Digitilt AT Inclinometers

The Digitilt AT Inclinometer System includes a digital probe, control cable marked in feet or meters, a cable gate, a Bluetooth reel, Reader APP for Android based tablet and DigiPro2 Basic software. The AT System now features custom length cables from 100m (300 ft) to 300m (1000 ft).

Digitilt Classic Inclinometers

The Digitilt Classic Inclinometer System consist of a control cable marked in feet or meters, a Datamate II readout. DigiPro2 software and a pulley assembly are options to complete a system is designed to measure subsurface deformations in vertical and horizontal boreholes.

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Message from the President

Richard J. Bathurst, President of Canadian Geotechnical Society

One of the pleasures of being President of our Society is that I am often the first to hear of the great accomplishments of our members and to congratulate them on your behalf. An example is the announcement this winter that Dr. **Suzanne Lacasse,** former President of the CGS (2003-04), was chosen by the British Geotechnical Association to be the 55th Rankine Lecturer. Suzanne will give her lecture in London in March 2015. Other Canadians who have been so honoured are **Norbert Morgenstern** (CGS President 1989-90), **Evert Hoek, Serge Leroueil** and **Kerry Rowe** (CGS President 2001-02). What makes this honour even more significant is that Suzanne is the first woman to win this prestigious award. This recognition is just the latest in a string honours that Suzanne has accumulated. Suzanne was also selected to present the Terzaghi Oration at the ISSMGE conference in Paris, last September.

The CGS Cross Canada Lecture Tour (CCLT) brings one national and one international expert to selected Sections across the country each year. The spring 2014 (national) speaker was Professor Emeritus **Jim Graham** from the University of Manitoba. Professor Graham delivered his talks at 11 different venues across the country. He offered local Sections one of five different presentations for his talk. The selection included *Embankment Deformations Include Creep in Compression and Shear; Seepage, Leaching and Embankment Instability - A*

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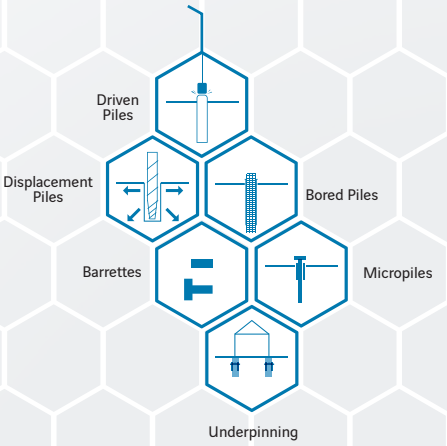
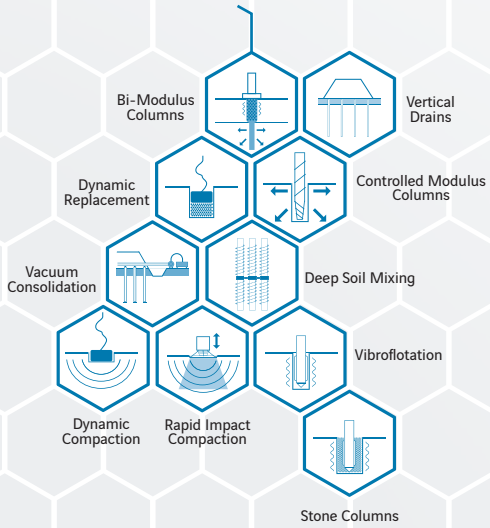
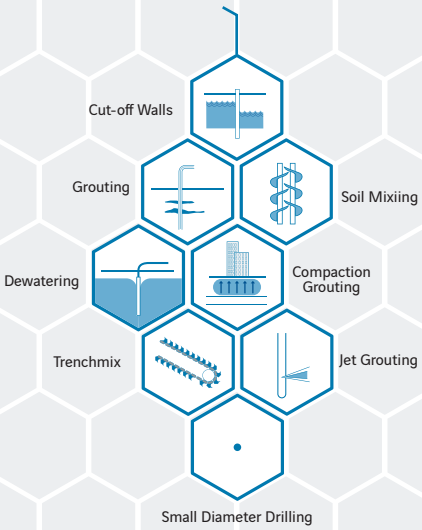


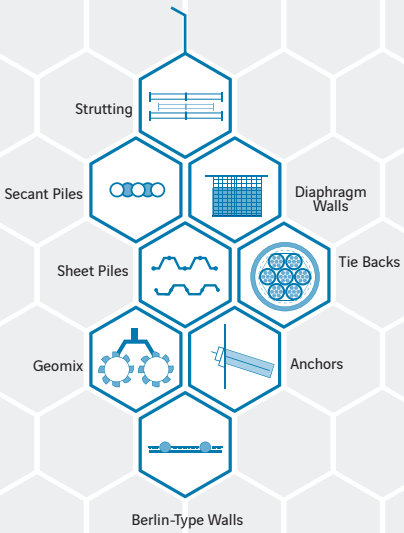
GROUND IMPROVEMENT



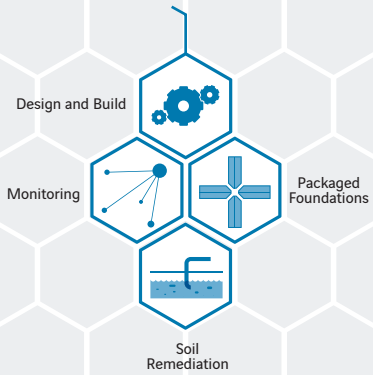
STRENGTHENING & CUT-OFF



RETAINING WALLS



SOIL REMEDIATION



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Case Study; Natural Processes and Strength Degradation; or *Soil Parameters for Numerical Analysis in Clays*. At the time of this newsletter we have not yet finalized our international speaker for the Fall 2014 CCLT. Our local Sections will be contacted once our speaker is finalized.

Since my last President's Message, I am pleased to report that the CGS has inked Memorandums of Understanding (MOU's) with the Local Organizing Committees (LOC's) who will host the next two annual CGS conferences; **GeoQuebec** in 2015 and **GeoVancouver in** 2016. I, along with the Secretary General **Victor Sowa**, have made it a priority to have these MOUs completed well in advance of the conferences so that the LOCs can benefit from the experience at CGS headquarters and to ensure that important organizational details are not overlooked at the planning stage. The CGS Executive also held its spring meeting in Quebec City on May 23 to 24. This gave them the opportunity to meet with the Chair of the Quebec City LOC, **Jean Côté**, and to tour the venue selected for the conference. The CGS is also in early discussions with the Ottawa Geotechnical Group, which has expressed interest in holding the **70th Annual CGS Conference** in Ottawa in 2017.

At time of this article, the plans for the September 28 to October 1, 2014 **GeoRegina** conference are well advanced with accepted papers in hand and exhibit space totally sold out. The conference chair, **Dr. Wayne Clifton** and his group are an excellent example of how to plan a conference! Note that the early-bird registration closes **July 31, 2014**. For further information, please point your browser to *www.georegina2014.ca*.

I would also like to congratulate the organizers of 6th Canadian Geohazards Conference and their chair, Dave Gauthier, who will be hosting this conference at Queen's University in Kingston, Ontario on June 15 to 18, 2014. Working with this group of superbly organized and enthusiastic young people has been a pleasure for both Victor and myself.

Finally, I am pleased to congratulate CGS members **Régis Bouchard** and **Gordon Ward Wilson** who were inducted as Fellows of the Engineering Institute of Canada (EIC) for their exceptional contributions to engineering in Canada. The awards were presented at the annual EIC gala held in May in Ottawa.

In closing, I wish you all a great summer and I hope to see you all at **GeoRegina 2014** this fall.

Provided by Richard Bathurst – President

Message du président

L'un des plaisirs que je retire de mes fonctions de président de notre Société consiste à être souvent le premier à connaître les belles réalisations de nos membres et de les féliciter en votre nom. J'en donne pour exemple l'annonce de l'hiver dernier, au sujet de **Suzanne Lacasse**, Ph. D. et ancienne présidente de la SCG (2003-04), qui a été choisie par la British Geotechnical Association pour prononcer la 55e conférence Rankine. Elle présentera sa conférence à Londres, en mars 2015. Au nombre des autres Canadiens qui ont reçu le même honneur, on peut mentionner **Norbert Morgenstern** (président de la SCG en 1989-1990), **Evert Hoek**, **Serge Leroueil** et **Kerry Rowe** (président de la SCG en 2001-2002). Ce qui rend cet honneur encore plus important est le fait que Suzanne est la première

femme à se voir décerner cette prestigieuse distinction. Mais ce n'est que le tout dernier honneur d'une longue série de prix que Suzanne a accumulé. Elle avait également été sélectionnée pour présenter l'allocution Terzaghi lors du congrès de la SIMSG qui avait eu lieu à Paris, en septembre dernier.

La Tournée de conférences pancanadiennes (TCP) de la SCG invite un expert national et un expert international à parcourir le pays pour faire des présentations à diverses sections. L'orateur (national) du printemps 2014 avait été **Jim Graham**, professeur émérite de l'Université du Manitoba. Il a présenté ses conférences à 11 emplacements différents au pays. Les sections locales pouvaient choisir parmi cinq sujets différents, notamment *Embankment Deformations Include Creep in Compression and Shear; Seepage, Leaching and Embankment Instability - A Case Study*; *Natural Processes and Strength Degradation*; ou *Soil Parameters for Numerical Analysis in Clays*. Au moment de mettre ce bulletin sous presse, nous n'avions pas encore déterminé le conférencier international de la TCP de l'automne 2014. Nous communiquerons avec les sections lorsque le choix sera arrêté.

Depuis mon dernier message de président, je suis heureux d'annoncer que la SCG a conclu des protocoles d'entente (PE) avec les comités d'organisations locaux (COL) qui seront les hôtes des deux prochaines conférences annuelles de la SGC, soit **GéoQuébec** en 2015 et **GéoVancouver** en 2016. De concert avec notre secrétaire général **Victor Sowa**, j'avais accordé la priorité à ces PE pour qu'ils soient conclus longtemps d'avance, afin de permettre aux COL de profiter de l'expérience du siège social de la SCG et de veiller à ne pas oublier de détails d'organisation importants lors de la planification. Le Comité exécutif de la SCG a également tenu sa réunion printanière à Québec, du 23 au 24 mai. Les membres de ce comité ont ainsi eu l'occasion de rencontrer le président du COL de la ville de Québec, **Jean Côté**, et de visiter l'endroit retenu pour le déroulement de la conférence. La SCG a également entamé des discussions préliminaires avec le Groupe géotechnique d'Ottawa, qui a indiqué qu'il souhaitait organiser la **70e conférence annuelle de la SCG** à Ottawa, en 2017.

Au moment de la rédaction de cet article, la planification de la conférence GéoRegina, qui aura lieu du 28 septembre au 1er octobre, était fort avancée. Les articles sont désormais acceptés et le Salon professionnel affiche complet! Le président de la conférence, **Wayne Clifton**, Ph. D., et son groupe sont un excellent exemple

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de la façon dont il faut s'y prendre pour planifier une conférence! Veuillez prendre note que la préinscription prendra fin le 31 juillet 2014. Pour en savoir plus, cliquez sur www.geo-regina2014.ca.

J'aimerais aussi féliciter les organisateurs de la **6e conférence canadienne sur les géorisques (Géorisques 6)** et leur président, **Dave Gauthier**, qui organiseront cette conférence à l'Université Queen's à Kingston (Ontario), du **15 au 18 juin 2014**. Victor et moi avons eu beaucoup de plaisir à travailler avec ce groupe de jeunes personnes enthousiastes et superbement organisées.

Enfin, j'aimerais féliciter **Régis Bouchard** et **Gordon Ward Wilson**. Ces deux membres de la SCG ont été nommés fellows de l'Institut canadien des ingénieurs (ICI), pour leur contribution exceptionnelle au domaine de l'ingénierie canadienne. Cette distinction leur a été décernée lors du gala annuel de l'ICI qui a eu lieu à Ottawa, en mai.

Pour terminer, je vous souhaite de passer un bel été et j'espère vous voir tous à **GéoRegina 2014** cet automne.

Del la part de Richard Bathurst - président

From the Society

Upcoming Conferences and Seminars

2014 Canadian Geotechnical Conference September 28 - October 2, 2014, Regina, Saskatchewan

The Canadian Geotechnical Society (CGS) invites you to its 67th annual conference at the Delta Hotel in Regina, Saskatchewan. **GeoRegina 2014** will be held from Sunday, September 28 to Wednesday, October 1, 2014.

The theme for **GeoRegina 2014**, *Engineering for the Extremes*, will highlight current trends in geotechnical engineering by addressing increasingly complex problems under more extreme operating conditions. The organizers intend to bring a focus to local challenges, such as climate, expansive clays, and permafrost, in the face of unprecedented economic and population growth. The technical program will offer opportunities for delegates to explore various examples ranging from environment damage to rehabilitation of failing infrastructure. We hope to present a conference where innovative, multidisciplinary solutions and best practices for dealing with extreme engineering challenges are openly shared and discussed. In keeping with CGS practice, challenging and informative workshops, seminars and tours will be offered in conjunction with the conference, along with a Partners Program that will high-

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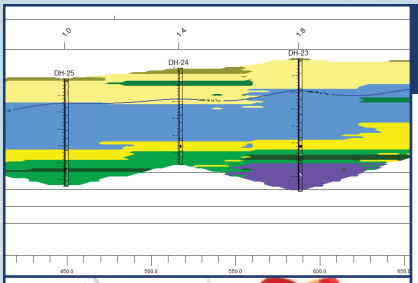

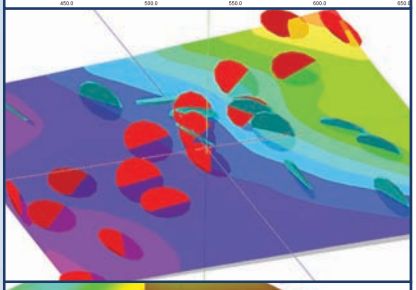

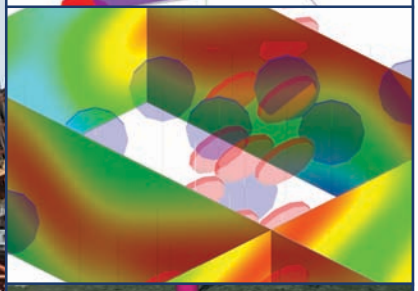

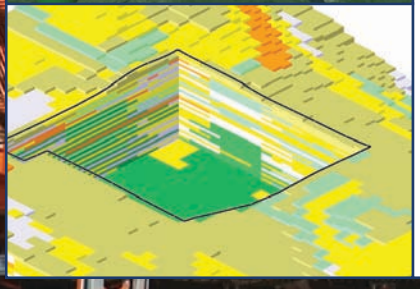

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For more information on **GeoRegina 2014**, including delegate pricing, please visit the conference website at *www.georegina2014.ca.* The early bird delegate registration deadline is July 31, 2014.

First International Conference on Discrete Fracture Network Engineering
October 19 - October 22, 2014, Vancouver, B.C.

The Vancouver rock mechanics community is pleased to host **DFNE 2014**, the **1st International Conference on Discrete Fracture Network Engineering,** *http://www.dfne2014.ca*.

This conference will be the inaugural international meeting of engineers and geoscientists who use discrete fracture network engineering in the characterization of rock masses and solutions of engineering problems.

This new and rapidly expanding area of engineering has wide applications, including underground and surface mining, underground nuclear waste disposal, petroleum geomechanics, civil engineering and natural hazards. Most modern geomechanical simulation software packages now include the option to consider discrete fracture networks which are increasingly important to engineers and geoscientist involved in practical rock engineering and fluid flow problems. This conference will include keynote lectures by experts in the areas of Discrete Fracture Networks and their application to mining, civil and petroleum engineering.

With almost 170 accepted abstracts and five short course/workshops dealing with a wide range of DFN topics from data collection and structural geology to DFN development and geomechanical modeling, a major focus of the conference is to provide a practical introduction to DFN engineering and its relevance to industry as well as to introduce state-of-art developments.

DFNE 2014 will be held at the Sheraton Wall Centre in scenic downtown Vancouver, British Columbia, Canada from October 19 - 22, 2014.

The **DFNE 2014** organizing committee invites you to join us to share your ideas and experiences in the increased development and practical use of this technology under the theme **Engineering Characterization of Fractured Rock Masses: Applications of Discrete Fracture Network Engineering**.

The Conference Co-Chairs are **Doug Stead** of Simon Fraser University and **Bill Dershowitz** of Golder Associates. For more information contact Doug Stead at *dstead@sfu.ca*

6th Canadian Geohazards Conference
June 15 to 18, 2014
Queen's University, Kingston, Ontario

The **6th Canadian Geohazards Conference** will be held at Queen's University, Kingston Ontario from June 15 to 18, 2014. The GeoHazards conferences are the premiere forums in Canada for the sharing and dissemination of scientific and engineering knowledge related to geohazards. Geohazards affect a broad spectrum of public and industrial interests in Canada. In many ways the risks posed by geohazards are increasing as we spend more time in hazardous places, and place more infrastructure there. The need to assess, mitigate, and communicate these risks is likewise becoming more relevant to more Canadians. **GeoHazards 6** will include applied

research reports and case studies related to a broad range of geohazards, and the risks they pose, with the goal of sharing ideas, approaches, and solutions to similar but unique engineering and scientific problems related to geohazards.

Kingston and Queen's University are ideally situated for **GeoHazards 6**. Kingston is located within easy travel distance from international airports in Toronto, Ottawa and Montreal, and is near to many universities and companies in both Ontario and Quebec. Queen's University is host to many productive and influential natural and applied scientists and engineers in Canada, who are often working closely with federal government scientists in Ottawa. The campus borders Lake Ontario and is within easy walking distance of Kingston's downtown core, offering a self-contained and collegial atmosphere.

For more information, email **Dave Gauthier,** *gauthier@geol.queensu.ca*

22nd Symposium of the Vancouver Geotechnical Society Foreshore Engineering June 13, 2014 Vancouver, B.C.

The 22nd Symposium of the Vancouver Geotechnical Society will take place on Friday June 13, 2014 on the topic of Foreshore Engineering. Keynote addressees will include **Dr. Adda Athanasopoulos-Zekkos** of the University of Michigan presenting on *Assessment of Seismic Vulnerability of Earthen Levees* and **Neil Peters**, Inspector of Dikes, presenting on *Geotechnical Design Challenges Associates with the Lower Fraser River Dikes.*

For more information, contact the Symposium Chair, **Marc Bosse** *mbosse@thurber.ca* or visit the VGS website at *http://v-g-s.ca/2014-symposium/*

Members in the News

Winners of the 2014 CSCE's Thomas C. Keefer Medal

The Canadian Geotechnical Society is pleased to congratulate **Bonnie Dobchuck**, **Craig Nichol**, **G. Ward Wilson** and **Michel Aubertin** as winners of the **2014 CSCE's Thomas C. Keefer Medal.** The award was for their paper entitled *Evaluation of a Single-layer Desulphurized Tailings Cover* and was published in Canadian Geotechnical Journal, Volume 50, pp. 777-792. The award was officially announced during the CSCE Gala on May 30 in Halifax, Nova Scotia.

Submitted by Michel Aubertin Technical Committee on Mining Geotechnique.

In Memoriam

Benjamin Torchinsky 1926 – 2013

Friends and colleagues of **Benjamin Torchinsky** were saddened to learn of his death on December 23, 2013. Ben was born in Calgary, Alberta in 1926. In 1947 he received a Bachelor of Science degree in Civil Engineering from the University of Alberta and a Master of Science degree in Civil Engineering in 1949. From 1947 to 1949, he was a Sessional Instructor in Civil Engineering at the University of Alberta.

In 1949, he joined the faculty of the University of Saskatchewan in Saskatoon. He held the position of Assistant Professor and then Associate Professor in the Civil Engineering Department of the College of Engineering. During this time, while conducting research for the Saskatchewan Research Council on cracking and deterioration of buildings, he realized that shallow foundation systems such as conventional spread footings were not performing satisfactorily with the swelling soils encountered in the City of Regina.

For foundations to perform satisfactorily in these areas, it was necessary to use deep foundations extending below the "active" zone of seasonal moisture variation. He concluded that a bored type concrete pile was the most economical deep foundation system that would extend below the active zone, and which he recommended in areas with potentially active clay soils.

In 1952 he founded B.B. Torchinsky & Associates Ltd., which specialized in soil mechanics and foundation consulting engineering. Two years later he started the piling company, Western Foundation Borings Limited which subsequently became Western Caissons Limited to construct bored type pile foundations.

In 1957, due to the increasing tempo of his outside interests, he resigned from the University of Saskatchewan to manage the business enterprises. As president, he directed the rapid growth of the firm until it provided services across Canada, United States as well as overseas. By 1970 these engineering and construction companies were consolidated into publicly traded AGRA Inc. and in 2000 AGRA merged with U.K. based AMEC plc. Torchinsky retired from AGRA in 2000.

There were many entrepreneurial "firsts" in Torchinsky's career. In the early 1950's he pioneered the installation of deep piles and caissons in Western Canada; by the mid-1950's he established the first cable television system in Western Canada (Cablenet); in 1960 he built the first canola oil refining plant in Canada; in the late 1970's he established the first all-news radio network across Canada (CKO); and at the turn of the century he spearheaded construction of the first electronic toll highway in Canada (Highway 407 in Ontario).

In 2003 he received an Honorary Doctor of Science Degree from the University of Alberta, his alma mater. His accomplishments have also earned him many awards. He was nominated by the Canadian Geotechnical Society for the 1997 Sir John Kennedy Medal which he received, and which is the most distinguished award from the Engineering Institute of Canada. He was also named, Fellow of the Engineering Institute of Canada in 1997. He was awarded the Beaubien Award in 2001, the highest recognition presented by the Association of Consulting Engineers of Canada.

This obituary was prepared (with permission) from information presented in Agra Foundations in 2006.

Submitted by Victor Sowa
Secretary General – Canadian Geotechnical Society

Heritage Committee

History of Local Chapters of the Canadian Geotechnical Society

The Heritage Committee believes that the history of the local chapters of the Canadian Geotechnical Society to be valuable part of the Society and its members. The CGS Heritage Committee would like to assemble if at all possible, a collection of historical summaries of all the chapters. As an example, the CGS Heritage Committee is pleased to provide a third history of one of our prominent local chapters.

This month, the focus is on the history of the Calgary Geotechnical Society. Hopefully these stories will encourage other local chapters of the CGS to gather their archives and write their own history.

If you have any questions or have other historical information that you wish to share or know of any opportunities to acquire material that is at risk of being lost, please contact the Chair of the CGS Heritage Committee, **Dr. Mustapha Zergoun**, at *mustapha.zergoun@metrovancouver.org*.

A Brief History of the Calgary Geotechnical Society

The birth of geotechnique in Calgary - as in the rest of Alberta - is closely associated with **Dr. R.M. (Bob) Hardy** (1906-1985). Although Hardy was based in Edmonton, he was involved in a considerable amount of work in southern Alberta dating back to the 1940s, especially highway and airport construction related to the war effort. In 1951, Hardy and **Leroy "Chick" Thorssen** (1916-1996) established Materials Testing Laboratories (MTL) in Edmonton. In 1953, **Keith S. Goodman (**1921-2010**)** was transferred from Edmonton to Calgary to open its second branch. Despite its name, MTL engaged in much more than materials testing, undertaking numerous soil investigations related to foundation engineering and slope stability. It was, in fact, Calgary's first geotechnical firm, and Goodman likely has the distinction of being Calgary's first geotechnical engineer. MTL remained active until 1972, when its operations were consolidated under its parent company, R.M. Hardy and Associates.

The **Soil Mechanics Interest Group**, which would later become the **Calgary Geotechnical Society**, was formed in 1966. Its original participants included academics and practitioners in geotechnical and structural engineering, geology, groundwater, geophysics, and geography. Key members were **J.I. (Jack) Clark, P.Eng.** (1932-2010), **Henry H. Ricketts, P.Eng.** (1917-2010), and **Peter Gretener, P.Geol., P.Geoph.** (1926-2008). Clark was well known in the geotechnical community and the recipient of the Canadian Geotechnical Society (CGS) R.F. Legget Award in 1983. Ricketts was a structural engineer involved with the design of the Husky Tower, and Gretener (known amongst his colleagues as "Pore Pressure Pete") was an academic who believed strongly in inter-disciplinary dialogue.

The 1960s were exciting times for those interested in soils. The Sixth International Conference of the International Society of Soil Mechanics and Foundation Engineering (ISSMFE) was held in Montreal in 1965, spawning interest in geotechnique across Canada. In Calgary, a construction boom proved to be the source of many foundation-related issues that challenged established beliefs and stimulated innovation. Ongoing projects included new buildings at the University of Alberta's "Calgary Branch" (as the University of Calgary was known prior to 1966), the Foothills Provincial General Hospital (now called the Foothills Medical Centre), and the 626-foot-tall Husky Tower (presently known as the Calgary Tower).

The tower's shallow, ring foundation on Bow River floodplain gravels was the subject of several advanced technical studies, and is reportedly the first project in Calgary for which reliable data on both in situ ground properties and settlement performance were obtained. This provided the basis for more economical designs in the city's downtown core.

The activities of the Calgary Geotechnical Group intensified in the 1970s. The group, in cooperation with the University of Calgary, was instru-

Construction of the Husky Tower in 1967 (Glenbow Archives)

mental in organizing the Calgary-Banff Canadian Geotechnical Society Conference in 1970. It also hosted numerous world-renowned consultants to speak at its monthly meetings on the U of C campus, including **Nathan M. Newmark** (1910-1981), **Frank E. Richart** (1918-1994), and **G. Geoffrey Meyerhoff** (1916-2003). Prominent engineers were recruited into groups to study the technological and economic feasibility of constructing crude oil and gas pipelines from Alaska and northern Canada to Alberta, mostly in permafrost areas.

The group continues to be very active today. In addition to the 1970 CGS Conference, the Calgary Geotechnical Society has hosted national CGS conferences in 1980, 1992, 2001, and 2010, as well as periodic symposia on topics of local interest. Presentation meetings take place each month and attendance is free thanks to funding by local geotechnical consultants and contractors. The annual schedule of presentations includes two Cross-Canada Lecture Tours (CCLTs) sponsored by the Canadian Foundation for Geotechnique, as well as a keynote presentation by a distinguished geoprofessional at the group's Annual General Meeting each spring.

The **Calgary Geotechnical Society Award** was introduced in 1998 to recognize individuals who have demonstrated exceptional effort, energy, and/or contributed to the art of geotechnique in Calgary. The first recipient was **Milos Stepanek, P.Eng**., a geological engineer who, together with Hardy and Clark, conducted several landmark slope stability and slope stabilization studies in the Calgary area. In 2004, a **Student/EIT Award** was initiated to provide financial support for a graduate student, engineer, or geoscientist in training to attend the annual national conference of the Canadian Geotechnical Society. The intent of this award is to encourage young professionals to join in the Society's activities and to become its future leaders.

In 1998, a Heritage Working Group was formed within the Calgary Geotechnical Society, led by **Heinrich K. Heinz** and **Tai T. Wong**, members of the Group's Executive at the time. Over the years, information has been collected from various sources, and interviews have been conducted with individuals involved with the development of geotechnique in the city. In 2003, an interview was conducted with the late Jack Clark, which formed the basis for preparation of this brief note.

The Calgary Geotechnical Society maintains an informative and regularly updated website where further information can be found at *www.cgygeosociety.org*.

Submitted by Heinrich Heinz, M. Pinheiro and Tai Wong
Calgary Geotechnical Society

2014 GSE Symposium Lecturers, Front Row (left to right) Dr. Scott Burns, Dr. Suzanne Lacasse, Dr. Derek Cornforth, Dr. Delwyn Fredlund. Back Row (left to right) Dr. Norbert Morgenstern, Dr. Scott Anderson, Dr. Doug Stead, Dr. David Cruden, Dr. Serge Leroueil, Dr. Richard Fredlund, Missing Dr. Derek Martin

Section News

Geotechnical Society of Edmonton
Two Day Symposium
April 3 to 4, 2014
Edmonton, Alberta

The Geotechnical Society of Edmonton (GSE) hosted a successful Symposium on the subject of **Landslides: Assessment, Characterization and Risk** at the Edmonton Petroleum Club on April 3 and 4, 2014. The two-day event was sold out with approximately 150 people in attendance from around the province and across the country. The GSE was proud to welcome eleven eminent geoscience lecturers from Canada, the USA and abroad. They included **Dr. Scott Anderson, Dr. Scott Burns, Dr. Derek Cornforth, Dr. David Cruden, Dr. Delwyn Fredlund, Dr. Richard Goodman, Dr. Suzanne Lacasse, Dr. Serge Leroueil, Dr. Derek Martin, Dr. Norbert Morgenstern** and **Dr. Doug Stead**.

Day one of the Symposium focused on *Natural Slopes and their Assessment*, and Day two covered *Rock Slope Engineering and Risk Assessment.* Highlights included Dr. Suzanne Lacasse's delivery of her 2013 Terzaghi Oration, entitled **Protecting Society from Landslides - the Role of the**

Geotechnical Engineer, and Dr. Norbert Morgenstern's presentation of his 2013 Stanley D. Wilson Memorial Lecture, **In Praise of Inclinometers**. In addition to his scheduled lecture, Dr. Scott Burns presented a synopsis of the recent deadly Oso Landslide in Washington, before opening the floor to a timely discussion of both technical and socio-political issues surrounding the recent tragedy.

David Elwood, Program Chair for the GSE, oversaw the organization and execution of the Symposium. He also served as the master of ceremonies for the event. The Symposium was deemed a rousing success by the attendees and invited speakers alike. The intimacy of the gathering, surrounded by large posters outlining the contribution of ten eminent local geotechnical and hydrological practitioners, allowed for networking and reconnecting among colleagues. There was a palpable conviviality in the air and it was certainly an event to remember.

The Executive Committee of the GSE would like to express their sincere thanks to the distinguished lecturers and all of the attendees for their enthusiastic support.

Submitted by Kristen Tappenden
Past President – Geotechnical Society of Edmonton

Editor

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GEO Regina 2014

67TH CANADIAN GEOTECHNICAL CONFERENCE / 67E CONFÉRENCE GÉOTECHNIQUE CANADIENNE

September 28 - October 1 / 28 septembre - 1 octobre, Regina, Saskatchewan

Join us in Regina this September for the Canadian Geotechnical Society's 67th annual conference. With 150 presentations anticipated and more than 50 organizations participating as sponsors or exhibitors this will be Canada's foremost geotechnical conference in 2014!

The **GEOREGINA 2014: ENGINEERING FOR THE EXTREMES** theme will highlight current trends in geotechnical engineering by addressing increasingly complex problems under more extreme operating conditions. The technical program will offer opportunities for delegates to explore various examples ranging from environment damage to rehabilitation of failing infrastructure.

GEOREGINA 2014 CONFERENCE PROGRAM HIGHLIGHTS WILL INCLUDE:

- R M Hardy Address presented by Dr. Lee Barbour (Professor, Civil and Geological Engineering, University of Saskatchewan)
- Comprehensive Industry Trade Show with over 35 exhibitors
- Over 400 delegates and 150 technical and special presentations over three days!
- 7th annual CGS Gala Awards Banquet and Local Colour Night at Casino Regina

TENTATIVE TECHNICAL PROGRAM

Climate Change and Sustainability
Cold Regions Geotechnics
Engineering Geology
Geoenvironmental Engineering
Geosequestration
Geosynthetics
Hydrogeology and Groundwater
Infrastructure
Instrumentation and Monitoring
Issues in Geotechnical Practice
Laboratory and Field Testing
Landslides and Geohazards
Mining Geotechnics
Risk Assessment and Reliability
Rock Mechanics
Soil Mechanics and Foundations
Transportation Geotechnics

Short Courses
- Terrain Analysis, Remote Sensing & GIS
- Bioengineering Workshop
- Introduction to Applied Geochemistry
- Cover Systems for Managing Solid Waste

Technical Tours
- Qu'Appelle Valley – Terrain Analysis for Geotechnique
- The Gardiner Dam – Geotechnical Focus on an Engineering Marvel
- Saskatchewan Legislature Building Rehabilitation –100 years on an Expansive Clay Foundation

The conference will be held at the Delta Hotel in downtown Regina, Saskatchewan. Come and enjoy the "Infinite Horizons" that Saskatchewan has to offer along with our Prairie hospitality!

Please see the conference web site at **www.georegina2014.ca** for detailed conference information and to register online. Be sure to register before July 31, 2014 to take advantage of early pricing discounts!

PLATINUM SPONSORS:

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Introduction by John Dunnicliff, Editor

This is the seventy-eighth episode of GIN. Two articles this time.

Performance of ShapeAccelArray (SAA)

The first article, by Derrick Dasenbrock, describes the very positive experience of Minnesota Department of Transportation with the SAA instrument. Please read my *Editor's Note* at the end, indicating my concern about including this article in GIN because it may appear to favor one of the items in our tool box too strongly. I'd like to hear from others about their experiences.

Report on a workshop

The second article, by Bob Bachus, reports on a discussion of methods for geotechnical data management and visualization. We've tried to make this more useful that a mere report by including some technical information that we hope will be helpful to readers. If you'd like to have more 'meat', please contact the author.

Is anybody there?

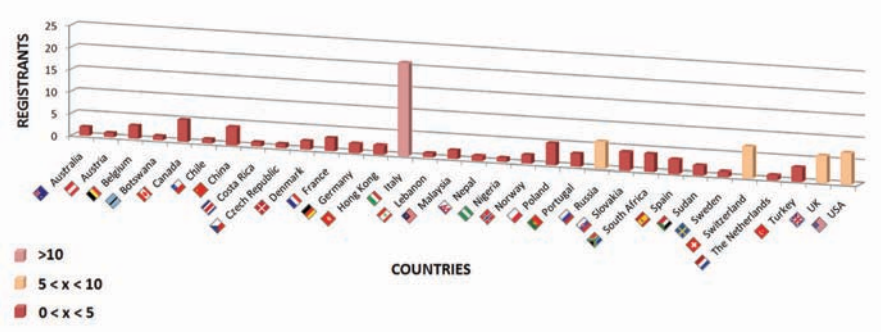
In the previous episode of GIN I asked, **"Do you want GIN to continue? The ball is in your court."** Not a single ball has come my way. I know that some of you read this stuff, so …!

International Course on Geotechnical and Structural Monitoring

Here's a status report on the course to be held in Italy on June 4-6 this year *(www.geotechnicalmonitoring.com)*.

We seem to have a tiger by the tail! At the time of writing, almost two months before the start of the course, there is no more capacity in our 95-seat room in the 10th century castle. We have more than ten on the overbooking list.

Registrants are from 32 countries (see the graphic), predominately from Europe but also from Asia, North and South America, Africa and Australia.



Now that we're encouraged by the worldwide interest in the course, we plan to offer a second course on 4-6 June, 2015**,** also in Tuscany - the same region as the 2014 course. Perhaps in Poppi, perhaps elsewhere. The 2015 edition will not be an exact repeat, as we already have ideas for different topics, and of course we'll learn from evaluations of the 2014 course

Closure

Please send contributions to this column, or an abstract of an article for GIN, to me as an e-mail attachment in MSWord, to john@dunnicliff.eclipse.co.uk, or by mail: Little Leat, Whisselwell, Bovey Tracey, Devon TQ13 9LA, England. Tel. +44-1626-832919.

Nien Nien nu e. Kong Chien (China)

Performance observations of MEMS ShapeAccelArray (SAA) deformation sensors

Derrick Dasenbrock

Introduction

Historically, traversing-probe inclinometers, settlement platforms, or survey hubs with manual surveys have been used for monitoring slope stability, settlement of embankments or movement of foundations or structures. Today, automated technologies to assess deformation include robotic total station systems, hydraulic settlement systems, in-place inclinometers, ShapeAccelArray (SAA) systems (www.measurandgeotechnical.com), and remote sensing methods. Costs and benefits of monitoring techniques need to be evaluated to see if they are well suited to project needs. SAA systems appear to have a particular

usefulness in targeted applications with frequent monitoring requirements or large anticipated deformations.

SAA instruments are linear arrangements of linked elements with MEMS accelerometers manufactured to prescribed lengths for installation in geotechnical environments. By relating the segment lengths and the tilt (calculated from the sensor inclinations with respect to gravity) of each segment with reference to a fixed end, the spatial position of the array can be calculated. As the array moves with time, subject to geotechnical effects, deformation along the array is measured, providing information on both the rate and magnitude of the movements. Figure 1 shows a typical up-hole system cabinet and a team installing a SAA sensor in a vertical borehole.

Performance

Based on an assessment of SAA data from several project sites and applications, the system performance has been found to be sufficient for transportation applications, particularly where relatively large deformations (meters) are being measured. After seven years, Minnesota Department of Transportation (MnDOT) SAA sensors, except for those that have been sheared off by exceptional deformations, continue to function well. SAA systems appear to provide similar accuracy (at the ground or structural surface) to that achieved by robotic total station systems, with the added advantage that movement inside soil masses is characterized. In our experience, we have not observed any systemic data quality effects due to sensor compression, extension, alignment, twist, temperature sensitivity, or other inherent 'device' characteristics. SAA sensors do display occasional spurious readings due to electrical or other effects—absolute data integrity, as with most electronic sensors, is not perfect. Filtering or engineering judgment may be required to properly interpret SAA response. As SAA sensors are manufactured to specified lengths, the array length cannot be changed "on the fly" in the field if changes are made to the monitoring program. Advanced planning of installations is required; the fixed length of the sensor arrays can also limit the efficient reuse of the sensors at new sites.

Automation, particularly when everything is working properly, can lead to undesirable user complacency and poor practice.

Figure 1. Typical SAA up-hole cabinet (left) and crew installing a SAA sensor in a borehole (right).

Automation

A particular strength of the SAA, which is also present in in-place inclinometers, is the ability of the sensor to remain in-situ and for data to be automatically collected and transmitted to a web-based data storage and presentation system in near-real-time.

However, a warning is appropriate. Automation, particularly when everything is working properly, can lead to undesirable user complacency and poor practice. Schedules should be established to regularly check that automated systems are properly functional. Additionally, automation should not be seen as a substitute for site visits and application of the observational method. Fewer site visits may have the unintended consequence of removing opportunities for important field observations and better understanding of mechanisms and triggers causing deformation. Geo-engineering requires an appreciation of site characteristics that are not always well captured at-a-distance.

Related beneficial aspects to sensor automation include the ability to establish movement thresholds, event triggers, and automated warnings. A bi-monthly interval was previously considered 'frequent' for traditional inclinometer installations. With system automation, it is now possible to read sensors several times daily—allowing for the collection of data sets capable of accurately depicting movement trends, such as seasonal variation, and discrete events such as those induced by contractor operations, rainfall, or earthquake. SAA systems can also provide near-real-time information to multiple users at multiple locations (via the web) with comparative ease, making the systems especially useful for construction monitoring where contractors and owners, in different locations, have an interest in immediate information for decision making.

With increased data frequency there is also the potential for improved data interpretation. If a particular

data point from a sensor monitored quarterly appears 'out of line' with earlier readings, the data quality may be immediately suspect. With automated systems, the trend leading up to an apparently anomalous point can be recorded and it may be far easier to assess incongruous data as to whether it is erroneous or representative of actual physical conditions. It has been MnDOT's experience that there is less user-intervention (assessment, validation, and correction) required with SAA installations, as the "human element" has been largely removed from the data acquisition and processing portions of the process—especially when considering the relatively large number of readings associated with frequently acquired SAA data.

SAA systems are useful for monitoring remote sites. There is no significant cost increase to poll the sensors several times daily as compared to monthly or longer intervals, (as was more common with traditional manual systems). In seven years of operations, and today with about 30 operational systems, there has been no data loss related to IT or server problems, although there have been data gaps due to system faults related to power or telecommunications. Electronic components do fail, and while SAA sensors and related architecture of data collectors, uplinks, servers and web-interfaces, have been shown in our experience to be robust, some up-hole electronics are susceptible to influences including lightning, flooding, rodent infestation, temperature, humidity, and vandalism. It is easy to become accustomed to a level of reliability, only to find after several months have passed, that a modem developed a fault or wiring has become part of an industrious bird's nest.

System automation of data acquisition, monitoring, and reporting tasks also requires some degree of specialty computer support. SAA system set-up has a distinct learning curve. Reliance on computers, coding, and infrastructure design and support is greater than with manual systems. In general, the most challenging aspects of automated systems have been related to initial system deployment, cellular modem telecommunication set-up and service, and maintaining system power at remote locations.

Large deformation applications

MnDOT first installed three SAA systems in the summer of 2007 in Crookston, MN at a site where large known movements were occurring. Several traversing-probe inclinometer installations at the site had crushed, sheared, and in one case trapped a probe in the ground. An early conclusion from that project was that the SAA systems appeared to be ductile in nature and the sensors could report exceptionally large deformations while maintaining operational integrity. Deformations of several feet were observed in two of the three sensors along relatively narrow shear bands (slip planes); the other SAA was installed outside the active slide area.

Based on the success of that project, two additional sensors were installed to monitor a nearby project where a roadway embankment failed only a few months after the monitoring program began in the summer of 2008. Lateral movements of over 100 inches (2.5 m) were accurately recorded by the two SAA sensors—well outside the operational boundaries of typical traversing probe systems. The frequent monitoring of the SAA sensors at this second site enabled MnDOT to close the roadway and begin building emergency bypasses prior to the collapse of the westbound portion of the highway. Figure 2 shows the embankment failure area where the SAA systems identified multiple slip surfaces and recorded significant lateral deflections.

MnDOT has also successfully installed SAA systems below roadway embankment surcharge operations to monitor large settlements over soft compressible soils. Based on project data, it appears likely that the curvature of traditional plastic conduit would have been challenging for a horizontal traversing-probe to negotiate (especially with single-end entry). On this project, contractor operations were controlled based on embankment settlement response. Monitoring the SAA systems and other sensors to review construction activities on a daily basis had significant project benefits, particularly as it could be done via the internet.

Broader application of automated systems

While not immediately appreciated, it became clear that SAA systems had additional advantages over manual systems. The sensors can be polled even in poor weather conditions such as when the installation area may be covered with snow and ice. SAA systems also continue to function when the sensing elements are below floodwaters. The ability to monitor a

Figure 2. SAA systems reported and recorded a significant landslide event in near-real-time to geotechnical offices five hours away. The SAA systems remained fully operational as over 100 inches (2.5 m) of lateral deformation was measured.

slowly creeping landslide during flood conditions played an important role in quantifying the stabilizing influence of high water levels on the project. SAA sensors can be installed within embankments, walls, or slopes immediately below travelled roadways. Monitoring then occurs without traffic interruption—an important consideration from cost, roadway user inconvenience, and safety standpoints.

SAA systems have also been useful in monitoring construction deformation of spread footing foundations in response to loading. Construction projects are often active, dynamic, and unsafe. As SAA systems can be installed and buried with only a small up-hole cabinet for support, high quality, frequent data, can be obtained to monitor the influence of construction sequencing safely and with minimal contractor impact. In general, automated sensors and systems (of all types) have been shown to be highly beneficial on projects where the influences of construction staging are of interest and frequent monitoring intervals are desired.

System costs

In common uses, the cost to install a borehole for a vertical monitoring system in native ground is roughly the same for a traditional inclinometer as it is for a SAA. A traversing probe may be used at multiple installations—it is possible for a $6K probe to be used to effectively monitor either one borehole or ten nearby boreholes. Conversely, a SAA system for one similar hole may cost $15K and perhaps $10K for each additional nearby hole for the sensing element (sharing some up-hole resources). It may therefore appear that SAA systems may only be appropriate for very specialized projects. However, the difference in total monitoring cost for a project depends on more than the initial cost. If a site with ten instrumented boreholes was four hours from the closest project office, it could take a technician an entire day to collect data, with associated time and travel expenses. For a five-year project with monthly reporting, sixty site trips would be needed; weekly reporting would require 260 trips, and daily reporting would require 1825 trips. On inspection of the cost of daily trips, this option might not even be considered as a plausible alternative—it would be clearly "cost prohibitive." Here, automation can bring previously discounted options back to the table. SAA systems become more cost competitive if system components, or entire systems, can be redeployed elsewhere at the end of a monitoring program; costs can be amortized across projects. Several MnDOT systems have been removed from service on initial projects and repurposed at new sites.

Ten observations on SAA system performance

SAA systems have both positive and negative attributes. "Lessons learned" from a number of installations and projects include:

1. Predetermined sensor lengths require advance planning and can limit the potential efficient reuse of the sensors at new sites.
2. Reliance on computers, coding, and system support is greater than with traditional systems; electronic systems have a distinct "learning curve."
3. Cellular modems and power supplies are often "weak links" in system.
4. Sensor readings can be subject to some spurious (electrical or other) effects—the data quality, as with most electronic sensors, is not perfect. Filtering or engineering judgment is required in some cases.
5. Installation procedures are similar to traditional inclinometers.
6. SAA sensors are very robust in large-displacement environments.
7. With seven years of operational experience, data can be acquired in severe environmental conditions (during floods, below ice and snow, under roadways).
8. Automation allows high frequency readings for better data analysis of rate information and capture of seasonal variation and unexpected events.
9. SAA systems provide generally well-behaved data-sets in horizontal applications, especially as compared to many common settlement sensors;
10. Relatively high initial costs are offset by improved data quality, near-real-time event reporting, and life cycle savings in manual labor and travel costs, particularly if components can be re-used on future projects. Systems can also improve safety with fewer field visits and reduced field construction conflicts.

As with other automated systems, users should take care that SAA monitoring systems compliment site visits, observations, and thoughtful evaluations of the geologic character of project sites to better evaluate causes and impacts of the ground movements being monitored.

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Editor's Note

I've had some concerns about including this article in GIN because it may appear to favor one of the items in our tool box too strongly. If you have experience with the SAA instrument and have anything to add about performance, pro or con, will you please send me a discussion of this article, and I'll consider it for a future GIN?
JD

Advances in geotechnical data management and visualization

Robert Bachus

What were you doing on Sunday morning, 12 January 2014? If you are a die-hard, geotechnical data "geek" you should have been at the Transportation Research Board (TRB) annual meeting in Washington, D.C at 9:00 am with 75 of your colleagues to participate in a workshop titled "Advances in Geotechnical Data Management and Visualization." I served as the moderator for the workshop. TRB established the theme for the 2014 annual meeting as "Celebrating Our Legacy, Anticipating Our Future" and the workshop certainly reflected that motto. The three-hour long session included seven invited podium presentations and a panel discussion that featured six invited panelists, as well as participation from the early-risers in the audience. While the workshop participants certainly wanted to celebrate the legacy of geotechnical data management, the real focus of the presentations was to alert all participants to the opportunities that we will be afforded in the future should we adopt these advances. A wide range of discussion and presentation topics were broadly categorized to capture advances in:

- Software and data formats
- Data capture and interpretation
- Data management and visualization.

Highlights and lessons from the workshop are summarized below.

Software and data format updates

The workshop started with a reflection and recognition of the series of articles from the December 2010, March and June 2011 issues of Geotechnical Instrumentation News that highlighted advances in web-based data management software, given that this was the most recent compilation of articles on this topic. *[The initial article by David Cook, titled "Fundamentals of Instrumentation Database Management – Things to Consider" was followed by eight one-page articles by ten suppliers of the software. These are, of course, accessible on www.geotechnicalnews.com/instrumentation_news.php. JD].*

At the TRB workshop, recent additional updates and innovations to these software packages were presented by some of the presenters/developers, including Ed Kirby (itmsoil usa), Andres Thorarinsson (Vista Engineering), and Allen Marr (Geocomp), who provided updates to Argus, Vista Data View, and iSiteCentral, respectively. As a tribute to the benefits of technology, Roger Chandler (Keynetix) was unable to attend the workshop but through the use of a video presentation from his office in the U.K. was able to provide software updates and reported on the recent efforts in the U.K. to require/incorporate geotechnical data into Building Information Modeling (BIM) software. A primary message from these presenters was that members of the software development community have their collective ears close to the ground and are continuously refining products and utilizing technology that allows the geo-professional to be more effective at doing their job. A good example of this was the relatively recent capability to store and manage information "in the Cloud", as do many of the software packages presented. It was interesting that many of the presenters acknowledged the benefits and recent efforts in the U.K. and the U.S. to standardize the storage and transfer of geotechnical data using the Association of Geotechnical and Geoenvironmental Specialists (AGS) format that is used across the U.K. and the Data Interchange for Geotechnical and Geoenvironmental Specialists (DIGGS) format being advocated in the U.S. Rob Schweinfurth (Geo-Institute of ASCE) and Marc Hoit (North Carolina State University) subsequently provided the participants with an update of recent efforts to resurrect the DIGGS development efforts and indicated that the Geo-Institute of the American Society of Civil Engineers (ASCE) has recently taken responsibility for final development and public release of the DIGGS format by October 2015.

Data capture and interpretation

A number of the presentations were focused on the interest in and propensity to require collection of large amounts of data and the accompanying need and importance of accurately interpreting these data. Shaun Dustin (Campbell Scientific) summarized the efforts and commitment of vendors/developers to provide reliable data collection hardware, but cautioned that as an equipment provider, their job is not to maintain the project databases. Gary Young (Underground Imaging Technologies) discussed how equipment manufacturer partners are utilizing instrumentation on equipment to monitor engineering performance, but emphasized the need to be able to quickly and reliably interpret results. He specifically acknowledged collaboration/interaction with Caterpillar and its project teams working with Caterpillar's Katherine Braddy. Two examples were provided to demonstrate the benefit (and thus the necessity) to accurately interpret the collected data. Ken Fishman (McMahon and Mann) presented a case history regarding corrosion in steel strips and performance monitoring of mechanically stabilized earth (MSE) structures. Hai-Tien Yu

(itmsoil usa) presented a case history regarding the corrections that need to be applied to collected vibrating wire strain gage data to account for temperature impacts on readings. These examples illustrate the closing gap between data collection and interpretation. While the previous discussions focused on data collected from geotechnical instrumentation, Jamey Rosen (Geosyntec Consultants) provided information regarding the "philosophy" of good data management and showed how construction performance "information" can be collected and managed as "data." Lessons learned from this block of presentations were:

- We now have instruments and capabilities to capture significant amounts of data/information…so owners and engineers now often require that these be captured.
- If we collect the information, we have to be prepared to review and interpret the information in a timely manner.
- There exist much more information that should now be considered geotechnical "data" and we need to be prepared to capitalize on the opportunities the capabilities presented by timely and efficient data capture.

Data management and visualization

There was significant interest and numerous examples were cited by several of the presenters regarding the advances and benefits regarding the visualization of collected data. Semiha Ergan (Carnegie Mellon University) provided illustrative examples of how the BIM software historically used by the construction industry has evolved and is now being used by designers and architects to visualize a wide range of data to allow modeling of building life-cycle costs. Raphael Siebenmann (Geosyntec Consultants) offered several examples of how the use Cloud-based data collection and geographic information system (GIS) technology have been used to capture information and visually present geotechnical and construction information to the user. Scott Deaton (Dataforensics) highlighted many examples of the benefits of data visualization and demonstrated the benefits of developing and using standardized data formats to truly capture these benefits. The primary lessons from these discussions were:

- Data visualization is an emerging area that provides immeasurable benefits to all project stakeholders.
- Geotechnical professionals will benefit from the collaboration of colleagues in practice areas (e.g., computer science and informatics) that are considered non-traditional to the geotechnical engineer.

Looking to the future

The advocates of geotechnical data management, and many of the readers of Geotechnical Instrumentation News, know all too well that advances in technology have allowed geotechnical engineers to do so much more with geotechnical information that was simply not available 20 years ago. Many of the participants noted that as technology has advanced the profession's ability to capture data, recent project experience has shown that owners are fast to require that more data be collected. In some cases, the ability to capture the information seems to become the justification for collecting the information. It is doubtful that this trend will change in the foreseeable future. Unfortunately, many of the participants at the workshop voiced opinions that the collection and management of this information has been a source of ongoing frustration regarding the various procedures for data management that are being used across the industry. The discussion at the workshop indicated that there was little doubt regarding the benefits of "standardized" data collection, reporting, and management. However, the participants acknowledged that despite the mood of the workshop, the vast majority of practicing engineers involved in this field likely will not voluntarily adopt the standardized data concept because it will require them to change their current practice and processes. Therefore, there was a feeling that "change" had to be driven by the owner or by project specifications. An action item from the workshop was to continue the advances but also to encourage the development and implementation of standardized data formats (e.g., AGS and DIGGS efforts) by demonstrating the benefits of adoption. So, the readers of Geotechnical Instrumentation News should expect to be hearing more about this important workshop outcome in future issues.

I appreciate that this brief report on the workshop is only an outline of what took place. If readers would like to have more information regarding the workshop, they are encouraged to contact me.

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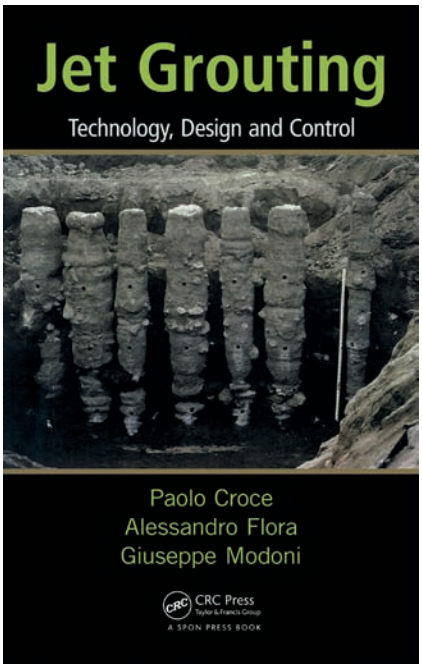
Paolo Gazzarrini

Overture

35th episode of the Grout Line. For this issue a short review of mine about a very interesting and unique book about Jet Grouting, and a short article from my friend Sam Bandimere - Grouting Consultant in Denver- Colorado (sbandimere@msn.com), with a brief review of the grouting industry today.



Having done my first Jet Grouting job in 1981, I am always interested in articles and books about Jet Grouting. A great number of papers have been published at dedicated geotechnical conferences about research, theories, quality control, results and case histories. Several students' theses have been done with very interesting research, but not summarized in a single and a complete publication. This book, at last, summarizes all-we-must-know about Jet-Grouting; if not all, definitely a lot!

I read consequently, over the past few weeks, with great interest this book that is written, I believe with passion and a lot of effort, by Professors Croce, Flora and Modoni with the title "Jet Grouting -Technology, Design and Control".

In 2004, the same authors published a similar book about Jet Grouting, only in Italian and consequently for a restricted market, and I was curious to compare the old Italian version (that I considered very general) with this new English version.

The authors, Paolo Croce and Giuseppe Modoni, are Professor and Associate Professor of Geotechnical Engineering at the University Of Cassino (Frosinone-Italy) and Alessandro Flora is Associate Professor of Geotechnical Engineering at the University Of Naples (Italy).

The book is divided into 8 chapters:

- Chapter 1 starts with a brief introduction and history of Jet Grouting
- Chapter 2 describes briefly the technology
- Chapter 3 Mechanisms and effects of Jet Grouting
- Chapter 4 Column properties
- Chapter 5 Jet Grouted structures
- Chapter 6 Design principles
- Chapter 7 Design examples
- Chapter 8 Controls

Some Chapters are more detailed, some less. A lot of case histories and references are presented, and very interesting design approaches and examples are illustrated. The book closes with a long list of possible controls for the results, sometimes problematic in this technology.

Something more, maybe, could have been said, about equipment (pumps, drill rigs, mixers etc) and small tools and devices (data loggers, verticality control devices, etc.), but I found the essence of the book to be excellent. I read with special interest the two chapters related to the design with both principles and examples.

Only a small criticism (or what I might call myself a venial sin), about the visual "feeling" of the technology; the Cover!

The front picture doesn't do justice to a good Jet Grouting job. It is, of course, only a field test to calibrate the parameters, and it is very interesting, but it can give a negative impression of the technology. Of course this can happen anytime if the Jet Grouting parameters are not correctly calibrated with respect to the type of soil to be treated!

Currently Jet Grouting is sometimes considered unpopular (due to mishandling of spoil and sometimes difficulties in the final control), and a picture like that can help those who mistreated or neglected this very strong and flexible soil improvement technique. I would have preferred a picture like the one at the top of the next page.

In a conclusion, despite -marginally- the cover page, I consider this book very complete and a must-read and must-have book for anyone interested in Jet Grouting and generically in grouting, from Agencies to Engineers to Contractors.

I would recommend that you include it in your library and .... happy reading!

A grouting industry review

Sam Bandimere

As a grouting consultant, I thought it might be a good time to share some observations of the Grouting Industry and how it is doing in these challenging economic times. I don't mean to just address the "feast or famine" issues we all face and must deal with in the course of doing business, but rather the broad spectrum of the industry as a whole.

Before going any further, may I say that nothing replaces the daily routine of taking care of business in terms of making sure your field operations are properly supported with training, manpower, and properly maintained equipment, etc. There is no better marketing strategy than making sure your company's reputation is positive and supportive. With that said, let me continue.

In the years of owning a grouting company, I was always interested in acquiring as much information about the industry as I could, for two reasons: (1) I wanted to determine what could be expected in terms of marketing opportunities as the industry moved forward and developed, and (2) for focusing efforts of our own operations and marketing program.

When an industry's overall market expands, stabilizes or declines, it allows for a review of how, where and why to focus your marketing efforts, i.e. When the overall market is growing, you need to research the reasons that expansion is occurring. If your company is to maintain "market share", you will need to focus on making sure you're current with the technical reasons for this growth. If

the market has stabilized, you may want to focus on maintaining and/or increasing your market share. This can be accomplished by taking a hard look at your existing operations to see what can be done to stabilize your operations with a more cost- effective approach to your current market-share.

When the market is declining, that is when I believe the greatest opportunities are available. In work and in life, exploration moves us forward. We find new ways to work, welcome new ideas, and try new fields, if there is ever a time to make your mark, it is then. Sometimes the greatest motivator is when our back is against a wall. We just need to make sure that wall is not of our own doing but is the result of things beyond our control.

I, for one, am proud to be part of an industry that has at least a 50-year history of innovations and explorations. There are new application methods that continues to break down walls built with bricks of "can't." It is said that innovation is the antithesis of fear. If there has ever been an industry that has learned to control the "fear" factor, it is the Grouting Industry.

One of my favorite definitions of marketing is, "a gathering of people for buying and selling." (Webster Dictionary). I learned many years ago from Jim Warner that this gathering of "people" needs to include good competitors. I could get on a long soap box of explanation, but just suffice it to say "a rising tide lifts all ships." If all you want to be is an island, you might find it gets to be a lonely place. Eventually you will find that there is a world out there moving forward without you.

It is no secret that the Grouting Industry is somewhat recession-resistant. When an economy goes into a recession, governments usually step up their infusion of money for infrastructure upgrades and new construction which is conducive to the grouting industry. Also, existing structures don't really care what the economy is doing. There will always be the need for specialty engineers and contractors who are adept at stabilizing, re-leveling or doing some type of grouting repairs either structurally or geotechnically.

When I look at the success of the 4th International Grouting Conference held in New Orleans (February 2012), is it any wonder that this industry is moving forward at the pace it is going! The continued success of the annual Colorado School of Mines Grouting Course, the participation in the Geo-Institutes Grouting Committee, the numerous websites and blogs by manufacturers, engineers, contractors and suppliers are all testaments to the success of this industry.

One of the most encouraging aspects of this industry is the inclusion of some very innovative and motivated new companies that I believe will be the long-term continued success of this industry. Obviously, our community of existing companies continues to hold the bar very high for new companies to compete, but there are times when those with a whole new look at the challenges this industry addresses come up with some very innovative ideas. In today's business environment, it is more important than ever that we constantly look forward, consistently innovate, and implement new and better ways of doing business.

Constantly innovating might mean learning a new aspect of existing grouting applications or drilling capabilities. There are numerous ways of acquiring information and help through webinars and seminars the drilling and grouting industries provide. I can't stress enough the need to share your knowledge and experiences through participation in these opportunities. Because this is an international magazine, I can't begin to list all the organizations that need your participation, but let me say, you could start by looking into such organizations as the ASCE Geo-Institute, Deep Foundations Institute (DFI), The International Association of Foundation Drilling (ADSC), International Concrete Repair Institute (ICRI), American Concrete Institute (ACI), World of Concrete (WOC), just to name a few. Most, if not all these organizations, have grouting or ground improvement committees that are always looking for active members.

I would, also, mention that a lot of manufacturers and suppliers now hold some very good training sessions, so when purchasing materials or equipment, you may want to select a product or manufacturer who has the capability of training your operators. Just be responsible in your due diligence, making sure you are dealing with a supplier or manufacturer who has a good record within the industry and that you're not just falling for a good sales pitch.

As a Grouting Consultant, I've had the privilege of working with numerous contractors around the world. It never ceases to amaze me how robust and vibrant this industry is. Success usually requires sacrifice, and if there has been one huge fault to this industry, I would say it has to do with the amount of travel involved. Projects are site-specific and require a lifestyle of temporary locations which is very hard on families. This industry is doing a great job of addressing the "safety" issue, but is doing a poor job of addressing the "family" issue. The only solution I have found is to recommend that your company establish regional boundaries for your marketing strategy for the sake of your crews. When hiring a new employee, you really need to establish the number of days per year that employee is willing to travel and abide by those agreements. I speak from experience - there is no amount of compensation that replaces family time. Whenever I speak at seminars, I try to challenge the engineering community to make sure they give their local contractors a chance to bid on their projects without bringing in an out-of-town contractor. I'm convinced more than ever that when we have successful family members in

our companies, this industry is truly a success no matter what the economy is doing.

Our industry is really all about people. Sure, there's equipment and technology and materials involved, but it's the people who put it together who make it great.

Sam Bandimere

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If you have some comments or grouting stories or case histories, send them to me at:

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Ciao! Cheers!

UQAT-Polytechnique establishes a unique Research Institute on Mines and the Environment

Vivian Giang

Necessity is the mother of invention. In the early 1990s, Dr. Michel Aubertin saw a need for improving how the mining industry dealt with its tailings and waste rock to better protect the environment as well as a need to train specialists with an understanding of hard rock mine waste management and site reclamation. Since then, he has dedicated 25 years of his career to developing new tools and techniques to advance mine waste geotechnique as it is practiced in Canada and internationally while training the next generation of mine waste management and reclamation engineers and geoscientists for industry and academia. Most recently, Aubertin and his long-time collaborator Dr. Bruno Bussière spearheaded the creation of the Research Institute on Mines and the Environment (RIME) UQAT-Polytechnique, a unique research organization in Quebec that focuses on the hydrogeological, geotechnical and geochemical aspects of mine waste management and on developing new technologies to better design and reclaim mine waste disposal areas.

Aubertin, Professor in the Department of Civil, Geological and Mining Engineering at École Polytechnique de Montréal, surprisingly was never formally trained in mine waste management and reclamation. "I completed my MSc in soil mechanics and PhD in rock mechanics, and I was quite active in these fields. However, environmental engineering became the order of the day about 25 years ago – there was a great need for engineers who could work on mine wastes disposal and site reclamation, and there was no graduate program at the time for training specialists to deal with such issues," says Aubertin. There were also significant problems to be solved, particularly for old (and sometimes abandoned) mine sites.

Waste rock inclusion constructed in the tailings impoundment at the Canadian Malartic mine. Such inclusions act as drainage and reinforcement elements to improve the hydro-geotechnical behaviour of the impoundment (photo provided by Osisko).

Though there were some oil sands and mine tailings research programs developing across the country (mainly in the west), there were no comparable mine wastes research programs in the province of Québec. So, Aubertin dove into numerous textbooks, conference proceedings and journal papers on a broad range of subjects within geotechnical and geoenvironmental engineering to become well versed in the knowledge he would need to develop a mine tailings research program at École Polytechnique. With the help of colleague Dr. Robert Chapuis, Aubertin began developing the first French-language undergraduate and graduate courses on mine waste management in Canada to train young engineers in, what was then, the newest area of mining and civil engineering.

At the same time, Aubertin was interacting with mining companies through the Canadian Mine Environment Neutral Drainage (MEND) Program, and he developed innovative research projects involving the hydrogeotechnical and hydrogeochemical behaviour of mine wastes, particularly those that are reactive and prone to generate acid mine drainage (AMD) and the reclamation of waste disposal sites. Between 1989 to 2001, several companies and the Québec Ministry of Natural Resources supported his research on mining geotechnics and hydrogeology, including constitu-

tive and numerical modelling of the behaviour of geomaterials, reclaiming acid generating tailings and developing cover systems using tailings rather than soil. The need to further investigate issues related to the environment and mine wastes management grew to the point that a major concentrated effort involving academia and industry needed to be established.

In May 2001, after nearly two years of exchanges and preparation, the NSERC Polytechnique-UQAT Industrial Research Chair (IRC) in Environment and Mine Wastes Management was established as a collective effort between Université du Québec en Abitibi-Témiscamingue (UQAT) and École Polytechnique de Montréal, supported by Barrick Gold Corp., Noranda (now GlenmoreXstrata plc), Agnico-Eagle Mines Ltd., Aur Resources Inc., Dessau-Soprin Inc., Golder Associates Ltd., Inmet Mining Corp., SNC-Lavalin Inc., McWatters Mining Inc., BHP Billiton and Quebec Iron and Titanium (now Rio Tinto). Aubertin was appointed the Senior Chairholder for the five-year program, which was successfully renewed for a second phase in 2006. Bussière from UQAT was appointed the Junior Chairholder for the program in 2001 and was later appointed Associate Chairholder in 2006.

"The [IRC] research work aimed at developing tools and techniques for the characterization, modeling and evaluation of various mine wastes and of management and reclamation practices… [to] lead to improved practices for solid and liquid waste disposal," says Aubertin. Between 2001 and 2006, the IRC revolved around two broad research themes: i) waste management during mining operations and ii) closure and reclamation of disposal sites. From 2006 to 2012, the research focused on integrating mine closure aspects with actual mine operation issues. The program was then structured around eight main research projects: 1) improved surface disposal of tailings; 2) optimizing surface disposal of waste rock; 3) disposal in mine openings; 4) properties of acid mine drainage treatment sludge; 5) use of wastes on mine sites; 6) water quality prediction; 7) evaluation of cover systems; and 8) passive treatment systems. These projects have been summarized in a keynote presentation and in the Proceedings of the Tailings and Mine Waste 2013 Conference held in Banff, Alberta (see *www.ostrf.com/TMW)*.

The impact of the IRC program spanning from 2001 to 2012 is substantial. Over 140 graduate students and 20 undergraduate students were trained and conducted research in projects directly related to the IRC program. Upon graduation, these students became the much needed specialists in mine waste management, geotechnique, hydrogeology and geochemistry to tackle the reclamation challenges in the mining industry. Eight of the PhD graduates and postdoctoral fellows have gone on to obtain faculty positions at various universities, while many others occupy key positions in industry. "My greatest satisfaction is seeing former students be in positions to take action or make decisions to improve mine waste management to protect the environment. I'm very proud to have been part of their training," says Aubertin.

The IRC collaboration with researchers in Canada, France, Belgium, Australia, Mexico, Morocco, and Tunisia resulted in an impressive 300 publications (120 peer reviewed journal papers, 160 conference papers and 20 technical reports), making significant contributions to the international mining community and state of practice. Additionally, Aubertin and Bussière, with the help of many colleagues, have promoted technology transfer from the IRC program through hosting symposia, conferences, workshops, seminars, short courses and graduate courses.

Another important contribution of the IRC program was the groundwork it laid that led to the creation of RIME UQAT-Polytechnique. Aubertin is the Director of RIME-Polytechnique with Bussière as the Director of RIME-UQAT. RIME, which is pronounced "rhyme", was established in April 2013 and is supported with funding from federal and provincial governmental agencies and several mining companies. "RIME UQAT-Polytechnique targets the development of environmental solutions for the entire mine life cycle. With a value of nearly $10 million provided by mining companies over seven years, it can be expected that this innovative partnership will produce a top-notch research program and train a large number of highly qualified professionals," says Aubertin.

"We have gone a long way in improving waste management in the last 25 years, but mining is still facing major challenges. If we want the population to maintain their support toward mining operations, industry must continue to invest on the development of technologies to close mines in the right state. This is usually well understood by the major players, which invest in research to understand the problems and ensure we achieve our goals."

For more information on RIME UQAT-Polytechnique, visit *http://rime-irme.ca.*

Welcome by Jonathan Fannin, Editor

In gathering my thoughts for the return of this column on geosynthetics, I am reminded that all endeavours to disseminate knowledge, be they in the form of a conference gathering, a workshop meeting or a webinar broadcast should adhere to the basic principle of a timely contribution that is informative – and, most importantly, should provide at least some lasting influence. In other words, endeavours to disseminate knowledge should be thought-provoking. Now, on the subject of webinars and geosynthetics, I have more to share later in this column. But first, on the matter of being thought-provoking, let us go back in time and give brief consideration to the organization of the 1st International Conference on Soil Mechanics and Foundation Engineering that was held at Harvard University in June 1936. In a Foreword to the conference proceedings, Arthur Casagrande wrote "*The unexpectedly large number of contributions to the Conference and the fact that the majority of the authors, particularly of some of the most valuable papers, have partially disregarded one or other of the conditions for contributions to the Conference, have made the work of the Editorial Board very difficult*." Notwithstanding these 'local' difficulties, the conference gathering proved to be a tremendous success, attracting so many contributions that the papers, discussions and additional contribution of special merit filled three volumes: Casagrande went on to declare that "*in view of the fact that the printing costs for the entire three volumes will be more than double those estimated, the Committee on Organization has decided that the registration fee for the Conference members applying after May 15, 1936 shall be ten dollars.*" I hope the return of this column on geosynthetics proves equally attractive as a means for knowledge dissemination, albeit in a different format, and provides an equally good return on the investment of time and effort by you, the reader, to peruse its contents.

Karl Terzaghi (Fig. 1) was elected, at the 1936 conference, to the office of President of the newly-formed International Society for Soil Mechanics and Foundation Engineering. In his opening presidential address to the delegates, he spoke to a number of issues including *The Conflict between Theory and Reality*, and *The Truth and Fiction in Textbook Engineering*. Some may consider these two issues to be as relevant today, more than 75 years later, as they were at the time of his original address. On the latter, Terzaghi observed "*In pure science a very sharp distinction is made between hypotheses, theories, and laws. The difference between these three categories resides exclusively in the weight of sustaining evidence. On the other hand, in foundation and earthwork engineering, everything is called a theory after it appears in print, and if the theory finds its way into a textbook, many readers are inclined to call it a law.*" He proceeded to observe that "*Whatever evidence is available can be classed into one of the following five categories:*

a. No evidence whatsoever;

b. Evidence obtained by distorting the facts;

c. Unbalanced evidence; that is, evidence obtained by eliminating all those facts which do not sustain the claim;

d. Inadequate evidence, covering the entire range of present knowledge, yet insufficient to exclude the possibility of a subsequent discovery of contradictory facts; and,

e. Adequate evidence."

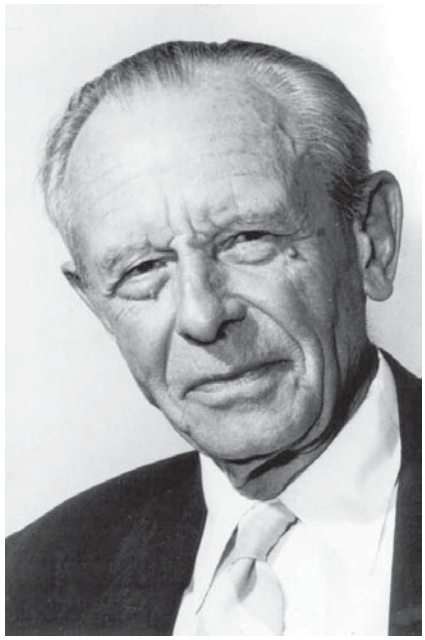

Figure 1. Karl Terzaghi, project specialist for the selection and installation of the PVC geomembrane at the Mission (now Terzaghi) Dam, Canada.

All of which led him to believe that "*successful work in soil mechanics and foundation engineering requires not only a thorough grounding in theory combined with an open eye for possible sources of error, but also an amount of observation and of measurement in the field far in excess of anything attempted by the preceding generations of engineers.*" Optimistically, he was of the opinion that "*By patient observation we have learned to discriminate between what we really know and what we merely believed*". He was, by all accounts, an exacting individual, an insight that became very apparent to me when reading through a significant portion of his professional correspondence held in the collections of the Terzaghi Library at the Norwegian Geotechnical Institute (Fig. 2), while preparing a manuscript on

Figure 2. Reading through professional correspondence in the Terzaghi Library at the Norwegian Geotechnical Institute.

Terzaghi's path-of-discovery toward the design of granular filters (Fannin, 2008). I grew to appreciate the legacy of his systematic experimentation as a university academic, his challenging assignments as a specialist consultant, his life-long respect for the influence of minor geologic features, his rigorous approach to the interpretation of evidence, and his unstinting commitment to performance monitoring. And with this appreciation, I too sought out every opportunity to ensure that I had a proper understanding of events related to the nature and origin of geotechnical filter design, for which I acknowledge, with gratitude, conversations with several individuals including Terzaghi's co-author on the textbook "Soil Mechanics in Engineering Practice", Ralph Peck, at the 57th Canadian Geotechnical Conference (Fig. 3).

Figure 3. Consultation with Ralph Peck on the origins of the filter design criteria appearing the "Soil mechanics in engineering practice" co-authored with Karl Terzaghi.

I also have no doubt that Terzaghi brought the same unstinting commitment to excellence when he oversaw the design and installation of a PVC membrane liner during construction of the 55 m high Mission Dam, British Columbia, Canada that was subsequently renamed the Terzaghi Dam, in 1965. As might be expected, the problem was anything but simple. Following early exploratory work in 1955, placement of zoned embankment materials commenced in 1957 and continued through to 1960 (Terzaghi and Lacroix, 1964). The dam is founded on a discontinuous clay stratum that is underlain by sand and gravel, and overlain by alluvial and river channel deposits. The clay stratum itself represents the downstream portion of glacial lake deposits arising from the last stage of recession of the Pleistocene ice sheet: the boundary between it and the overlying coarse-grained sediments was found to be clear but very uneven, likely as a result of geological processes following retreat of the valley ice. Settlement of the embankment occurred during construction, including differential settlements of up to 3 m. The zoned embankment dam has a sloped till-core that is covered by an upstream blanket of plastic clay, about 2.5 m thick. The performance of the dam is contingent on the clay blanket remaining intact, without any cracks or fissures arising from the influence of differential settlement. Concern for the adverse impact of any cracking led to the decision to cover select portions of the clay blanket with a plastic membrane. The choice of plastic material

was informed by its "*impermeability, stretchability, durability, stability with reference to sliding, and the price of the installed membrane*" (Lacroix, 1960), and was made after exploring alternatives, including that of an asphalt coating. In the end, as Lacroix observed somewhat perfunctorily "*Polyvinyl chloride membranes appeared to be the most satisfactory. Several brands were available. Their properties were similar. The selection was then based merely on economical grounds.*" The rationale for the specification criteria that were developed for the plastic membrane remain as instructive today as they were at the time of construction. The required strength was selected on the basis of field trials to ascertain the likelihood of puncture during handling and placement; a strain at failure of the order 200 % at room temperature was considered satisfactory; explicit recognition was given to the absence of knowledge regarding durability of the plastic membrane, and the effects of time on its extensibility; and, in anticipation of most deformations occurring within a couple of years of completion of construction and first filling, it was considered sufficient that the membrane possess 5 % of its original extensibility after a period of 10 years. As Lacroix acknowledged "*Terzaghi specified the tests leading to the selection of the type of membrane, outlined the design, and suggested most construction procedures.*" In 2010, and some fifty years after its original installation in 1960, I was fortunate to receive from BC Hydro, a sample of the PVC geomembrane that had been retrieved during a program of fieldwork at the Terzaghi Dam. Comparison showed the thickness of the exhumed sample to be a little less than that of the specified material, however its specific gravity was measured and found consistent with that of PVC, and its plasticiser content was, likewise, determined and found consistent with that of PVC. Indeed, upon inspection of the sample of 50 year-old geomembrane, apart from the presence of surficial scratches, it looked and felt almost brand new - Terzaghi himself would surely have been impressed, doubtless satisfied, but certainly not surprised!

It was in 1977 that the International Conference on the Use of Fabrics in Geotechnics, which is now considered to have been the 1st International Conference on Geotextiles, was organized in Paris, France and it was during this meeting that the words "*geotextile*" and "*geomembrane*" were proposed by J.P. Giroud. The 2nd International Conference on Geotextiles was held at Las Vegas, USA in 1982 and, subsequently, the International Geotextile Society (IGS) was founded in 1983: it was just over ten years later that the word "Geotextile" was replaced by "Geosynthetic" with approval of the IGS Assembly in 1994. The initial presidency of C. Schaerer (1983-86) was followed by J.P. Giroud (1986-90), K. Rowe (1990-94), C. Jones (1994-98), R. Bathurst (1999-2002), D. Cazzuffi (2002-06), and F. Tatsuoka (2006-10).

These conferences were effectively the precursor to a series in which the upcoming 10th International Conference on Geosynthetics that will be held at Berlin, 21-25 September 2014 is the latest to be organized under the auspices of the IGS. During this time, as the current IGS President George Zornberg (2010-14) recently observed, the changes in the growth of the discipline are reflected in the advance from a first conference on the use of "Fabrics" to "Geotextiles", to "Geotextiles, Geomembranes and Related Products" and, since 1998, to the collective term "Geosynthetics". The IGS has organized international, regional, and chapter conferences, and has founded IGS chapters in 41 countries or groups of countries (Zornberg, 2013). The first to be formed was the Japanese chapter, in 1985, and it was followed soon after by the North American chapter, in 1986. A year later, in 1987, the journal "Geotextiles and Geomembranes" (edited by Kerry Rowe) became the official journal of the IGS and was joined, in 1994, by a companion journal "Geosynthetics International" (edited by Richard Bathurst). It is this body of information, contained in conferences and peer-reviewed journals, which serves the core purpose of the IGS "to provide the understanding and promote the appropriate use of geosynthetic technology throughout the world".

"the value of a good education is not the learning of many facts, but the training of the mind to think of something that cannot be learned in textbooks"

A recent innovation of the North American Geosythetics Society (NAGS) has been a webinar series, the first of which was given by Kerry Rowe on "Recent insights on the performance of GCLs in bottom liners and covers" in March 2014. The next is to be delivered by Bob Mackey on "Composite Drainage Nets – Design and Testing" in July 2014 (for more details see the upcoming events section at http://www.nags-igs.org/). The following webinar in the series is to be given by your erstwhile Editor of this column, Jonathan Fannin, on the subject of "Geofilters" in October 2014.

Returning now to the philosophical observations of Karl Terzaghi on both the meaning and value of evidence-based claims, I am reminded of the quote that is attributed to Albert Einstein on the subject of a good education and the textbook "*the value of a good education is not the learning of many facts, but the training of*

the mind to think of something that cannot be learned in textbooks". I am concerned that we are in danger of losing our collective appreciation for the purpose of the textbook, and indeed other related publications – it is a guide in support of acquiring a good education, and not simply a repository of facts that should be committed to memory in order to progress steadily through a program of study or, for that matter, and recalling one of Terzaghi's concerns in his presidential address, a repository of claims that should be accepted as universally correct statements of fact. If we are not careful, it seems to me that the "thinking" part of a good education, and indeed, a good continuing-education, may be lost in the rush to acquire yet more facts at the expense of nurturing the imagination for purposes of problem-solving, and cultivating a sixth-sense for sources of error. I raise this concern because it appears to me that many, if not perhaps most, undergraduate textbooks on geotechnical engineering address the subject of geosynthetics in a simply woeful manner, if indeed the subject of geosynthetics is addressed at all.

So where exactly does this leave us and, more to the point, leave future articles in this column on the subject of Geosynthetics? We can no longer claim geosynthetics are a new material in construction practice, nor can we overlook the fact that, when properly used in a relatively benign environment, like many other materials, they prove durable (Fig.4). We also have a very extensive body of information on geosynthetics, published in the form of conference papers, peer-reviewed journal articles, and specialist technical literature, all of which complements the many published standards for materials testing and the design guidance of regulatory agencies. Well, in answer to my own question, I would venture that it leaves us in a position to benefit from an informed synthesis of the available information, a synthesis that discriminates between what is really known and what has been merely believed (if I may paraphrase Terzaghi), and a synthesis that encourages thinking above a mere recital of facts (if I may also paraphrase Einstein).

Figure 4. Sea-trial on the durability of a moulded polyethylene surf kayak, Tofino, Canada by your erstwhile Editor.

In closing, I hope that you have enjoyed my gathering of thoughts for this opening article. I will certainly endeavour to bring much of the same spirit-of-engagement to future articles that will feature in the column – which I hope you will find interesting, informative and thought-provoking. Furthermore, I also hope that you find "adequate evidence" in support of any and all claims made on the subject of geosynthetics.

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GEO Regina 2014

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THESIS ABSTRACTS

Laboratory Characterization of Recycled and Warm Mix Asphalt for Enhanced Pavement Applications
Rouzbeh Ghabchi, The University of Oklahoma

Simulation of Failure Mechanisms around Underground Coal Mine Openings using Discrete Element Modelling
Fuqiang Gao, Simon Fraser University

Soil Restraints on Steel Buried Pipelines Crossing Active Seismic Faults
O. Manuel Monroy-Concha, University of British Columbia

Quantitative Risk Assessment of Natural and Cut Slopes: Measuring Uncertainty in the Estimated and Proposed Framework for Developing Risk Evaluation Criteria
Renato Macciotta, University of Alberta

High Stress Flow Behaviour and Constitutive Modeling of Dry Granular Materials
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Application of Dewatering Technologies in Production of Robust Non-Segregating Tailings
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Stabilization of Oil Sands Tailings Using Vacuum Consolidation
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Re-Visitation of Actual Evaporation Theories
Dat Tien Quoc Tran, University of Alberta

Understanding and Predicting Excavation Damage in Sedimentary Rocks: A Continuum Based Approach
Matthew A Perras, Queen's University

Durability of HDPE Geomembranes for Municipal Solid Waste Landfill Applications
Fady Badran Abdelaal, Queen's University

Performance of Geosynthetic Clay Liners in Cover, Subsurface Barrier, and Basal Liner Applications
Mohamed Said Hussein Hosney, Queen's University

Longevity of HDPE Geomembranes in Geoenvironmental Applications
A. M. R. Ewais, Queen's University

Interpretation of Pumping Tests in Confined Aquifers in the Case of Interferences
(Original title in French: Interprétation des essais de pompage dans les aquifères à nappe captive en cas d'interférences)
Simon Weber, Ecole Polytechnique

Laboratory Characterization of Recycled and Warm Mix Asphalt for Enhanced Pavement Applications

Rouzbeh Ghabchi

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Over the past two decades, many transportation agencies, asphalt producers, and pavement construction companies have taken major initiatives to implement green paving technologies. Saving energy during asphalt production and increased use of reclaimed asphalt materials are important elements of such initiatives. Consequently, there is a need for the characterization of the associated mixes for their performance and Mechanistic-Empirical Pavement Design Guide (M-EPDG) input parameters. The present study addresses two areas of green pavements: characterization of warm mix asphalt (WMA) and characterization of hot-mix asphalt (HMA) containing higher amounts of reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS) than normally used in Oklahoma. It was found that the WMA mixes have lower dynamic modulus (lower stiffness), reduced potential of low temperature cracking, lower fatigue life, and a higher rutting potential compared to their HMA counterparts. For mixes containing RAP and/or RAS, it was found that dynamic modulus increases and creep compliance reduces, with an increase in the amount of RAP and/or RAS. The fatigue life was found to increase with an increase in RAP content up to 25%, and to decrease when the RAP and/or RAS content exceeds 25%. Increased resistance to rutting and moisture-induced damage was observed, with an increase in the amount of RAP and/or RAS. The Surface Free Energy (SFE) study on WMA additives revealed that Sasobit®, Advera® and Evotherm® reduced the moisture susceptibility of the WMA, except when Sasobit® and Advera® were used with granite. Also, it was found that the resistance to moisture-induced damage increased with an increase in RAP content. Moreover, a new composite energy ratio parameter, based on the job-mix formula and SFE parameters, was proposed and shown to be capable of evaluating the moisture-induced damage potential of the tested asphalt mixes. The findings of this study are expected to be useful in understanding the effects of using different WMA technologies, RAP,

and RAS on the performance of asphalt mixes, and the moisture-induced damage mechanism. Important design input parameters, developed in this study, may be used for the local calibration of M-EPDG for new asphalt mixes.

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Simulation of Failure Mechanisms Around Underground Coal Mine Openings Using Discrete Element Modelling

Fuqiang Gao

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Roof failure has always been a major concern in underground coal mine roadways. Understanding the failure mechanism of roadway roofs is important for improving the safety of underground coal mines and reducing economic loss. In this research, a numerical modelling methodology named UDEC Trigon in 2D and 3DEC Trigon in 3D and based on a discrete element framework is developed to model rock mass behaviour, with a particular focus on the damage process including generation and propagation of fractures, and heavy dilation in the post-peak failure stage. Simulation of compression and Brazilian tests indicates that the methodology can capture different failure mechanisms under varying loading conditions. The UDEC Trigon is then used to investigate shear failure mechanism in roadway roofs. The results suggest that shear cracking plays a dominant role in the roof shear failure. Rock bolts can aid in ensuring the retention of more rock bridges which is critical to the roof stability. Cutter roof failure, which is a three-dimensional roadway rock failure mechanism, is studied using both PFC3D and 3DEC Trigon. The 3D models explicitly capture the cutter roof failure process and found that incorporating bedding planes and cross joints results in a more distinct cutter failure. Roadway squeezing failure mechanism is studied using the UDEC Trigon approach. The results show that the UDEC Trigon approach is able to reproduce the large dilation due to fracturing of rock mass surrounding a roadway under two distinct situations: high mining-induced stress and strength degradation of moisture sensitive rocks. In addition, the UDEC Trigon approach is used to simulate the progressive caving process of a longwall panel of coal. It is found that compressive shear failure, rather than tensile failure, is the dominant failure mechanism in the strata above the goaf. A further demonstration of the potential of UDEC Trigon in capturing roadway failure is presented as a case study of a roadway driven adjacent to unstable goaf in the Wuyang Coal Mine. The case study reveals that the combination of Synthetic Rock Mass (SRM) and UDEC Trigon is able to evaluate failure mechanisms in underground coal mines.

The insights gained from this research provide an improved understanding of typical failure mechanisms in underground coal mine roadways, guiding the design of panel layout and roadway support. The 3DEC Trigon method provides an alternative for simulating rock damage under real 3D conditions.

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Soil Restraints on Steel Buried Pipelines Crossing Active Seismic Faults

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The quantification and prediction of soil restraint on buried pipelines are essential for the design of pipeline systems crossing seismic faults, and in turn to reduce the risk of pipeline damage due to geotechnical earthquake hazards. Full-scale soil-pipe interaction tests were undertaken to better simulate the mobilization of soil restraints under controlled conditions and to provide insight on a number of currently unresolved technical issues that so far have been investigated only based on small-scale tests. In particular, an existing full-scale testing chamber was significantly modified to simulate pipeline breakout from its soil embedment on one side of a strike-slip fault and on the footwall side of a reverse fault in an effort to characterize lateral, combined axial and lateral, and vertical oblique soil restraints. The experimental system was also used to assess the effectiveness of reducing soil loads on pipelines using geotextiles. The following was noted: (1) approaches based on limit equilibrium reasonably well predict maximum values of lateral soil restraint for shallow pipelines backfilled with sand, with mixture of crushed gravel and sand, and with crushed limestone; (2) the lateral soil restraint on pipes in geotextile-lined trenches increased with increasing relative pipe displacement and could even be higher than the restraint without the geotextile lining. A procedure was developed to capture this behaviour; (3) experimental and numerical results for geotextile-lined trenches suggest that the shear resistance is not controlled solely by the geotextile interface; as such, there is no clear benefit in using geotextile-based mitigation measures for reducing soil loads; (4) the results from tests on combined axial and lateral soil restraints provided limited clarification on whether or not these soil restraints should be considered independent for fault crossing designs. This was due to the difficulty in selecting an axial soil restraint value to anchor existing soil restraint interaction relationships. No axial soil restraint tests were

conducted in this work; and (5) values for the maximum vertical oblique soil restraint diminish as the inclination of the angle of breakout of buried pipelines increases with respect to the horizontal.

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Quantitative Risk Assessment of Natural and Cut Slopes: Measuring Uncertainty in the Estimated and Proposed Framework for Developing Risk Evaluation Criteria

Renato Macciotta

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Understanding and limiting the risks inherent to natural and cut slopes are now recognized to be a priority in achieving an acceptable quality of life. Various methods of risk management that have been proposed in the last three decades have evolved into a general framework for landslide risk management. In particular, quantitative risk assessments can assist in communicating risks. They also provide a clear and systematic framework to analyze slope failure processes, from origin, to movement, to consequence; and the effect of different remedial works and strategies.

Some of the challenges and perceived limitations of quantitative risk assessments are related to the necessary input of expert opinion when estimating the risk levels in a quantitative manner. One objective of this work is the systematic assessment of the uncertainties in the estimated values of risk. Quantitative risk analyses are carried out for two case histories, where population of the analyses input parameters is done as probability distributions rather than fixed values. The probability distributions of the input parameters cover the range of values believed realistic for each input parameter. The risk is then estimated through a Monte Carlo simulation technique, and the outcome of the analysis is a probability distribution of the estimated risk. This methodology shows the potential for evaluating the uncertainties related to risk estimations.

The full potential of the risk management framework is best met with the establishment of risk evaluation criteria. The other objective of this work focuses on the development of risk evaluation criteria. It is not the intention of this work to develop case specific criteria, as this responsibility should lie with owners and regulators, but to propose a framework for developing the criteria, where the risk analyst takes an active role.

A summary of the state of practice for quantitative risk assessments is included as part of the thesis. The work on the evaluation of uncertainty related to the estimated risks and a proposed framework for developing risk evaluation criteria are then presented. The last two chapters of the thesis present a summary of the research results, conclusions and proposed future research.

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High Stress Flow Behaviour and Constitutive Modeling of Dry Granular Materials

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Landslides include various forms of geological mass movements such as falls, slides and flows under the force of gravity. Predictions of landslide kinematics and dynamics require knowledge of flow behavior and mathematical modeling. Research into the flow behavior of granular materials has revealed the existence of rate-dependent frictional behavior at high shear rates and void ratios as well as ratedependent frictional behavior as low shear rates and void ratios. However, the results of high stress shear experiments on small particles indicate that shear rate has no effect on flow behavior. Following this finding, most geotechnical analyses of landslides have considered mainly frictional flow behavior. Since the collisional behaviour of granular materials depends on particle inertia, both shear rate and particle mass (or particle density and diameter) are equally important in its occurrence. In this research, the relevance of ratedependent collisional behavior flow behavior at high stress was reinvestigated using simulation experiments on large size particles. The results indicate that ratedependent flow behavior is more likely to occur in rapidflow landslides involving large particles, such as debris avalanches and rock avalanches. The critical state framework which captures the frictional behavior was extended to capture ratedependent collisional behavior by adding shear rate as an additional state variable, based on the pioneering work of Campbell. The extended framework was used for flow classification, study of flow progress, and constitutive modeling. The effect of particle shape on granular flow behavior and the extended critical state framework was reviewed using simulation experiments.

Selected unified constitutive models proposed by Savage and Louge were evaluated using the extended critical state framework. In this research, new unified constitutive model is developed. The new model combines the frictional collisional stress contributions using weighting functions called stress coefficients to determine the total stress. The stress coefficients are interdependent and are determined using empirical equations and detailed theoretical analyses. The new model is used to predict the extended critical state

framework and implemented in the numerical model for inclined flows. The model performs well in capturing the extended framework and flow profiles of dense granular inclined flows on flat-frictional and rough bases.

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Application of Dewatering Technologies in Production of Robust Non-Segregating Tailings

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One of the current technologies used by the oil sands industry to reduce the volume of fluid fine tailings and create a dry landscape is production of CT (Composite Tailings) and NST (NonSegregating Tailings). CT and NST are engineered tailings streams obtained by recombination of fines (MFT or TT) and coarse tailings (sand) plus a chemical amendment. If produced on-spec, the main advantage of CT/NST would be its improved dewatering behavior and rapid release of relatively clear water during the hindered settling and selfweight consolidation, while a majority of the fine particles are entrapped within the matrix of its coarser fraction (sand).

Production of a robust CT/NST at a commercial scale has been a challenge for the industry. While CT/NST has been expected to be non-segregating when discharged, partial segregation and release and re-suspension of the fines has been observed following deposition. To produce a robust CT/NST and reduce its susceptibility to segregation, the yield stress of the carrier fluid (i.e. fines + water) must be enhanced. This can be achieved by increasing the solids content of CT/NST).

The present research reviewed the different methods of solid-liquid separation and experimentally investigated the possible application of some of these methods for improving the quality of CT/NST. A major part of this research was focused on dewatering of MFT and using it as a component for making CT/NST. A batch filtering centrifuge was utilized to dewater MFT samples received from three different operators and the major factors affecting the process of centrifugal filtration were investigated. The resultant dewatered MFT samples were mixed with a mixture of sand and pond water to produce CT/NST with higher solids content. The depositional behavior and robustness of the produced CT/NST samples were investigated using a flume apparatus. The flow profile and variations of solids content and SFR (Sand to Fines Ratio) were identified for each deposition test, also the yield stress of the CT/NST samples was evaluated using a strain-controlled viscometer and vane spindles. The results of this study indicate that using dewatered MFT promotes production or robust CT/NST streams achieved with lower dosage of chemical additives.

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Stabilization of Oil Sands Tailings Using Vacuum Consolidation

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This research is an experimental design and numerical analysis of a novel technique of the vacuum consolidation of Mature Fine Tailings (MFT). A meso-scale test was conducted to examine the feasibility of the MFT dewatering process. Vacuum consolidation involves applying a negative water pressure to the coke layer overlain by a saturated sand layer and underlain by MFT. Numerical modeling was conducted using the finite element program SoilVision to model the meso-scale experiment. Unsaturated behavior of Suncor coke, Suncor sand and MFT was investigated using Tempe pressure cell and capillary rise in an open tube prior to commencement of tests. Results indicate that a flux of water flows from the MFT layer into the coke layer, which is indicative of the MFT dewatering. The modeling analysis indicates that suction has little effect on the settlement while the overburden has the significant effect on consolidation. This thesis also illustrates the importance of recalibrating TDR probes for different materials. The three layered system testing of MFT, Suncor coke and Suncor sand indicates that applying suction causing MFT to dewater, can set the stage for a four layered system in which another layer of MFT is placed on top of the sand layer. The suction applied to the coke layer causes the double-drained MFT to dewater faster.

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Re-Visitation of Actual Evaporation Theories

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Evaporation from a deposit of thickened or paste tailings or cover system is increasingly becoming a big challenge for geotechnical engineers. Accurate calculation of the actual evaporation from a saturated-unsaturated surface requires

accurate specification of vapour pressure or relative humidity at ground surface. Flux of water at the soil boundary is also a boundary condition of moisture for the analysis of the problem of the flow of water at the ground surface.

The evaporation of water from water surface known as potential evaporation is quite well understood. However, the evaporation of water from a saturated-unsaturated surface known as actual evaporation needs to be re-evaluated. Several methods of estimating evaporation from unsaturated soil surfaces can be found in the literature. According to these methods, the actual rate of evaporation has been calculated on basis of the total suction or relative humidity predicted at the soil surfaces. Total suction not only depends on the character of the soil matrix but also on salt concentration in the pore-water. Currently, the accuracy of these methods can be questioned since they overestimate the actual rate of actual evaporation. To overcome this deficiency, either a variety of adjustment factors of total suction or modified relative humidity at the soil surface have been used to compute evaporative flux from the soil surface.

In this thesis's work, the fundamental physics of water transfer from a soil surface are reconsidered. The mechanism of mass and heat transfer and the derivation of the equation of evaporation are also re-visited. At the end, a theoretical model (i.e., new soil-atmosphere flux equation) is developed for prediction of evaporation rate from a soil surface using the concept of "surface resistance" to vapour water diffusion from the soil surface to atmosphere.

Soil suction and the corresponding water content at which the actual rate of evaporation begins to depart from the potential rate of evaporation during drying process are re-assessed using a series of laboratory data (i.e., thin soil section drying tests and soil column drying tests) collected from the research literature. It is observed that soil suction at which the actual rate of evaporation begins to reduce from potential one for soil columns may be different from thin soil sections. For example, the value of suction at evaporation-rate reduction point appears to be approximately 3,000 kPa for the thin soil sections regardless of the soil texture. However, it is observed that this suction appears to be in between the air-entry value and residual soil suction for the soil columns. As a result, a formula to determine soil suction at evaporation-rate reduction point is derived for soil columns. A new set of equations related to the coefficient of surface moisture availability, vapour pressure at soil surface and soil surface resistance is then proposed.

The effect of pore-water salinity on the evaporation rate from salinized soils was also considered. A function of osmotic suction which depends on initial salt content and volumetric water content at soil surface is derived for thin soil layers during drying process and verified using data of osmotic suction measured in the laboratory testing program.

Drying tests on thin soil layers as well as thick soil layers were conducted using the non-saline and salinized soils (i.e., the selected sand and silt). The obtained results were utilized to verify the proposed equations. Good agreement was generally found between the computed and measured rate of evaporation. In addition, these equations were also verified using the evaporative data collected from the research literature. The findings throughout this thesis will help solve the challenge of predicting evaporation from non-saline and salinize soil surfaces with which the geotechnical engineers are facing in many practical problems.

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Understanding and Predicting Excavation Damage in Sedimentary Rocks: A Continuum Based Approach

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The most widely accepted approach to long-term storage of nuclear waste is to construct a deep geological repository, where the geological environment acts as a natural barrier to radio nuclide migration. Sedimentary rocks, particularly argillaceous formations, are being investigated by many countries. Underground construction creates a damage zone around the excavation. The depth of the damage zone depends on the rock mass properties, the stress field, and the construction method. This research investigates the fracture development process in sedimentary rocks and evaluates continuum modelling methods to predict the depth of the damage zone.

At the laboratory scale, a complete classification system for samples of carbonate and siliciclastic rocks has been developed, with geotechnical considerations. Using this system, crack initiation (CI) shows the most uniform range in each class, particularly for mud rocks. Tensile strength was found to be higher for the Brazilian method than Direct method of testing. Brazilian reduction to Direct values was found to be rock type dependent.

Bedding was found to influence the excavation behavior; observed at the Niagara Tunnel Project and various excavations in the Quintner limestone in Switzerland. A conceptual damage development process and potential fracture networks in sedimentary rocks are used to summarize the understanding of excavation damage developed in this thesis.

Using a continuum modelling approach, a set of predictive damage depth curves were developed for different damage

zones. This approach was found to be most sensitive to the input tensile strength. Back analysis of the Niagara Tunnel Project, forward prediction of damage around a shaft in the Queenston Formation, and cut-off dimension and placement modelling are used to illustrate the importance of this research. This research has enhanced the understanding of excavation damage in sedimentary rocks and provided a methodology to predict the depth of the damage zones using a continuum approach.

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Durability of HDPE Geomembranes for Municipal Solid Waste Landfill Applications

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A series of laboratory accelerated immersion tests are used to examine the effects of different chemicals found in municipal solid waste leachate, geomembrane thickness, and incubation temperatures on the degradation of different high density polyethylene geomembranes. It was found that surfactant was the key leachate constituent affecting antioxidant depletion while salts accelerated degradation of the mechanical properties, especially stress crack resistance. Immersed in synthetic leachate, the time to nominal failure at 35°C was predicted to be 62% longer for the 2.5 mm, and 12% longer for the 2.0 mm, than for the 1.5 mm geomembrane tested. The antioxidant depletion in synthetic leachate and air at temperatures > 85°C was consistent with what would be expected from Arrhenius modeling based on data from lower temperatures (≤ 85°C). However, the early depletion rates in water incubation decreased with the increase of the temperature above 100°C. It was also found that at temperatures above 100°C, there was significant change in the polymer morphology that affected the stress crack resistance at early incubation times prior to polymer degradation.

Large-scale geosynthetic liner longevity simulators (GLLSs) which simulated field conditions were used to investigate the susceptibility of pre-aged high density polyethylene geomembranes to stress cracking and to evaluate the performance of geomembranes under a 150 mm sand protection layer. A pre-aged geomembrane with a 560 g/m^2 geotextile protection layer experienced brittle rupture at local gravel indentations. The time to failure was correlated to the incubation temperatures. The use of a sand protection layer not only delayed antioxidant depletion compared to that with a traditional geotextile protection but also substantially reduced the long-term tensile strains in the geomembrane below the allowable strain limits.

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Performance of Geosynthetic Clay Liners in Cover, Subsurface Barrier, and Basal Liner Applications

Mohamed Said Hussein Hosney

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The use of geosynthetic clay liners (GCLs) as (i) covers for arsenic-rich gold mine tailings and landfills, (ii) subsurface barrier for migration of hydrocarbons in the Arctic, and (iii) basal liner for sewage treatment lagoons were examined.

After 4 years in field and laboratory experiments, it was found that best cover configuration above gold mine tailings might include a layer of GCL with polymer-enhanced bentonite and a geofilm-coated carrier geotextile under ≥ 0.5 m of cover soil above the GCL. However, acceptable performance could be achieved with using a standard GCL with untreated bentonite provided that there is ≥ 0.7 m of cover soil.

When GCL samples were exhumed from an experimental landfill test cover after complete replacement of sodium in bentonite with divalent cations, it was observed that the higher the hydraulic head across the GCL and the larger the size of the needle-punched bundles, the higher the likelihood of preferential flow for liquids to occur though bundles. A key practical implication was that GCLs can perform effectively as a single hydraulic barrier in covers provided that the water head above the GCL kept low.

The hydraulic performance of a GCL in the Arctic was most affected by the location within the soil profile relative to the typical groundwater level with the highest increase in the hydraulic conductivity (by 1-4 orders of magnitude) for GCL below the water table. However, because the head required for jet fuel to pass through the GCL was higher than that present under field conditions, there was no evidence of jet fuel leakage through the barrier system.

The leakage through GCLs below concrete lined sewage treatment lagoons was within acceptable limits, in large part, due to the low interface transmissivity (in order of 10^{-11} to 10^{-13} m^2/s) between GCLs and the overlying poured concrete.

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Longevity of HDPE Geomembranes in Geoenvironmental Applications

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With sufficient time, a high density polyethylene geomembrane will degrade and lose its engineering properties until ruptures signal the end of its service-life. This thesis examines the longevity of nine different geomembranes; five of them were of different thickness manufactured from the same resin. The degradation of properties and times to failure are investigated for geomembranes: in immersion tests; as a part of a landfill composite liner; and, exposed to the elements. The different thermal and stress histories associated with manufacturing geomembranes of different thickness are shown to affect their morphological structure; consequently, their stress crack resistance.

When immersed in synthetic leachate, it was found that: (a) thicker geomembranes have a longer antioxidants depletion time but the effect of thickness decreases with temperature; (b) inferences of geomembrane's longevity based on its initial properties may be misleading because a geomembrane may chemically degrade despite the presence of a significant amount of antioxidants/stabilizers (as manifested by the measured high pressure oxidative induction time); and, (c) stress crack resistance may change before antioxidant depletion or chemical degradation takes place, likely, due to changes in geomembrane morphological structure with the maximum decrease being observed at 55ºC. Reductions also were measured for geomembrane immersed in air and water at 55ºC.

The geomembrane aged in a simulated landfill liner at 85ºC is shown to have service-life as little as three years with 30,000 to >2.0 million ruptures/hectare at failure. The investigated degradation in the index properties of exposed geomembranes to the elements at different climatological conditions showed that geomembranes may lose portion of its stress crack resistance due to changes in the morphological structure of the geomembrane despite the presence of significant antioxidants/stabilizers and/or no evidence of chemical ageing. Nevertheless, exposed geomembranes may not crack although its stress crack resistance had dropped to 70 hours.

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Interpretation of Pumping Tests in Confined Aquifers in the Case of Interferences

(Original title in French: **Interprétation des essais de pompage dans les aquifères à nappe captive en cas d'interférences**)

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The influence of an active well located in the neighborhood of the tested well is often mistakenly neglected when interpreting pumping test data. This thesis presents analytical methods to determine the hydraulic parameters of a porous confined aquifer from data monitored during a pumping test influenced by the interferences of one or several neighboring wells. These methods are easy to use, since they are similar to the most commonly used methods in absence of interference.

The interpretation of pumping test data influenced by a neighboring well has first been studied in the simple case of a homogeneous and isotropic aquifer of infinite extension, before combining the proposed methods to existing methods developed for the cases without interference to take into account recovery, anisotropy or a partial boundary dividing two areas of different hydraulic parameters but with a similar diffusivity. Despite the simple proposed methods, it is still difficult to take into account the interfering wells if the pumping test is conducted in the vicinity of the aquifer boundaries.

The drawdown resulting from the interfering well being dependent on many parameters, it has not been possible to establish an easy criterion to determine a priori whether an interfering well influence will be negligible. Nevertheless, equations have been proposed for this purpose, but further studies on phenomena influencing the early times will have to be conducted for these equations to be used.

Other useful results, not related to the well interference problem but still relevant, have also been obtained: those relative to the influence of the position of the three monitoring wells that are used to interpret the pumping test data in an anisotropic aquifer; and those relative to the influence of the deviation from the diffusivity equality hypothesis in an aquifer divided in two areas of different hydraulic parameters by a partial boundary.

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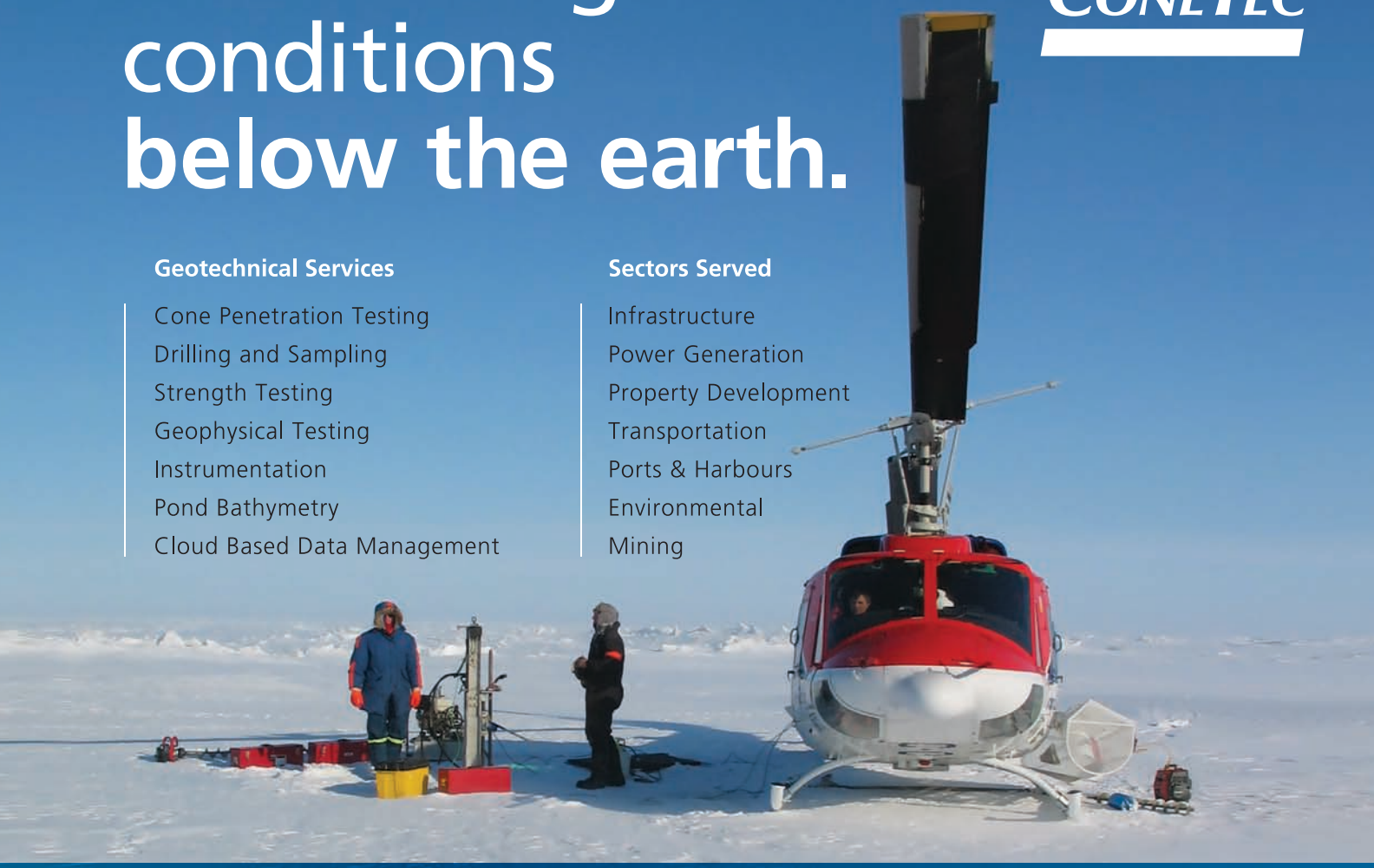

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