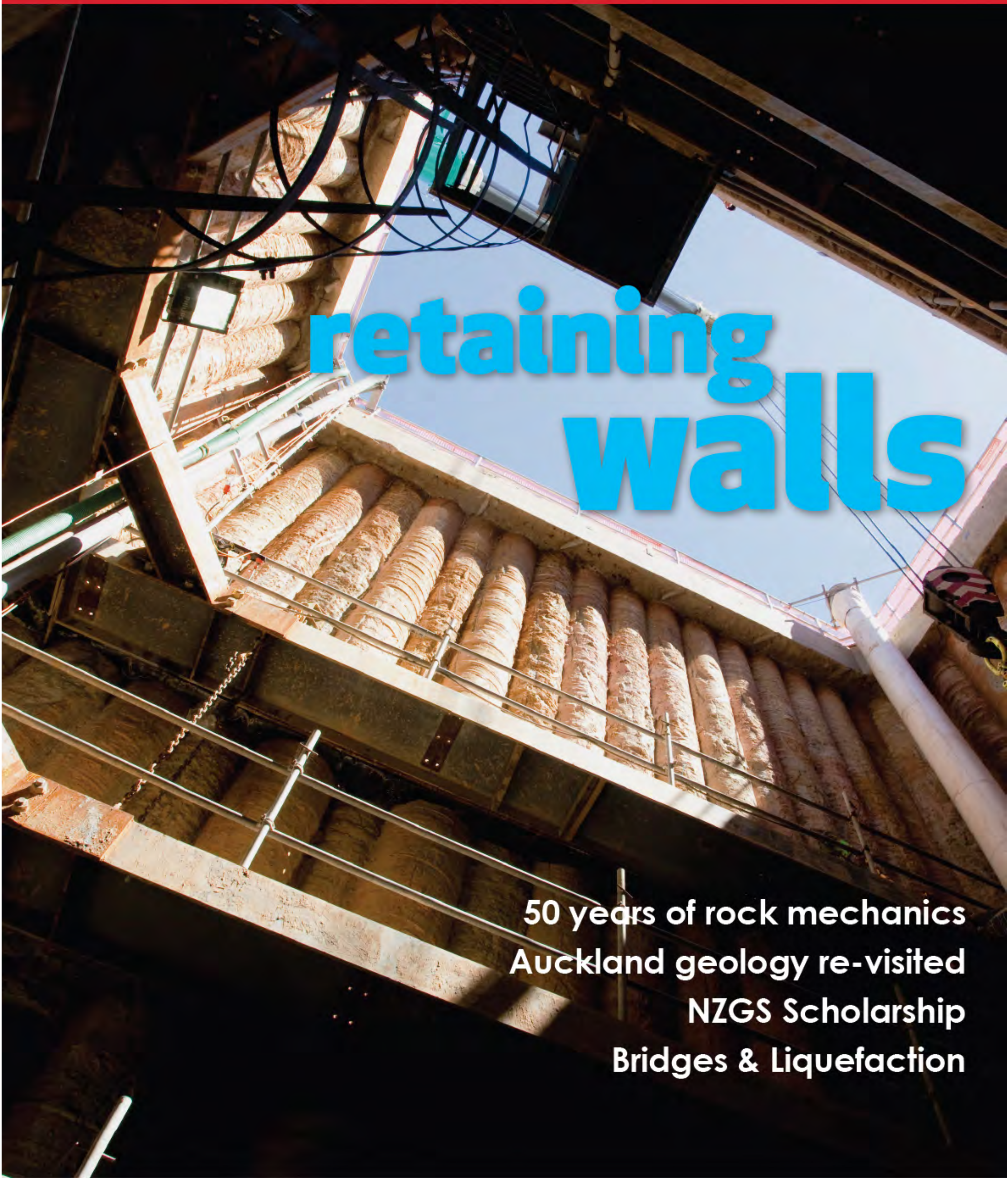
NEW ZEALAND GEOTECHNICAL SOCIETY INC

DECEMBER 2011 issue 82

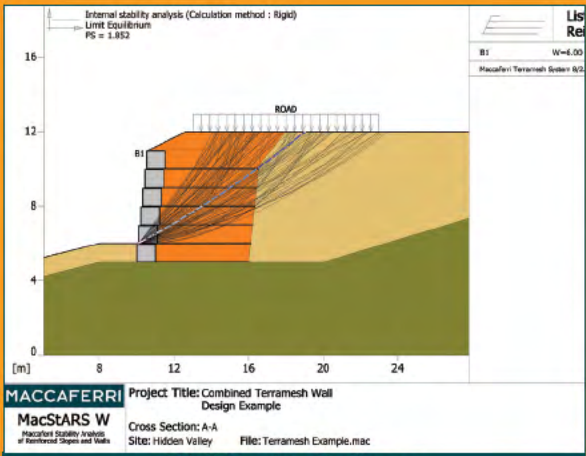
NZ GEOMECHANICS NEWS

Newsletter of the New Zealand Geotechnical Society Inc.

ISSN 0111–6851

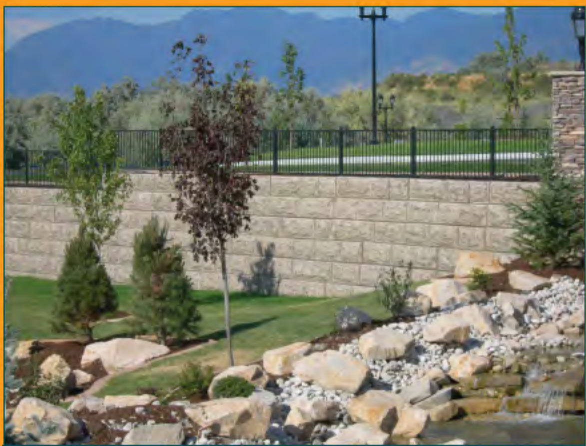


Retaining Wall Solutions



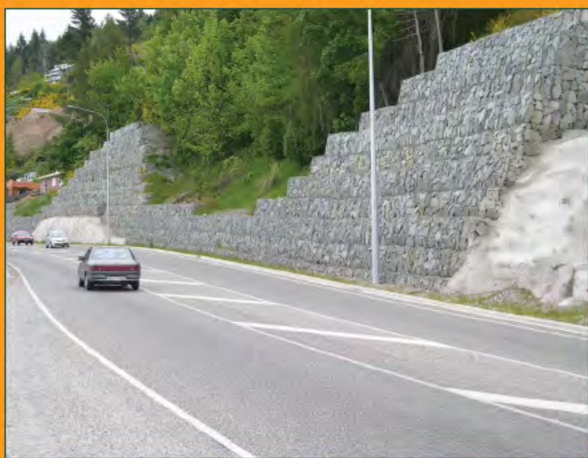
Wall Design Software


Terramesh Wall


Stone Strong Wall


Keystone Wall


Concrete Panel Wall


Gabion Wall

MACCAFERRI

0800 60 60 20

www.maccaferri.co.nz

NEW ZEALAND GEOMECHANICS NEWS

CONTENTS

DECEMBER 2011, ISSUE 82

Cover image: Pipe-jacking shaft, Roscommon Rd, Auckland. The photographer employed by Brian Perry Civil was Dave Olsen.

CHAIRMAN'S CORNER

WELCOME TO THIS end-of-year issue of NZ Geomechanics News. The end of 2011 has appeared on the horizon with unseemly haste and, along with most others I'm sure, it has taken me by surprise. The pressures of consulting engineering practice are such these days that time is squeezed, not the least also for your committee. I would like to take this opportunity therefore to acknowledge the efforts of the committee and other society members who have taken on roles and responsibilities through the year. The regional coordinators have been especially busy, which is very much appreciated.

As has now become the norm, the editors have compiled an impressive and interesting edition. The scale of the publication is such that the time is now fast approaching when the title 'Newsletter' will be a misnomer and not do justice to the content. A recent editorial (Geomechanics News Issue 81) canvassed opinion not only on this aspect, but also on whether the main title change to NZ Geotechnical News. While consensus formed around retaining the title 'Geomechanics News' to maintain historical links I believe that the newsletter at least now qualifies for the title 'magazine' or perhaps 'bulletin'. As always, member's views are sought and welcome. The committee will discuss options and make a recommendation prior to publication of the next edition.

I would like to welcome Dr Marc-Andre Brideau as the New Zealand liaison for the ISRM, taking over from John St George, who ably filled that role over the past four years. The current International Vice President for the region is David Beck from Australia. Marc-Andre lectures in engineering geology at Auckland University, a position that Warwick Prebble had made his own for so many years.

Prof Peter Taylor and Dr Roy Northey

This year marked the passing of two of the Society's founding members, Prof Peter Taylor and Dr Roy Northey. Both were members of the first committee of the New Zealand National Society for Soil Mechanics and Foundation Engineering, an organisation formed in 1958 to provide a New Zealand 'home' for what was later to become geotechnical engineering. They went on to have long, distinguished, and at times pioneering, careers at the forefront of the development of geotechnical engineering in New Zealand. An obituary for Prof Taylor prepared by Prof Mick Pender is included in this issue. An obituary for Dr Northey will be in the next issue of Geomechanics News. I would like to record the appreciation of the NZGS for the contributions of Prof Taylor and Dr Northey and extend the committee's sympathies to their families, colleagues and friends.

David is an engineering geologist at AECOM NZ (formerly Maunsell and prior to that, Worley Consultants). He has a masters degree in Earth Science from the University of Waikato and has been practicing in the fields of engineering geology and geotechnical and civil engineering for 30 years.

Projects have taken him to many out-of-the-way places in the Asia-Pacific region, as well as the length and breadth of New Zealand. Particular areas of interest are the volcanic geology of the North Island and Indonesia, natural hazard assessment, and civil engineering projects such as hydroelectric and transportation developments, particularly the early stages of site reconnaissance and feasibility assessment.

Geomechanics and Rankine Lectures

Dave Bell presented the 2011 Geomechanics Lecture at venues around the country commencing in late August and finishing in Christchurch in October at a joint meeting that included presentation of the Rankine Lecture by Prof Tom O'Rourke. Dave Bell's lecture was well received and offered a timely reminder of the often small elements of engineering geology practice that lead to a clearer understanding of how the ground behaves – not to mention of course, keeping geology firmly to the fore in geotechnical engineering. Dave will present his lecture at next year's ANZ conference in Melbourne.

Prof Tom O'Rourke presented the 2009 BGA Rankine Lecture in Auckland and Christchurch, in association with the local branch of the Institution of Civil Engineers. Presentation of the lecture had been in planning for a considerable period, with a number of false starts, but eventually the stars were aligned and very successful and well attended lectures resulted. His presentation, 'Geohazards and large geographically distributed systems,' included reference to both the Christchurch and Japan earthquakes and some of the consequences of those seismic events for the performance and survival of critical infrastructure.

Awards

The annual Student Awards were presented in Auckland in October. Four entries were received, three from the North Island and one from the South Island, the South Island candidate flying to Auckland for a joint north/south presentation. Standards were high and, as usual, the judges struggled to separate the candidates. Congratulations to the two winners, Saskia de Vilder and Sam Harris for the following presentations.

- **Saskia de Vilder:** An Engineering Geological Investigation of the Tutira Landslide Dam, Hawke's Bay, New Zealand.
- **Sam Harris:** A Site Specific Warning System for Rainfall Induced Landslides.

NZGS Scholarship

The inaugural NZGS Scholarship was awarded this year to Mohammad Jawad Arefi to complete his doctoral studies at Canterbury University. Jawad's research area is the effects of nonlinearity and uncertainty in site response analysis. A subcommittee chaired by Dr CY Chin prepared a short list of four from the many applicants and each made an oral presentation. The subcommittee was impressed with the standard of applicants, but were unanimous in selecting Jawad, noting particularly the relevance of the aims of his research.

Conferences

The 2012 YGP conference has now been scheduled for the days preceding the ANZ conference next July in Melbourne. The dates, still provisional, are Wednesday 11 to Saturday 14 July 2012. Details from the AGS organisers will be posted on the website as they become available. Direct enquiries can be made to Erica Cammack, our YGP representative.

Seismic Guidelines

With a year having passed since the first of the devastating earthquakes in Canterbury, the subsequent investigations and enquiries have highlighted a need to revise Module 1 of the NZGS publication 'Geotechnical earthquake engineering practice' (the Seismic Guidelines). A proposal has been received from the subcommittee that prepared the Guidelines, with general aims to:

- Update the seismic hazard section to reflect changes in the GNS approach to hazard (specifically PGA and magnitude weighting) and provide additional guidance as necessary
- Update the liquefaction sections to incorporate lessons from the Christchurch earthquakes
- Add (non-residential, engineered) foundation design section to give more guidance on earthquake resistant design of foundations

The subcommittee is being lead by Kevin McManus and the aim is to complete the revision by April next year.

The second module of the guidelines (retaining walls) is currently being prepared by a subcommittee led by Dr Chin.

Season's greetings and I hope you all manage capture a sufficiently long and stress-free holiday break.

David Burns
Chair, NZGS
David.burns@aecom.com

EDITORIAL

THE CLOSE OF 2011 ends a tough year for New Zealand. The CBD of our second largest city is still effectively off-limits due to the Christchurch Earthquakes, our worst ever natural disaster. The word "Geotechnical" has come into everyday useage by politicians from the PM down and geotechnical practitioners are playing a leading role in shaping the rebuild.

It's timely that prior to the Christchurch Earthquakes a NZGS sub-committee had begun work on a set of guidelines for the seismic design of retaining walls. This work, headed by NZGS Past-Chair CY Chin, is now well underway and when completed these guidelines will be available for incorporation into the numerous replacement retaining walls that will be required in Christchurch. With this in mind we have canvassed NZGS members for examples of various types of retaining walls and ground retention they have been involved with, and the results are in this issue – along with technical notes on some of the design features and challenges associated.

Several very interesting technical papers are included in this edition, including; new insights on the geology of Auckland, a review of the development of modern rock mechanics, and

Paul is an Engineering Geologist and Hydrogeologist at URS Auckland. He studied Engineering Geology at Auckland University and after completing his MSc in 1993 worked for Earthtech Consulting for 3 years. Since then he has worked for URS, including 6 years in their Santa Ana, California office. He currently leads the URS Auckland Geotechnical Team.

Hamish is a Geotechnical Engineer with Tonkin & Taylor Ltd in Auckland. He completed his Civil Engineering degree at The University of Auckland. Following valuable construction experience working for Fletcher Construction on the later stages of the second Manapouri tailrace tunnel, he has spent the past seven years working as a geotechnical engineer in the Tonkin & Taylor Auckland office. This has included a wide variety of projects with a focus on retaining wall design and landslip assessment and remediation.

seismic considerations for the design of bridge foundations in liquefiable soils. This issue also recognises the up and coming talent in the NZ geotechnical community with the award of the inaugural NZGS Scholarship to Jawed Arefi, and details of NZGS Student Awards.

Inside, the winner of the annual photo competition is also announced and there are a couple of items to keep the brain-engaged over the holidays - a geotech teaser and crossword to complete.

As we look ahead into early 2012, I know that NZGS branch activities are already being planned and visiting lecturers pencilled in – details will follow from your branch coordinators and will be listed on the NZGS website. Have a great Christmas.

Paul Salter, NZ Geomechanics News Co-editor
paul.salter@urs.com

NOW THAT THE World Cup and the Election are behind us, I hope that you can all manage to find a spare moment to read this interesting and varied issue of 'GeoNews' before getting too wrapped up in the Christmas season.

In his article titled 'Geology of the Auckland Urban Area,' Kevin Hind makes the interesting observation that our collective knowledge of the geology of the Auckland urban area is not always advanced in any meaningful way by the thousands of geotechnical investigations undertaken across the City. A recent project has provided a rare opportunity to develop a geological model across a large part of central Auckland. Kevin uses this information to develop a fuller understanding of the Manukau Fault which challenges the lack of information shown on existing geological maps.

A new initiative titled 'Academic News' is being launched in this issue and aims to provide a communication link between tertiary institutions and practitioners. This article includes information from tertiary institutions around the country and provides a quick and easy update on study options, current research and general news.

This issue also marks the passing of Peter Taylor with an obituary prepared by Mick Pender (and others).

Enjoy the December Issue and Merry Christmas from the NZ Geomechanics News Team!

Hamish Maclean, NZ Geomechanics News Co-editor
HMaclean@tonkin.co.nz

EDITORIAL POLICY

NZ Geomechanics News is a biannual newsletter issued to members of the NZ Geotechnical Society Inc. It is designed to keep members in touch with matters of interest within the geo-professions both locally and internationally. The statements made or opinions expressed do not necessarily reflect the views of the New Zealand Geotechnical Society Inc. The editorial team are happy to receive submissions of any sort for future editions of *NZ Geomechanics News*. The following comments are offered to assist potential contributors. Technical contributions can include any of the following:

- technical papers which may, but need not necessarily be, of a standard which would be required by international journals and conferences
- technical notes
- comments on papers published in *NZ Geomechanics News*
- descriptions of geotechnical projects of special interest

General articles for publication may include:

- letters to the NZ Geotechnical Society
- letters to the Editor
- articles and news of personalities
- news of current projects
- industry news

Submission of text material in Microsoft Word is encouraged, particularly via email to the editor or on CD. We can receive and handle file types in most formats. Contact us if you have a query about format or content.

Diagrams and tables should be of a size and quality appropriate for direct reproduction. Photographs should be good contrast, black and white gloss prints or high resolution digital images. Diagrams and photos should be supplied with the article, but also saved seperately as 300 dpi .jpgs. Articles need to be set up so that they can be reproduced in black and white, as colour is limited.

NZ Geomechanics News is a newsletter for Society members and articles and papers are not necessarily refereed. Authors and other contributors must be responsible for the integrity of their material and for permission to publish. Letters to the Editor about articles and papers submitted by members will be forwarded to the contributing member for a right of reply.

Persons interested in applying for membership of the Society are invited to complete the application form in the back of the newsletter. Members of the Society are required to affiliate to at least one International Society and the rates are included with the membership information details.

LETTERS TO THE EDITOR

22nd October 2011

The Editor
NZ Geomechanics News

After completing (I thought) a Geotechnical Report on a proposed house site, my attention was drawn to the District Council's *Engineering Standards* which required sites on (or near) sloping ground, to have a Factor of Safety of at least 2.0.

In the June 2010 edition of *NZ Geomechanics News* I showed that the assumption of a "worst case scenario" with the water table at the ground surface was unwarranted. Groundwater head at depth "d" could be significantly larger than "d" and reduce effective stresses (and therefore FS) very significantly.

In the following, December 2010, edition of NZ Geomechanics News, Laurie Wesley illustrated this in his answer to a "brain-teaser" he had set re the flow net in a uniform soil with a 45 degree cut face. He showed that on that slope the conventional assumption led to an FS value "in error by about 50%" for a reason I included in my analysis of a slope in natural layered ground. The error in Laurie's uniform soil with a 45 degree slope was on the unsafe side, so a conventional calculation would give FS = 2.0 when it was actually about 1.0, ie the slope was on the point of failure. The drainpipe effect I included would introduce error in addition to that.

Both papers illustrated a very serious flaw in the conventional assumption re groundwater pressures/heads within sloping ground, a flaw which becomes apparent the moment a flow net is drawn for groundwater flow within a slope. In my paper I had shown that this was exacerbated in layered ground, - which is the usual situation in natural slopes.

The error will be reflected in misleading values of cohesion and internal friction deduced from back-analysis of slope failures.

Both papers showed *inter alia* that conventional slope stability analyses are unsound under rainfall conditions, and indeed under virtually any conditions where the pore pressure heads in the vicinity of likely failure surfaces have not been measured.

If I were to provide the District Council with a conventional slope stability calculation, the progress of my client's application for Subdivision and Building Consents could progress freely. **BUT I would be knowingly providing information which I knew to be flawed and probably misleading. For that I would deserve to be struck off the roll of Chartered Professional Engineers.**

If another CPEng were to provide such a calculation he/she could be criticised for not keeping up with the literature as published in *NZ Geomechanics News*.

District Councils should delete the requirement for such calculations from their Engineering Standards and professional engineers should stop doing them.

Yours faithfully

John Hawley, CPEng

THE SECRETARY'S NEWS

A DAY IN the life of the NZGS Management Secretary – This roll keeps me hopping from task to task: from liaising with members, organising events, keeping tabs on the committee, sorting out publications, directing information flow and always emails, emails, emails… Here's an example:

To: secretary@nzgs.org
From: Steve Branch-Guy
Hi Amanda, Can you please advertise this event for us? Thanks, Steve

To: Steve Branch-Guy
From: secretary@nzgs.org
Steve, yes, of course. Would you like it advertised to all of NZGS or just Wellington? I'll put it on the website too, if you could let me know who the contact is for the event and all the normal details about venue and date, speaker and topic. Thanks, Amanda

To: secretary@nzgs.org
From: Steve Branch-Guy
Amanda, it's all on the attached flyer. Steve.

To: Steve Branch-Guy
From: secretary@nzgs.org
Oh, there was no attachment Steve. Could you please send it again? Amanda

To: secretary@nzgs.org
From: Steve Branch-Guy
Sorry, here it is.

To: Steve Branch-Guy
From: secretary@nzgs.org
That's fantastic. I see the date on the flyer doesn't match the date on your original email– which date is the event actually being held? Amanda

To: secretary@nzgs.org
From: Steve Branch-Guy
Oh, sorry, I'm just checking with the other Branch Coordinators, one of them is friends with the speaker, who is overseas, and they are overseas too, and we'll let you know as soon as we can. Steve

To: Steve Branch-Guy
From: secretary@nzgs.org
Lovely, just check once you're sure of the date that your venue is still available for the time you want and you've re-ordered your refeshments, booked the live streaming, secured your sponsor, chosen a contact and someone to introduce and thank the speaker on the night, finalised your flyer (parking suggestions are helpful), and then I can turn it into a PDF for you and we'll be ready to advertise. Do you still want it on the website, via email, and possibly to IPENZ, SESOC and NZSEE too? I will need approvals from their Chairs before advertising to their members. Do you want to know how many people may attend? We can add an RSVP if you would like. Does the speaker have a short biography we could add to the flyer, and perhaps a photo or two would make it look better? They'd need to be hi-res though. Amanda

To: secretary@nzgs.org
From: Steve Branch-Guy
Ugh, uummmm, ohhhh – I think maybe I should hand this over to you....is there any chance you could do all that?

To: Steve Branch-Guy
From: secretary@nzgs.org
Sure Steve, bye.

Names, places and actual events have been altered to hide the true identity or event that may, or may not, have taken place. No Branch Coordinator was intended to be harmed in the retelling of this story. Best wishes to all my Branch Coordinator friends who do an amazing job and in reality do a lot of this themselves!

Please continue to send information about events and conferences, change of contact details and branch news to put on the website and send to members.

New Members

Welcome to the following new members since May 2011:

Auckland: Julie Zou, Moru Jia, Saskia de Vilder, Megan Baddiley, Alicia Newton, Ben Roy, Aidan Thorpe, Angus Newsam, Sam Broom, Doug Ramsay, Mark Hill, Tim Hodgson, Conrad Jenkins, John Leeves, Max McLean, Dominic Hollands, Marcus Gibson, Chris Ritchie, Dennis Koumoutsakos, Elby Tang, James Botting, Charles Sweeney, Alastair Blackler, Sharon Hunter-Smith

Hamilton: Pat Wardlaw, Sam Harris, Natasha Jokhan, Alex Naylor, Glenn Gill

New Plymouth: Daniel Budd

Wellington: Emma Beech, Alan Wightman, Karly Shields, TC Teoh, Christopher Robson, Gemma Hayes, Martin Wilson, Paolo Re, Fred Harris

Dunedin: Katherine Yates

Christchurch: Mark Sjoberg, Shelley Nankivell, Jessie Herbert, Simon Holmes, Sally Lochhead, Lee Buhagiar, Rebecca Hawksworth

Timaru: Alberto Silva

Australia: Lee Tasker, Trishn Nand

France: Sarah Chauvin **Singapore:** Mathava Dineshharan

Amanda Blakey
Management Secretary
secretary@nzgs.co.nz

INTERNATIONAL SOCIETY REPORTS

International Association for Engineering Geology and the Environment

Report from IAEG Executive and Council Meetings held 04 - 05 September 2011, Moscow

Above: Convenors of EngeoPro 2011, Olga Eremina and Victor Osipov with the President of the IAEG, Carlos Delgado and Secretary General of the IAEG, Faquan Wu

Above: Ann Williams delivering a key-note address

THE NEW PRESIDENT of the IAEG, Carlos Delgado, identified membership as a key issue for IAEG. Fundamental to increasing membership are:

- Increasing exposure to and attractiveness of IAEG to young engineering geologists with an aim to initiate membership while at university that is continued into professional life
- An effective interactive website; the new website is now operational and functionality will continue to be increased; it is proposed that in the future output from the Commissions will be accessible to members only
- The Bulletin. Citation index for the Bull. IAEG has improved since last year and this needs to continue. The Bulletin is available at a cost of 400 Euros to non-members or 37 Euros to members! A very good reason to be an IAEG member in itself.

Key outcomes from the FEDIGS meeting of May 15 2011 in Rome are:

- IGS joined (International Geotextile Society)
- Each member society will maintain its own identity and independence
- Maintain a nominative president
- Objectives to co-ordinate scientific and technical activities of overlapping interest
- Associated expenses will be kept to a minimum; there will be only an annual meeting
- No annual fee charged
- Communication of conference and symposia schedules
- Maintain only 3 JTCs (1, 2 and 3)
- FEDIGS will be open to other international societies
- Founding members have the right of veto in the event an issue arises with potentially negative consequences for any of the founding members.

Other matters:

JTC3 – Education in Engineering Geology

- Prof Keith Turner (USA) has agreed to re-establish JTC3 and take the role of Chair.

International Association of Hydro Research – Dr Christopher George

- Identify opportunities for cross-collaboration

ISSMGE has proposed a name change to ISGE International Society for Geotechnical Engineering. Such a name would encompass IAEG, ISRM and ISSMGE and was therefore opposed by IAEG. Opposition was widespread and the name change has not been carried through.

A new IAEG National Group has been established in Haiti (SOHAGIE).

The Secretary General role has been transferred from Paris to Beijing and archives of IAEG have now also been successfully transferred.

New Award

A new award has been established in memory of Marcel Arnould, which will be made to a person with outstanding services to IAEG. The inaugural award will be made at the next IAEG Congress to be held in Torino, September 2014. The Hans Cloos Medal criteria will be altered slightly to focus fully on outstanding scientific/ technical contribution and remove the requirement for significant contribution to IAEG.

The next IAEG Executive and Council meetings will be held at Banff, Canada on the occasion of the joint International Landslide Conference and 2nd North American Landslide Conference in June 2012.

Website

- A group has been established to set up and maintain the website, led by Giorgio Lollino (Italy).
- There is now the ability for direct management by National Group Presidents/Secretaries and commission Chairs to allow updating of address lists, material etc.
- The homepage will highlight a National Group and its significant outputs/ work/ characterisation/ events/ etcetera each month; data as supplied by the National Group
- All members can subscribe; outputs from the Commissions will be available only to members (currently these are available to all, so take a quick look!)
- Young Professionals can upload their CVs to the website if seeking work/ research positions
- Periodically rolling head page available for companies to advertise
- The Executive has established a sub-committee to identify how the website will continue to be developed.

Commissions

There are currently 21 active Commissions. A Technical Overview Committee (TOC) has been established to monitor and support the Commissions. Outputs from those commissions that have completed their work will be available on the website along with outputs of current commissions.

IAEG Awards

Hans Cloos Medal

The recipient of the Hans Cloos medal should be a person of international repute who has made a major contribution to engineering geology in his/her written papers or to the development of engineering geology and/or the IAEG in their own area. Dr Warwick Prebble has made an outstanding contribution to Engineering Geology and to the IAEG in Australasia.

The NZGS Management committee nominated Warwick for the Hans Cloos Medal. Nominees included David Cruden (Canada), Resat Ulusay (Turkey) and Victor Osipov (Russia). Dr Osipov was selected as the recipient of the award for 2012.

Richard Wolters Prize

The Richard Wolters Prize has been awarded biannually since 1986 to commemorate the life and work of Dr Richard Wolters, his significant achievements in the advancement of engineering geology and his important role in the development of the IAEG. The Richard Wolters Prize specifically recognises meritorious scientific achievement by a younger member of the engineering geology profession. The candidates should be members of IAEG and less than 40 years of age on 1st January 2012.

Submissions are being called for this prestigious prize and the recipient will contest the award at the joint International Landslide Conference and 2nd North American Landslide Conference in Banff, June 2012.

Ann Williams
IAEG Vice President, Australasia

International Society of Soil Mechanics and Geotechnical Engineering Australiasia VP Report: September 2011

ONE OF THE challenges facing any large professional organisation or learned society – especially one that is truly international, such as the ISSMGE – is effective communications. For the ISSMGE the challenge is to provide information that members will find useful or informative in a timely and accessible manner. Members of the ISSMGE have always shared information and expertise between each other. Traditionally the way in which this has been achieved has been though published articles, lectures and conferences. However, increasingly ISSMGE members are using the internet and other social media to exchange ideas, information and expertise related to their professional or academic activities. For some time the ISSMGE Board has been considering how communications with and between members can be enhanced. The Innovation and Development Committee (IDC) – which has as one of its tasks the development of ways to enhance the value of the ISSMGE web site as a technical resource worldwide - has been investigating how this might done. This has led to a decision to enhance the ISSMGE website by increasing its functionality and to facilitate improved networking between members through a formal linkup with Geoengineer.org. In the coming months this will lead to the redesign of the ISSMGE website and the development of a "user-friendly" web based platform, which will be known as "GeoWorld". This platform will permit members to share professional information, identify and connect with colleagues, link to technical committees and professional organisations, become associated with companies and form groups to support their professional activities.

The IDC have also suggested that the ISSMGE should host webinars as an additional means for disseminating new research and best industrial practice to its members. The Board has accepted this proposal and the ISSMGE will be hosting a number of webinars each year presented by leading practitioners and academics in soil mechanics and geotechnical engineering. To cover the costs an access charge of US$200 will be made for each computer connecting to the webinar. The concern was raised at the Board meeting that, because of the difficulty in arranging the presentations at suitable time for different time zones, there would be difficulty in ensuring ISSMGE members in all parts of the world would be able to participate equally in live webinars. It is intended, therefore, to address this issue by each webinar being presented at least twice on the day of its broadcast. In addition, all webinars will be recorded and available for purchase (at a cost yet to be decided). The inaugural webinar was presented by the ISSMGE President, Professor Jean-Louis Briand on 23 August 2011 on the topic of Bridge Scour and Levee Erosion. On this occasion no charge was made for access and it attracted some 80 registrations.

Recent natural disasters in our region and elsewhere around the world have thrown the spotlight on to geotechnical engineering. Colleagues have generally responded very well to the requirement to inform the public and interact with the media regarding the geotechnical implications of these events. However, as a general rule as a profession we do not tend to promote the excellent and important work that we do when not responding to disasters. The ISSMGE Board has discussed how we might communicate better with the public and the media on a more frequent basis and this has resulted in the formation of the ISSMGE Public Relations Committee. In his 665 Days Progress Report the President requested that members let him know if they would be interested in working on or with this committee. Details of the proposed work for the committee can be found on the ISSMGE website.

Compared to other similar organisations the view has been expressed that the ISSMGE does not recognise to as great an extent the professional and academic achievements or service of its members. With the support of the Board, at the end of 2010 the President formed a short term awards committee to investigate this view and, if necessary, to make suggestions for new awards. The outcome of this process is that the Board has approved suggestions for the following new ISSMGE awards:

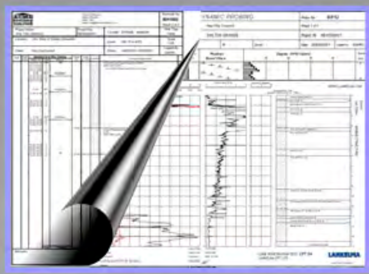
- The ISSMGE Outstanding Technical Committee Award
- The ISSMGE Outstanding Geotechnical Project Award
- The ISSMGE Outstanding Innovator Award
- The ISSMGE Outstanding Member Society Award
- The ISSMGE Outstanding Paper Award (International Journal of Geoengineering Case Histories)

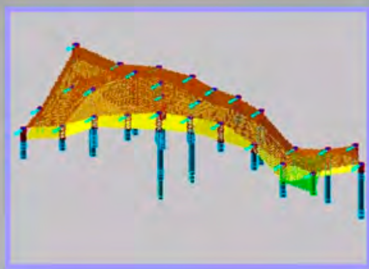
Details of the process for nominations for these awards will be issued once these have been formulated and agreed by the Board. The first set of these new awards will be presented in Paris in 2013 at the International Conference on Soil Mechanics and Geotechnical Engineering.

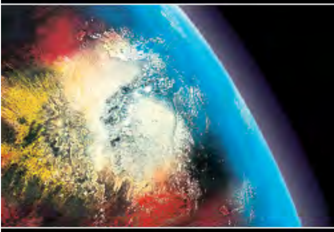
Since taking office the President has encouraged members of ISSMGE Technical Committees (TC) to institute a lecture named after someone who is recognised internationally for making a major contribution to developing the field in the area of a particular TC. This is not only to recognise the contributions of the distinguished person after whom the lecture is named but also as part of the same policy to recognise the contributions of current leaders in the field of geotechnical engineering. Eight such named lectures have now been proposed by TCs and approved by the Board. Nominations for these lectures are open to all members of ISSMGE and should be sent to the chair of the corresponding TC.

As you will have read in this and my previous reports, since his election in 2009, the President of ISSMGE has together with the Board introduced a number of new initiatives. The ISSMGE Council is the governing body of the Society and any changes to the Statutes and Bylaws of the Society proposed by the Board have to be approved by this body. Member Societies can also bring proposals directly to Council for discussion. At the forthcoming meeting of Council, which will be taking place in Toronto on 2 October 2011, there are two major proposals about which ISSMGE members in Australia and New Zealand might have a view. The first is a proposal from the USA, Mexico and Japan Member Societies to Change the name of the Society from "International Society for Soil Mechanics and Geotechnical Engineering" to "International Society for Geotechnical Engineering". The second is a proposal from the Member Society of Greece to Change of name of the quadrennial international conference from "International Conference of Soil Mechanics and Geotechnical Engineering" (ICSMGE) to "World Conference on Soil Mechanics and Geotechnical Engineering" (WCSMGE). If you have views on these new proposals that you would like to be considered please contact the AGS or NZGS – which will both be represented at the ISSMGE Council meeting – or send them directly to me.

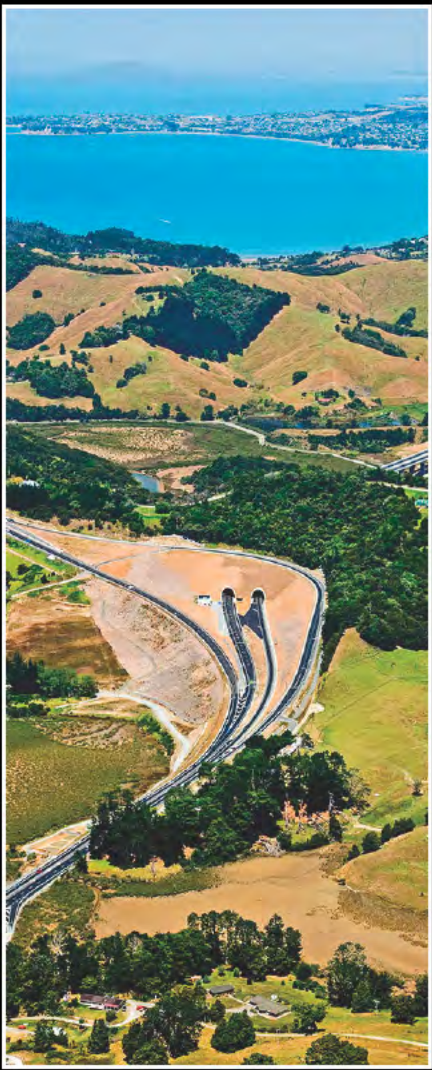
Professor Michael C.R. Davies
Vice-President for Australasia and First Vice-President
ISSMGE

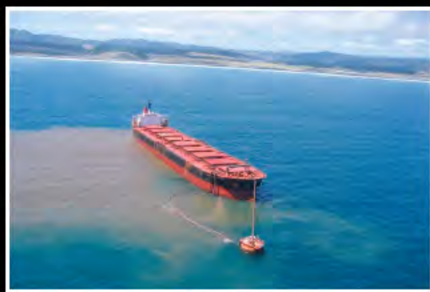






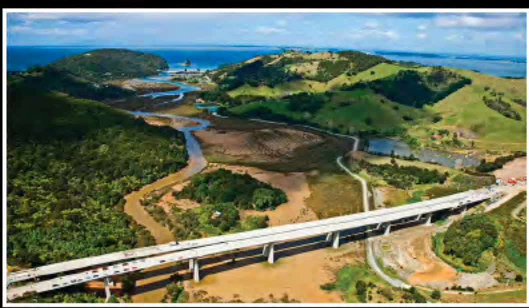
Tonkin & Taylor

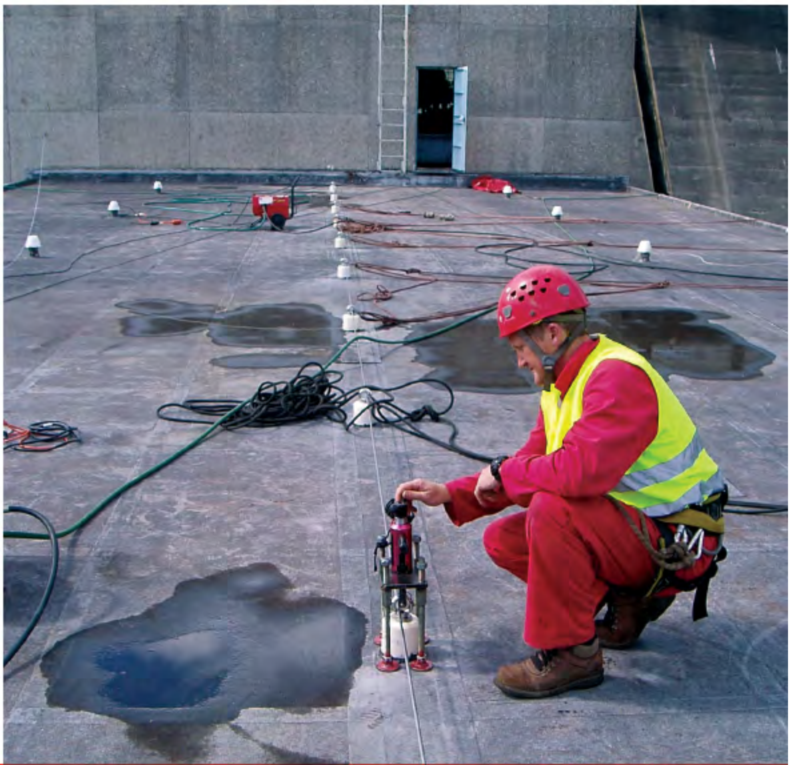




Welcome to our geotechnical playground

www.geotechnicalplayground.co.nz





International Society for Rock Mechanics

Australasia VP Report: September 2011

1 END OF BOARD'S TENURE

October 2011 will see the end of the tenure of the 2008 to 2011 Board and Presidency. A new Board will take over and Professor John Hudson from the UK will step down as President, to be replaced by Professor Xia Ting Feng from China.

Over the term of the outgoing Board, the Society has seen many changes. These changes came about because, at its inception, this Board decided to implement a major modernization plan. At the heart of this plan was the concept that the Society exists for its Members and that all activities should be aimed at providing Members with real benefits. Following are a list of the changes and initiatives.

1.1 Products

- Establish a Members Only area on the ISRM web site so that ISRM products are only available to Members. Login details are available to members from the Secretariat via the Regional VP.
- Provide significantly more pictures of rock engineering activities available for downloading by Members from the website.
- Begin production of Volume 2 of the ISRM Suggested Methods to be referred to as the "Yellow Book". This book will contain the many SMs that have become available since 2007.

1.2 Education

- Establish a digital on-line library through One-Petro to provide Members with access to hundreds of free downloadable papers each year.
- Scan hundreds of papers from most previous ISRM events and upload them into the digital library.
- Upload a series of lectures by Erik Eberhardt on rock mechanics and rock engineering and make available to Members for download.
- Upload a series of historical videos of keynote lectures from ISRM conferences and make available to members for download.
- Establish the concept of the ISRM Lecture Tour. From time-to-time, at the request of a region, the Board will organize an educational tour. Tours have been held to date in China, Peru and Colombia.

1.3 Communication

- Update the appearance and usability of the website.
- Start up the quarterly digital newsletter to provide Members with the opportunity to have regular updates on Society activites and to have a facility to which they can post information.
- Provide the News Journal on-line.
- Launch a CD containing PDFs of all ISRM News Journals from 1996 to 2008 and make available from the website.
- Significantly reduce the number of hard copies of the News Journal thereby reducing significantly the single greatest annual expense of the Society. Members preferring to have a paper version of the Journal will still be able to receive one.

1.4 Young Members

- Set up the Young Members Presidential Group to provide the President with the opportunity to receive feedback on concerns of Young Members, their thoughts about the Society and their ideas for making it more relevant to their interests.
- Have a competition for Young Members to come up with a new logo for the Society for its 50th anniversary year.
- Establish a slide show competition for Young Members.

1.5 Events

- Establish the requirement that organizers of ISRM sponsored events are to provide discounts of at least 20% to Members.
- Plan the ISRM 50th year anniversary celebration with an associated logo and book.
- Establish the concept of the ISRM Specialist Meeting. These meetings will be held on specific themes in rock engineering. They may be regional or international events. They are only required to pay 2.5% to the Society on registrations rather than 5% required from other types of sponsored events.
- Change the nature and frequency of ISRM Regional Symposia.
- The Board will award a Member from the region in which an ISRM Congress is to be held with the opportunity to give the ISRM Distinguished Lecture.
- Create the concept of the ISRM Annual Lecture which will be given at the International Symposium each year.
- Establish the concept of the ISRM Cultural and Field Trip. The Board will organize one such trip annually, usually to coincide with the annual ISRM International Conference.

1.6 Commissions

- Finalise the report of the ISRM Commission on

Mine Closure, upload it to the website for download by Members.

- Require ISRM Commissions to have their products completed in the term of the Board. Some previous Committees never produced anything.
- Significantly reduce the number of Commissions by culling those that had been active for too many years and/or never produced anything.
- Establish the concept of Pre-Commissions which enable commissions proposed for the next Board's tenure to formalise plans prior to the Commission being made active.
- Establish the ITA-ISRM Joint Action Group on "Site Investigation Strategy for Rock Tunnels" with the aim of preparing a Guidance Document.

1.7 Board Matters

- Establish a system whereby Presidential and Regional Vice-Presidential nominees are required to prepare a short video about themselves and their ideas for the Society. Videos are provided to National Groups to enable their local Members to have the opportunity to have input into who their next Board will comprise.
- Place a greater responsibility on Regional Vice-Presidents to contribute to the activities and future direction of the Society.
- Establish an Ex-Board Member's forum which will meet at each Congress to discuss and provide advice on Society matters.
- Create an all-language inclusive policy, but with English as the only official language. Revise the Statutes accordingly.

1.8 Membership

- Conduct a survey(2008) of all Members to ascertain what it is that they want from their Society and how the Society can be more relevant to them.
- Oversee a 18% increase in Members from 5354 in 2007 to over 6300 in 2011.
- Establish the membership grade of Fellows. This grade will be conferred from time-to-time on those Members who the Board believes have contributed significantly to the profession and the Society.
- Make available to members PDF certificates of membership. These certificates are available by contacting the Regional Vice President.
- Establish a new Membership Management System

1.9 Rocha medal

- Establish *Proxime Accessit* certificates for up to two Rocha medal runner-up theses. These theses are eligible for reconsideration for the medal in the

following year.

1.10 Relationship with Other Societies

- Participate with IAEG and ISSMGE in the reconfiguration of FedIGS to a less cumbersome operation.
- Reaffirm the principle that the ISRM is the international organization serving the interests of practitioners of Rock Mechanics and Rock Engineering and intends to remain so. Reject any approach by another International Society that there should be an amalgamation with, or takeover of, the ISRM.

2 WINNER ISRM COMMEMORATIVE LOGO COMPETITION

Dr Ludger Suarez-Burgoa from Colombia won the competition for a commemorative logo for the 50th anniversary of the Society. Ludger is a South American Member of the ISRM Young Members' Presidential Group. The logo will be used during the anniversary which will start in the Beijing Congress in October 2011 and will end in the ISRM International Symposium in Stockholm, in May 2012.

3 ONLINE NEWS JOURNAL

The first issue of the ISRM News Journal was published in 1992, as an initiative of the Board chaired by Prof. Charles Fairhurst. Until 2003, several editions of the News Journal were published in hardcopy annually and mailed to all Members. However, as the cost of printing and posting the Journal represented the single greatest annual expense of the Society, the number of annual editions needed to be reduced. Since 2007, only one annual issue, published in December, has been produced reflecting the activity of the Society during that year. This issue has been posted in hard copy to all Members.

Our on-line survey in 2008 indicated that the majority of Members were happy to not receive a hard copy and preferred to read the News Journal on-line. In response, an on-line version was produced and made available to Members only. The latest version, Volume 13 2010, is available from http://www.isrm.net/gca/?id=206.

In future, the still significant cost of printing and posting the News Journal, is requiring the Society to reduce the number of hard copies printed and only send them to those Members who prefer the Journal in this format. Stay tune to this column for more details on this initiative.

4 ONLINE NEWS LETTER

The quarterly on-line Newsletter is the primary means by which the Society communicates with its Members. Newsletter Number 14, June 2011, is now available. If you are not receiving the newsletter in your email in-box, register to do so (and view previous Newsletters) at http://www.isrm.net/newsletter/?show=info

5 2012 INTERNATIONAL SYMPOSIUM

Each year the Society nominates one international sponsored event to be the ISRM International Symposium. In 2012 the event will be Eurock 2012, to be held in Stockholm from May 28 to 30. The event is titled "Rock Engineering & Technology for Sustainable Underground Construction". It will be hosted by the Swedish National Group of the Society. The symposium aims to present and discuss new, sustainable development related to underground projects including mining with the emphasis on the complexity and the need for interaction between different disciplines. Keynote speakers at the event will be:

- Dr. Johan Andersson, JA Streamflow AB, Sweden
- Dr. Robert Sturk, Skanska-Vinci, Sweden
- Prof. Håkan Stille, Royal Sweden
- Prof. Roger Flanagan, UK
- Prof. Xia-Ting Feng, China
- Prof. Charlie Chunlin Li, Norway
- Prof. Wulf Schubert, Austria
- Prof. Uday Kumar, Sweden
- Prof. John Hadjigeorgiou, Canada

Three pre-symposium workshops will be held on May 27 and a Special Business Workshop "Going Underground" will take place on May 28. A two-day field trip to Northern Sweden will depart on May 24. Technical tours on May 31 will be to:

- Norra Länken/City banan in Stockholm, a 6 km long, twin-track commuter train tunnel;
- Dannemora Mine which was one of the most important iron ore mines in Sweden. The mine was closed by its owners SSAB in 1992 and has recently been reopened. It may have been operating since the 13th century,
- Äspö Hard Rock Laboratory in Figeholm organized by the Swedish Nuclear Fuel and Waste Management Company (SKB).

Further information can be obtained at www.eurock2012.com.

6 INTERVIEW WITH NICK BARTON

In June 2011 Dr. Nick Barton visited to Zagreb, Croatia, to hold a short course titled "Rock Engineering for Tunnels (Drill-and-Blast and TBM), Pre-Grouting, Caverns, Dam Abutments, Rock Slopes and Rockfill". He also gave the

10th Nonveiller Lecture titled: "Pre-Grouting for Water Control and for Rock Mass Property Improvement".
During his time in Croatia, Nick Barton was interviewed by Professor Ivan Vrkljan from Head of the Geotechnical Laboratory at the Institut IGH in Zagreb. A hard copy of the interview can be downloaded from http://www.isrm.net/fotos/editor2/nl14/interview_vrkljan_barton_isrm_2011.pdf

7 ISRM Rocha Medal 2013

Nominations for the Rocha Medal 2013 are to be received by the ISRM Secretariat by 31 December 2011. The winner will be announced during the 2012 ISRM International Symposium in Stockholm, Sweden, in May 2012, and will be invited to receive the award and deliver a lecture at the 2013 ISRM International Symposium.
The Rocha Medal has been awarded annually by the ISRM, since 1982, for an outstanding doctoral thesis in rock mechanics or rock engineering, to honour the memory of Past President Manuel Rocha while stimulating young researchers. Besides the Rocha medal awarded to the winner, one or 2 runner-up certificates may also be awarded.

8 UPCOMING ISRM SPONSORED EVENTS

- **27-30 May 2012**, Stockholm, Sweden – EUROCK 2012 – Rock Engineering and Technology: the 2012 ISRM International Symposium
- **15-17 October 2012**, Seoul, Korea – ARMS 7 – The present and Future of Rock Engineering: the 2012 ISRM Asian Regional Symposium
- **23-26 September 2013**, Wroclaw, Poland – EUROCK 2013 – Rock Mechanics for Resources, Energy and Environment: the 2012 ISRM European Regional Symposium
- **29 April-5 May 2015**, Montréal, Canada – Innovations in Applied and Theoretical Rock Mechanics: the ISRM 13th International Congress on Rock Mechanics

Details of these events can be found at http://www.isrm.net/conferencias/sp_conf.php?past=0&show=conf

9 ON A PERSONNAL NOTE

This RockNotes will be my final. I want to document my deep thanks to the Australian Geomechanics Society (AGS) and New Zealand Geotechnical Society (NZGS) for giving me the opportunity to hold this position for the past 4 years and to you the Members for allowing me to stay there.

The role has provided me with a wonderful opportunity to meet other rock engineers locally and overseas; I have regularly been humbled, and will continue to be, by the very high level of expertise out there. I've see so many exciting developments in the profession locally and overseas. Over the period I have tried to keep the ISRM "fires" burning in the Region. It will now be up to the new Regional Vice-President to take up the flaming stick.

After a request for nominations in the December 2010 RockNotes, the AGS voted the 2012-2015 VP to be Dr David Beck. David is Principal Engineer and Owner of Beck Arndt Engineering Pty Ltd. In his career he has shown a consistent effort to advance the profession through his company's research, by publicly advocating for high engineering standards and by encouraging students. He has worked in the minerals and civil industries, as a consultant and has maintained an ongoing professional and research interest in numerical modelling, mining rock mechanics, hydrology, tunnelling and petroleum rock mechanics. He is a regular presenter at "rock" events locally and internationally.

David's journal won't be without its challenges. There are many issues facing rock engineering in Australia, not least the necessity to:

- bring together practitioners in rock engineering from the mining and civil industries and from the research, education and training sectors in a spirit of collaboration and congeniality;
- improve communication between the professional societies with interests in rock engineering in the region;
- provide all practitioners with opportunities to contribute to discussions aimed at establishing uniform nationwide regulatory requirements pertaining to rock engineering;
- come up with a uniform system of chartered professional status that can apply to all rock engineers, no matter which area they principally practise in;
- give all practitioners in rock engineering the opportunity to share in the high level of expertise and be exposed to the exciting developments taking place in the profession both locally and overseas;
- address the dire shortage of trained, experienced rock engineers – the problem won't go away if we ignore it !!;
- keep the ISRM growing even stronger than it has now become by increasing further the dialogue with the Members in the Region and overseas.

I have no doubt that David will serve you well.

Tony Meyers
ISRM Vice President (Australasia)

NZGS BRANCH ACTIVITIES

Auckland Branch Activity Report

THE AUCKLAND BRANCH has continued 2011 with a diverse and interesting range of speakers and presentations. Our schedule has been quite busy for the year and is looking to continue that way into 2012 but we are always eager to hear from anyone interested in speaking at our branch events. Also, if you know of an interesting project or speaker, please feel free to get in touch with a Branch Coordinator.

The second half of 2011:

Since the end of May we have had some fantastic presentations and events every month:

31 May 2011: *Jacqui Coleman* from Beca presented a very interesting talk on Limestone Karstic Terrain for Beginners, with NZ examples of engineering issues and solutions. A very comprehensive study was undertaken by Jacqui and her colleagues for the Waitahora wind farm project that involved in-depth geological modelling of the site.

21 June 2011: *Trevor Matuschka* from Engineering Geology presented a well received talk on Geotechnical Issues and challenges at Martha Mine. He explored a vast array of geotechnical aspects of the mine that were very insightful. This presentation was the first to be advertised as being live streamed and we had a great response. We even had someone tune in from Europe and it is great to be able to have this sort of technology available to us.

26 July 2011: *Dr. Marc-Andre Brideau* from the Geology Department at the University of Auckland presented on two topics. The first was characterisation and numerical modelling of a large landslide complex in weak mudstone at Cape Turnagain, which was very interesting and displayed the wide suit of analyses he has undertaken to understand this landslide complex. The second investigated preliminary results from terrestrial photogrammetry of the source areas for seismically triggered rock falls in the Port Hills area, which was particularly fascinating for those of us fairly new to terrestrial photogrammetry and its applications.

29 August 2011: *David Bell* kicked off the tour of the NZ Geomechanics Lecture in Auckland with his presentation on Geo-logic and the Art of Geotechnical Practice. He continued down the country visiting all the branches and everyone enjoyed an insightful lecture.

20 September 2011: *John Hawley,* a semi-retired consultant from Algies Bay on the Whangaparaoa Peninsular north of Auckland, presented a fascinating account of his observations of his home town over 16 years. He commented on a wide array of topics including tectonics, mechanical slaking, soil shrink/swell, clay dilatancy, sand movement and slope instability in the bay area.

11 October 2011: *Professor Tom O'Rourke*, the recipient

Pierre Malan
Auckland Branch Coordinator
Tonkin & Taylor Ltd
Work: 09 355 0759
Email: pmalan@tonkin.co.nz

Pierre is a Geotechnical Engineer with Tonkin & Taylor Auckland. Pierre graduated from the University of Canterbury with a M.Eng and has subsequently worked around Auckland and throughout the United Kingdom and Ireland. He has worked on major infrastructure work, design and build contracts as well as a range of small to medium projects.

Luke Storie
Auckland Branch Coordinator
Coffey Geotechnics (NZ) Ltd
Work: 09 426 9707
Email: Luke_Storie@coffey.com

Luke is currently undertaking a PhD at the University of Auckland on the earthquake resistant design of foundations. He is investigating the response of a number of buildings in the Christchurch CBD following the 2010/2011 earthquakes and is following on from research that has been undertaken under the supervision of Professor Michael Pender. Previously, following his graduation from the University of Auckland with a BE(hons) and BA conjoint degree in 2009, Luke was a Geotechnical Engineer at Coffey Geotechnics (NZ) Limited where he worked on a range of small to large scale projects in New Zealand and Australia.

Erica Cammack
Auckland Branch Coordinator
Beca Infrastructure Ltd
Work: 09 300 9371
Email: Erica.Cammack@beca.com

Erica is an Engineering Geologist with Beca Infrastructure Ltd, based in Auckland. She graduated from Canterbury University in 2002 with a BSc Honours degree in Environmental Science. After graduating Erica worked as a ranger for 4 years with the Department of Conservation based mainly on offshore islands. She joined Beca in 2006 and has since worked on a variety of projects involving engineering geology and hydrogeology throughout New Zealand.

of the 2009 Rankine Lecture, presented his lecture on Geohazards and Large Geographically Distributed Systems to a captivated audience in Auckland. The scale of the systems affected by geohazards and the impact on the societies that rely on these systems was eye-opening. Particular reference was made to Christchurch and the performance of service networks during the recent earthquakes as well as other large systems that have been affected by geohazards all over the world.

20 October 2011: *NZGS Student Awards* were held as a combined North Island and South Island event in Auckland this year. There were four outstanding finalists who each presented their topics to a lunch-time audience and panel of judges. The competition was so close that two of the finalists received the student award – Samuel Harris who presented on a Site specific warning system for rainfall induced landslides and Saskia de Vilder who presented on an engineering Geological Investigation of the Tutira Landslide Dam, Hawke's Bay, NZ. They will both receive a $500 prize from NZGS.

Upcoming event at time of writing this report:

29 November 2011: *Dennis Waterman* from Plaxis in the Netherlands will be presenting on recent developments in finite element analysis. We are very lucky to have Dennis in the country to share his expertise. He will also be presenting in Wellington and Christchurch.

5 January 2012: *Peter Robertson* will be in Auckland for a short time very early in 2012 and has offered to give a presentation on the use of the CPT to evaluate liquefaction & cyclic softening. Make sure you pencil this date into your diary for next year as this is likely to be a very insightful and pertinent talk.

Looking forward for the Auckland Branch:

We are very pleased that our trials of live streaming have been largely successful. We have had a couple of company firewall issues (we suspect) but are hoping to find a way to sort these out in the future. Thanks very much to Sujith Padiyara from the University of Auckland for sorting out all the technical aspects of the live streaming, and to Pierre for getting it off the ground and running smoothly. We will be aiming to offer live streaming of all of our presentations in the future.

We are also planning to build relationships with SESOC and NZSEE for any interesting cross-discipline lectures that arise and are trying to increase our presence in the general IPENZ media received by members.

Lastly we would like to thank our sponsors for their continued support.

Waikato Branch Activity Report

Recent Activity

On 18th August 2011, the Waikato Branch hosted a joint event by Hiway Geotechnical, AECOM and Downer EDI Works on the Hamilton Ring Road Deep Soil Mixing (DSM) Ground Improvement.

This event started with a site visit at the Carrs Road Bridge site in Chartwell, followed by a Technical Presentation at Downer Office in Te Rapa. After a safety brief from Downer, the hardhat and fluoro clad site visit attendees observed the Hiway Goetechnical DSM rig in operation, grout batching plant and some earlier constructed columns now exposed in the large cut plus retaining wall works for the Carrs Road overbridge.

After seeing the construction aspect of the project, Andrew Holland from AECOM presented on the investigation, testing and design of the Hamilton Ring Road Upgrade and Extension project, Crosby Road to Cambridge Road section. In early design development, it was determined that the sensitive Puketoka Formation soils underlying part of the alignment would be susceptible to excessive deformations in an earthquake event. Extensive field and laboratory testing was undertaken to assess this hazard. Hiway Geotechnical was engaged to undertake detailed design for ground improvement works to prevent unacceptable deformation of a bridge structure and two large retaining walls. Andy O'Sullivan presented on the ground improvement theory and design along with the use of seismic flat dilatometer (sDMT) testing to verify the improvement in stiffness of the ground surrounding the installed columns.

Both parts of the event were very well attended by a good cross section of the Waikato engineering community. Thanks go to the design and construction team for providing a very interesting and informative event and also Hamilton City Council for allowing this visit on their project.

On the 30th August, the Waikato Branch hosted David Bell as part of his national tour presenting the NZ Geomechanics Lecture – "Geo-logic and the Art of Geotechnical Practice". David was well known to many in the audience of nearly 30 and need virtually no introduction.

His examples of engineering geological mapping, major landslips and the effects of the Christchurch Earthquakes gripped the attention of the audience for the duration of his presentation. The case studies he presented of large scale ground movement were a sharp reminder to look beyond the limits of your site and in some cases look at the very, very big picture.

Of particular interest, and thought provoking, were some of the questions arising from his Christchurch examples about just what should you design for in terms of earthquake risk?

This was our first meeting at Waikato University for some time and our thanks go to Vicki Moon for her assistance in arranging the meeting room and encouraging a good number of students along despite the University being in recess at the time! Hopefully we will be able to build on this and encourage greater student participation in times to come.

Ken Read
Waikato Branch Coordinator
Opus International Consultants
Work: 07 838 9344
Email: ken.read@opus.co.nz

Ken is a Senior Engineering Geologist with Opus International Consultants in Hamilton. He graduated in 1982 with a BSc in Geology from Edinburgh University, followed by an MSc in Engineering Geology from Newcastle University in 1984. He has worked primarily for consulting engineers but has also worked in site investigation contracting and environmental consultancy in the UK. His work has taken him to Jamaica, Malaysia, Nigeria and Croatia before moving to New Zealand in 2006. He is a Chartered Engineer (CPEng) and a UK Chartered Geologist.

Kori Lentfer
Waikato Branch Coordinator
Coffey Geotechnics (NZ) Ltd
Work: 07 571 6081
Email: kori_lentfer@coffey.com

Kori took over the role of joint Waikato/Bay of Plenty Branch Co-ordinator in June 2009.

Kori is a consulting Engineering Geologist who works for Coffey Geotechnics. He graduated in 1998 with a BSc(Tech) in Geology, followed by Masters study at Waikato University and an MSc thesis in Engineering Geology from Auckland University in 2007. Kori has worked for consultants based in the UK, Europe and the Middle East. On return to the homeland he joined Foundation Engineering in Orewa, which was acquired by Coffey Geotechnics in 2007. In April 2008 Kori transferred to the Tauranga office for the lifestyle and diverse geotechnical challenges.

Bay of Plenty Branch Activity Report

Matt Packard
Bay of Plenty Branch Coordinator
Coffey Geotechnics (NZ) Ltd
Work: 07 571 6081
Email: matthew_packard@coffey.com

Matt is an Engineering Geologist with Coffey Geotechnics. He graduated in 2000 with a BSc degree in Earth Sciences at Waikato University and is currently completing a MEngSc at University of New South Wales, specialising in Geotechnical Engineering & Engineering Geology.

He worked for Foundation Engineering in Orewa for some 5 years, focussing primarily on land development projects, before moving to the Bay of Plenty in late 2005 to help establish an office at Tauranga and to diversify his project portfolio. Foundation Engineering was subsequently acquired by Coffey Geotechnics in 2007.

On 31 September, the Bay of Plenty Branch hosted David Bell's presentation on 'Geo-Logic and the Art of Geotechnical Practice'. This presentation was part of David's national tour in recognition of his receiving the premier NZ Geomechanics Lecture award.

The presentation contained an array of fascinating case studies from his professional career, including examples on / in difficult terrain, where geological features may be hidden or may not always behave as first impressions suggest they should. There was also the gentle reminder to look beyond the boundaries of a particular site and consider the implications of what was happening at least regionally.

The presentation was the perfect balance of case studies regarding small scale and large scale geological issues, plus photographs of the examples taken in remote areas showcasing the South Island's wonderful scenery. It's almost something taken for granted in our profession, as to some of the wonderful locations we get to travel to.

There was much discussion after the presentation relating to recent events in Christchurch and about the difficulty in investigation and design within such a dynamic environment.

The event was well turned out for Bay of Plenty branch, with some 40 or so members attending.

With summer here, it'd be great to get out and have a look at some of the local Bay of Plenty projects currently underway. Please contact me if you have any interesting geotechnical or geological sites that you would like to visit and talk about. Likewise if you have any presentation ideas, or know of an international speaker visiting our area please let me know.

Wellington Branch Activity Report

David Stewart
Wellington Branch Coordinator
Aurecon
Work: 04 439-0318
Email: david.stewart@aurecongroup.com

David completed an MSc in Engineering Geology at Canterbury University and then worked in site investigations in the UK, returning to NZ to work on the Cromwell Gorge Landslides project. He then worked as an engineering geologist for GNS in Dunedin, followed by 2 years at the nearby Macraes Gold Mine. After a stint in Auckland picking up a BE (Civil), he moved to Wellington with Duffill Watts & Tse in 2001 and Opus International Consultants from mid 2004 to June 2011.

SINCE THE LAST Geomechanics News report the Wellington Branch has held the following events.

On May 17, Opus organised a site visit to SH2 Muldoon's Corner realignment construction project near the top of the Rimutaka Hill. Forty four intrepid souls visited the site, after postponement from the previous day when the site was shut down due to high winds.

The visit started with a presentation on design and construction issues by Opus project staff at the Kaitoke Gardens Café. Participants were then bussed to the Rimutaka Hill summit and split into four groups to walk through the main earthworks (cuts and reinforced fill) sections of the job. Afternoon tea was put on by Hawkins Infrastucture the main contractor. An article on the project was published in the previous issue.

Above: Three of the four tour groups viewing the rock cuttings and ground anchors at Muldoon's Corner

A group of about 12 met at Aurecon to view the live feed of the Auckland branch meeting in July/August. Unfortunately, due to technical issues this was not able to be viewed; – as a consolation a number of Christchurch Port Hills Youtube rockfall videos were shown!

On 13th September 2011 the branch hosted David Bell's 2011 Geomechanics Lecture– 'Geo-Logic and the art of Geotechnical Practice'. A diverse audience of 65 people attended David's talk, hosted by Aurecon.

Beverley Curley
Wellington Branch Coordinator
GHD
Work: 04 495 5832
Email: Beverley.Curley@ghd.com

Beverley is a Senior Engineering Geologist with GHD Ltd in Wellington. She graduated in 1998 with a BSc(Hons) in Geology from Kingston University, UK, followed a few years later in 2002 by an MSc in Geohazard Assessment from Portsmouth University, UK. Prior to January 2010 she was with Opus International Consultants in Wellington since her arrival in NZ in November 2004. In the UK she worked for Mouchel Parkman. Beverley loves being in NZ and finds working here excellent as, being so young geologically and seismically active, slopes tend to fall down quite regularly.

Upcoming meetings are :
1 December 2011 - Finite Element Analysis (Denis Waterman)

Early 2012
Christchurch Earthquake theme (Chris Massey, etc)
KiwiRail NIMT North South - Junction Project (Richard Justice and Guy Cassidy)

Nelson Branch Activity Report

No activity to report.

Andrew Smith
Nelson Branch Coordinator
Golder Associates (NZ) Ltd
Work: 03 548 1707
Email: ANSmith@golder.co.nz

Andrew Smith is a Senior Engineering Geologist with Golder Associates (NZ) Ltd in Nelson. He graduated in 1997 with a BSc (Hons) in Exploration Geology followed by a MSc in Geo-environmental Engineering from Cardiff University in 2004. Andrew is a Chartered Geologist with the Geological Society of London. He was worked for both marine site investigation contractors and environmental consultancies in the UK before moving to NZ in 2010.

Canterbury Branch Activity Report

NZGS CANTERBURY BRANCH members have been very busy attending seminars, informational meetings, national and international lectures. Nick Harwood has been instrumental in liaising with NZSEE, SESOC, ICE and Canterbury Technical Clearinghouse to facilitate our branch members keeping up with and sharing gained knowledge. Since the last Canterbury news we have had several joint meetings with NZSEE and SESOC covering geotechnical earthquake engineering and a number of other meetings with local and overseas presenters.

Meetings sponsored by the NZGS Canterbury Branch included a presentation in April on seismic design and pile foundations by Dr Gopal Madabhushi from the University of Cambridge, UK. Approximately 60 people attended the presentation and gained insight from the comparisons of Dr Madabhushi's observation of Christchurch pile foundations to his research findings.

Also in April along with NZSEE, members attended a presentation by Dr Paul Somerville from URS in Los Angeles. His presentation "Effects that cause large ground motions: their rupture directivity and basin effects" was well received.

In October Nick organized a forum of ground engineering contractors to provide a "show-and-tell" of ground engineering and improvement measures applicable to the repair and rebuild in earthquake-affected areas of Canterbury. Approximately 200 attendees filled the room with presentations by Maccaferri, Relevel, Uretek and Piletech, who also provided refreshments.

On 12 October NZGS and ICE sponsored a national and international presentation. David Bell presented the 2011 NZGS Geomechanics Lecture and Dr Thomas O'Rourke presented the 2009 BGA Rankine Lecture. The evening also included the presentation of the first NZGS scholarship award to University of Canterbury doctoratorial student, Mohammad Jawad Arefi. Again attendance was approximately 200, with NZGS and ICE providing refreshments.

Before the end of the year we will have a presentation by Dennis Waterman regarding recent developments in finite element analysis. With Christmas coming maybe we should call Nick – St Nick as he is quickly organizing a Christmas function for members with generous support from McMillan Specialist Drilling.

Otago Branch Activity Report

"IT HAD BEEN a frosty winter in Otago this year but David Bell kicked off the introduction to the warmer season with his talk, Geo-Logic and the Art of Geotechnical Practice. The talk was well attended and provided some interesting thoughts on the coupling of geology, geomorphology and engineering in our profession of geotechnical engineering. There were some Christchurch examples of interest considering that many geotechnical practitioners in Otago continue to be heavily involved with assessment and rebuild in the Christchurch area.

With summer upon us the opportunity for site visits has reappeared as sunlight hours in the evenings increase. Opus have planned a site visit to NZTA's Caversham Realignment in early November to get up close and personal with some Dunedin geology and the challenges it brings. I would be more than happy to help organise any other site visits that others would like to host in Otago or if someone is keen to give a talk on something near and dear to their heart.

On an organisational note, I have been at the Otago branch helm for 3 years now and am wondering if anyone else in the region is keen to take up the torch?"

Nick Harwood
Canterbury Branch Coordinator
Coffey Geotechnics (NZ) Ltd
Work: 03 374 9600
Email: Nick_Harwood@coffey.com

Nick is a consulting Geotechnical Engineer who works for Coffey Geotechnics. He graduated in 1990 with a BEng(Hons) degree in Engineering Geology & Geotechnics, followed by a MSc in Soil Mechanics & Engineering Seismology from Imperial College in 1994. Nick started out as a graduate working for British Waterways before moving onto Brown & Root (London) and Buro Happold (Bath) before finally escaping to New Zealand in 2002. He loves living and working in New Zealand, a place that combines sublime scenery and diverse assignments.

Joyce Seale
Canterbury Branch Coordinator
Pattle Delamore Partners Ltd
Work : 03 363 3117
Email: Joyce.Seale@pdp.co.nz

Joyce is an environmental scientist working for Pattle Delamore Partners Limited in Christchurch. She graduated from the University of Canterbury in 2002 with a BSc in Geology followed by a MSc in Engineering Geology in 2006. This is Joyce's "third" career, her first being a teacher and the second a mum. She is enjoying applying engineering geological principles to contaminated site investigations.

Shane Greene
Otago Branch Coordinator
Opus International Consultants Ltd
Work: 03 471 5509
Email: shane.greene@opus.co.nz

Shane is an Engineering Geologist with Opus International Consultants in Dunedin. Shane came to New Zealand from Canada in January 2006 and has been working with the Opus Geotechnical Team since that time. Shane has specialisations in Hydrogeology and Contaminated Land Assessment however since coming to New Zealand has turned his hand to everything from foundations to slope stability investigations.

STANDARDS, LAW AND INDUSTRY NEWS

NZGS Young Geotechnical Professionals

THE YOUNG GEOTECHNICAL Professionals group has been formed to represent, support and provide a voice for the young professionals in the NZ Geotechnical Society. We represent a lively, increasingly influential and rapidly growing section of Geotechnical Engineers and Engineering Geologists nationwide. Through a social culture of innovation, integrity, networking and the pursuit of excellence, we anticipate facilitating in the professional and personal development of the young professionals.

This role is about keeping young professionals informed on, and involved with, developments within the society and abroad; this involves working in coordination with other Young Professionals across the international societies NZGS represents.

Latest Activities:

- Student Awards 2011 were held on 20 October at Auckland University, we had a great response from the North Island and a lesser response from the South Island. So a note to those mainlanders out there, make sure you enter next year! As a result we awarded a national award this year. It turns out that the competition was so tight that the award had to be split between two winning presentations:
  - **Saskia de Vilder** - An Engineering Geological Investigation of the Tutira Landslide Dam, Hawke's Bay, New Zealand.
  - **Samuel Harris** - A Site Specific Warning System for Rainfall Induced Landslides

Well done also to Catherine Tatarniuk and Megan Baddiley for making the finals.

Thanks very much to the Auckland Engineering School for providing the venue and some delicious refreshments. And many thanks also to our judges: C Y Chin from URS, Gavin Alexander and Warwick Prebble from Beca and to Pierre Malan (AKL Branch) and Nick Harwood (CHC Branch) for providing assistance and support.

- The NZ Geotechnical Society Scholarship closed on 31 August and we received several quality applications. The Scholarship has been awarded to Jawad Arefi to assist with his PhD research into the effects of nonlinearity and uncertainty in site response analysis.

Upcoming activities:

- Organisation of the 9th ANZ YGP conference is in progress, a provisional date of 11 to 14 July 2012 has been decided to coincide with the ANZ Conference, and a request for abstracts should be sent out soon.
- Watch this space for an YGP/Auckland Branch quiz night/sport match early next year (and feel free to contact me if you would like to help organise!).
- Further promotion of NZGS in universities early next year.

We welcome support and inspiration from the young geotechnical professional's community and envision that all branch events, workshops, conferences/ congresses and symposiums that the NZGS hold will promote the on-going development of the Young Geotechnical Profession.

If you have any ideas or activities you would like to see happen please contact the new YGP Representative Erica Cammack (erica.cammack@beca.com).

Reported by:
Erica Cammack
YGP Representative, NZGS
Email: erica.cammack@beca.com

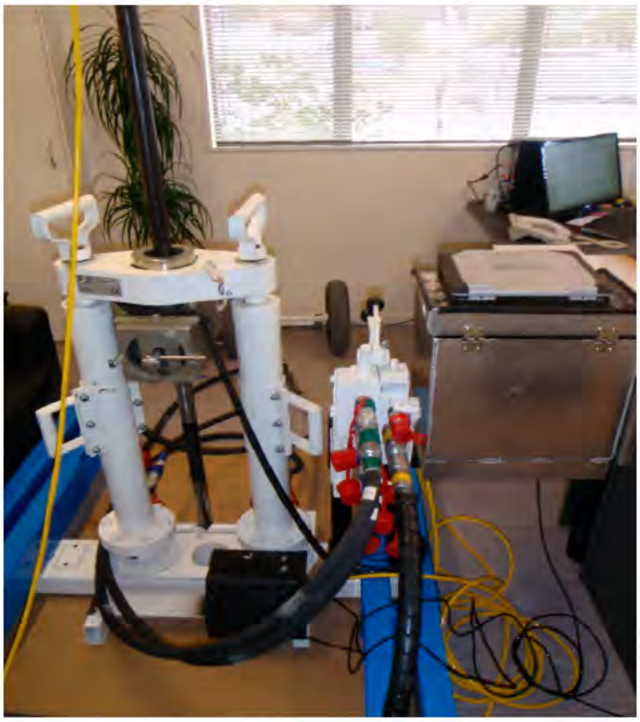
Perry DRILLING

GEO PROBE
A DIVISION OF PERRY DRILLING

Ground Drilling and Environmental Specialists

- Two John Deere 3720 Drilling rigs with dual speed head for efficient fast drilling.
- Drilling capacity of 100m HQ core but in a small compact rig.
- Self contained support vehicle and transporter to enable easy movement between sites.

- CPT01 currently on location in Christchurch working in all conditions!
- Rated at 200kN it is capable of pushing through the shallow gravel lenses and on to the Riccarton gravels with ease. No anchoring required making it fast, clean & efficient.
- It is complemented by CPT02, another 200kN rig based in the North Island.
- Both are capable of 50 plus metres of sounding with the option of conducting SCPT's.
- These are the Rolls Royce of CPT rigs!



- CPT04 has just arrived back from the Caribbean complementing CPT03 which is still on assignment in PNG.
- The MPP 150 (Modular Portable Penetrometer 150kN). Capable of pushing 15 ton in your office!
- Has 45m of CPT rods cabled and ready for sounding with the option of adding more if required.

Perry Drilling Limited
37 Glenlyon Ave,
PO Box 9376
Greerton, Tauranga, 3142
office@perrydrilling.co.nz
Tel: 07 578 0072

STANDARDS, LAW AND INDUSTRY NEWS

ACADEMIC NEWS – Study Options, Research and General News

GENERAL NEWS

University of Auckland

A new format for the graduate level engineering geology paper was introduced in 2011. The course is now composed of weekly assignments exploring various analysis techniques routinely used to solve engineering geology problems. Topics covered include rock mass strength, kinematic analysis, infinite slope, limit equilibrium, rockfall runout and finite element. A field trip and laboratory demonstration makes sure that the students have an appreciation for the origin and uncertainty associated with the inputs used in the various techniques. This course will be offered again in semester 1 2012 (late February – late May).

The Department of Civil and Environmental Engineering's, Master of Engineering Studies (Geotechnical) is a one year Master's degree by coursework (it can be done part-time). Next year courses available will include:

- Earthquake Engineering,
- Earthquake Geotechnical Engineering,
- Foundation Engineering,
- Design Analysis for Earthquake Resistant Foundations,
- Slope Engineering,
- Rock Mechanics and Excavation Engineering,
- Geotechnical Engineering in Residual Soils,
- Experimental Geotechnical Engineering (project)
- Computational Geotechnical Engineering (project)
- also various Engineering Geology courses.

The engineering department is also offering the *Master of Engineering Degree* (a one-year, research based degree that can also be done part-time).

Enquiries to: Rolly Orense, Tam Larkin, John St George or Mick Pender (and Marc-Andre Brideau for Engineering Geology courses).

University of Canterbury

A workshop on Internal Erosion of Embankment Dams was held at UC under the auspices of NZSOLD (the New Zealand Society of Large Dams) on Monday 3rd October. Key speakers at the workshop were visiting Erskine Fellow, Prof. Jonathan Fannin from UBC in Canada and Kaley Crawford-Flett, an alumnus of UC who is now researching her PhD at UBC. The workshop covered experimental work being conducted at UBC and UC as well as case studies on internal erosion from New Zealand. Jonathan has been teaching into the 2nd professional year geotechnical engineering course in the Department of Civil and Natural Resources Engineering and will return in 2012 and 2013 to again contribute to teaching and research collaborations within the department.

University of Waikato

Papers in Engineering Geology have been extensively modified over the past few years. We now offer *Engineering Geomorphology* at 2nd year to principally cover landslide geomorphology, together with fluvial, subsidence, karst, and soil erosion processes and impacts. Geomorphic mapping is introduced using GIS. *Engineering Geology* at 3rd year concentrates on soil and rock mechanics, and students develop site investigation skills including field mapping and logging, laboratory testing, and limit equilibrium slope stability analysis. Rock *Slope Engineering* at graduate level focusses on rock slope stability analysis but students are also encouraged to undertake a directed investigation: topics this year included magnitude-frequency lahar hazard assessment for the Wangaehu catchment, rockfall hazard assessment for Karangahake Gorge, stability assessment of notched ignimbrite cliffs using finite element modelling, and soil erosion susceptibility modelling with GIS.

CURRENT RESEARCH

University of Waikato

Key research at present is associated with our Intercoast programme in conjunction with Bremen University in Germany. Intercoast involves some 20 PhD projects across the two universities. Two are involved in geotechnical research, both related to in situ penetrometer testing of the sea floor:

Vigneshwaran Rajasekaran (started November 2009) is using free-fall penetrometers. These fall through the water column and record accelerations as the lance penetrates the surface sediments. Shear strength can be estimated from the acceleration profile, but is rate dependent. Viggi is developing rate correction equations by calibrating penetrometer data against laboratory shear vane measurements at controlled rates. An extensive testing programme using the NIMROD penetrometer has been undertaken in Tauranga Harbour. These coarse, pumiceous and diatomaceous sediments provide contrasting calibration data with North Sea muds. Bryna Flaim has also used NIMROD in her work on dredge spoil dispersion north of Auckland.

Ehsan Jorat (started August 2011) will be using a newly developed static high resolution cone penetrometer (GOST) in Tauranga Harbour in January. GOST has been deployed once before in deep water in the Norwegian Fiords; the work in Tauranga will be it's 2nd deployment, and again the pumiceous sediments provide contrasting materials in which to develop and calibrate this new tool. Ehsan will be concentrating on using the tool to identify sensitive materials in the main shipping channels

GEOLOGY 701
Engineering Geological Mapping Summer School
31 January -10 February 2012

This field-based course provides hands-on experience in outcrop mapping, geomorphic mapping and simple testing of rocks and soils for geotechnical purposes. A variety of rock masses and soil masses in the Auckland region will be mapped during an eight-day field session. One day of office-based work will follow to allow completion of field mapping assignments.

Learning Outcomes:
You will be able to

- develop the art of field observation and description
- draw engineering geological models
- recognise and map geotechnical hazards.

What is it: A 15-point, 700 level course within the School of Environment Geology programme.

When: Summer Semester, 31 January - 10 February 2012

Where: City campus, plus fieldtrips to localities in the Auckland region.

Pre-requisites: GEOLOGY 372 or equivalent course/ experience.

Assessment: Entirely based on the field mapping assignments.

Course details: see ***http://www.env.auckland.ac.nz/home_page/geol701/index.html***

For further information, contact:

School of Environment,
The University of Auckland
Dr Nick Richards (Coordinator)
Phone: +64 9 3737599 ext 85286
email: n.richards@auckland.ac.nz
or
Dr Warwick Prebble
email: w.prebble@auckland.ac.nz

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

Retaining your business is our business.

Driven Kite Anchors

Instant load locking capability

Anchor design loads range from 5kN to 300kN and have been tested in ground conditions from Auckland to the Coromandel.

Post-tensioning

Active in the reinforcement of concrete structures

Recent projects include Lion Breweries new warehousing and processing facility (50,000sq.m slab on grade), Britomart Oriental Markets Carpark (36,000sq.m suspended slab), Victory Christian Church Carpark (12,000sq.m suspended slab), Eden Park South and East Stands (40km prestressing strand).

HD180 Rig

Power and performance

High performance purpose designed anchoring rig with twin-rotation heads. Used recently on Victory Christian Church, Victoria Park Tunnel and Newmarket Viaduct projects to advance large diameter casing through steel and concrete obstructions.

Ground Anchor Testing

Verify and validate

Extensive data base of testing information throughout New Zealand. Test load capability ranging from 100kN to 10,000kN.

Grouting Services has delivered some of New Zealand's largest Ground Anchoring and Post Tensioning contracts with great results, creating an ever growing repeat business market.

It's not what we do but how we do it that distinguishes our company from the rest and we find solutions around problems that make things possible. We work in close liaison with our clients from inception to hand-over with strong emphasis on personal attention and close monitoring of all projects.

We specialise in design and construct solutions for:

- → Ground Anchoring
- → Post Tensioning

If you're interested in working with us or finding out more about the results we've achieved for our clients call 09 837 2510 or visit our website and watch this space for advances in removable ground anchor technology.

T 09 837 2150 or 021 75 75 66 W www.groutingservices.co.nz

GROUTING SERVICES NZ

ENGINEERING EXCELLENCE SINCE 1971

which may impact on Port operations. Deployment of the instrument is a major operation and is supported by the Port of Tauranga.

In other projects, David Du (MSc) is working with Solid Energy in interpreting data from a two-year installation of a deep (250 m) borehole inclinometer, Katrina Daysh (MSc) is working with Land Transport NZ to improve environmental auditing during a major roading project, Diana Macpherson (MSc) is starting a project looking at the impact of major landslide sedimentation at Te Angi Angi in Hawke Bay in association with Department of Conservation, and M0hammed Majeed (PhD) is beginning work on a feasibility study for a large pumped storage hydro scheme in Otago that will involve stability assessment for the potential reservoir.

University of Canterbury

Patrick Kailey (PhD started April 2008): *Debris flow mechanics in New Zealand Mountain Catchments.* This project combines physical modelling and field investigation to understand the behaviour of small debris flow events in New Zealand. Patrick has investigated 21 debris flows in four areas in New Zealand in order to better understand controls over erosion and deposition, how these flows compare to others around the world, and which empirical and numerical models might be appropriate to use. The second aspect of the project involves a series of flume experiments in a geotechnical centrifuge at ETH, Zurich.

Jawad Arefi (PhD started February 2009): *Ground Response Evaluation for Enhanced Seismic Hazard Assessment.* Dynamic response of soils has a significant effect on the ground motion hazard. The aim of this research is to develop a better understanding of the dynamic response of local surficial soils, and to compare and contrast methods of local soil response modelling. This research will therefore provide contributions in the understanding of soil behaviour and the development of improved soil classification for seismic hazard analyses.

Kim Rait (PhD started April 2009): *Numerical Modelling of the Micromechanical Behaviour of Long Run-out Rock Avalanches* There is still no agreed theory to explain the behaviour of long run-out rock avalanches. Kim's research aims to investigate what micromechanical behaviour may occur in different rock types under high overburden pressures and fast shear, utilising the discrete element numerical method. The idea to is examine whether rock fragmentation is responsible for causing a reduction in effective stress, and hence friction, to produce long run-out in rock avalanches.

Merrick Taylor (PhD started November 2009): *Assessment of Liquefaction Hazard using Effective Stress Analysis.* The project seeks to characterise the engineering behaviour of Christchurch sands, specifically with regard to modelling of liquefaction using an advanced constitutive soil model. A combination of field and laboratory testing will be used to derive parameters of varying quality (e.g. undisturbed samples and field penetration tests). Analyses will then compare to observed performance of ground and structures during the February 22nd 2011 earthquake.

Robert Hunter (MSc started June 2010) *Mechanisms causing internal erosion of filter materials used in embankment dams.* Rob's research is studying the mechanisms that cause internal erosion (loss of fines from a granular matrix due to seepage) in dam filter materials, using glass particles with optically matched oil and PLIF (plane laser induced fluorescence). Various particle size distributions are being tested in an instrumented permeameter while an increasing hydraulic gradient is applied until failure. A camera captures a 2D slice of particles within the sample throughout the test. Analyses will compare visual observations with results from the instrumentation.

Simona Giorgini (PhD started September 2010): *Seismic Design and Assessment of Reinforced Concrete Buildings Including Soil Foundation-Structure Interaction.* This research project aims to investigate non-linear dynamic Soil-Foundation-Structure Interaction on Multi-Degree-of-Freedom (MDOF) systems due to earthquake forces. Simona will develop design, assessment and modelling procedures capable of properly considering the nonlinear soil behaviour within an integrated approach, in which the soil, foundation and structure are considered as an integrated system when evaluating the seismic response.

Kun Ma (ME started February 2011): *Impacts of soil liquefaction on pipe networks in the 2010/2011 Christchurch earthquakes.* This project combines Christchurch land liquefaction damage with the city pipe networks damage from the 2010/2011 Christchurch earthquakes to characterise soil liquefaction impact on the pipe networks. Kun is conducting liquefaction assessment based on the recent geotechnical and seismological data, and using a GIS programme to produce land liquefaction and pipe networks damage maps.

Duncan Henderson (ME started February 2011): *The Performance of Residential House Foundations in the Canterbury Earthquakes.* This project is looking at the comparative performance of four standard residential house foundation types used in New Zealand when subjected to the liquefaction and lateral spreading loads from the Canterbury Earthquakes: The performance of the different foundation types will be compared using the results from around 160 house inspections conducted across four broad land damage areas, from severe (high liquefaction + lateral spreading) to no liquefaction. Some modelling of soil and structural loads will also be performed.

For further information on these and other projects see: http://www.civil.canterbury.ac.nz/postgrads/pgrad_students.shtml

University of Auckland

Saskia de Vilder (M.Sc. started February 2011): *Engineering geology characterization of the initiation zone at two landslides dammed lakes, central North Island*. This project combines terrestrial photogrammetry and traditional field survey techniques to characterize the rock mass in and around the headscarp of two landslides. Saskia is using limit equilibrium and finite difference codes to assess the influence of rock mass strength, discontinuities, pore water pressure, and seismic loading on the slope failure.

Megan Baddiley (M.Sc. started February 2011): *Limit equilibrium modeling of factors influencing the stability of coastal cliffs in weak sedimentary rocks in the Auckland region*. This project combines terrestrial photogrammetry and traditional field survey techniques to characterize the rock masses associated with the East Coast Bays Formation outcrops. Megan is using limit equilibrium models to assess the influence of slope angle, rock mass strength, pore pressure, and bedding orientation.

Jane Harvey (B.Sc. honours started July 2011): *Landslide runout in harvested terrain in the Coromandel Peninsula, North Island*. This project conducted a detailed reach by reach field description of the initiation, transport, and deposition of small debris avalanches and debris flows. Jane is using this data to model the runout behaviour of these mass movements using a dynamic analysis code.

Max McLean (M.Sc. started July 2011): *Field and numerical investigation of deep-seated deformation structures in the Tararua Range, North Island*. This project combines an inventory of these slope deformation structures obtained from remote sensing data, with a detailed engineering geology and geomorphology field mapping of selected features. Max will use a finite element code to model the importance of topography, rock mass strength, and structures in the formation, evolution, and stability of these landforms in the Tararua Range.

PhDs

Tom Algie (PhD, recently examined successfully). *Nonlinear Rotational Behaviour of Shallow Foundations on Cohesive Soil*.This thesis investigates the nonlinear rotational behaviour of shallow foundations on cohesive soil. The main aim of the research was to perform large scale field experiments on rocking foundations, develop numerical models validated from those experiments, and produce a design guide for design of shallow rocking foundations on cohesive soil subject to earthquake.

Lina Sa'don (PhD, recently examined successfully) *Full scale static and dynamic lateral loading of a single pile*. This study presents the results of full scale field tests on single free head piles embedded in Auckland residual clay. Four hollow steel pipe piles, each with an outside diameter of 273 mm and wall thickness of 9.3 mm were installed at a site in Pinehill, Auckland. Static lateral loads were applied by using hydraulic jack, while dynamic loads were applied using an eccentric mass shaker. The free vibration and snap-back tests were also performed by using instrumented sledgehammer and snap shackle as the quick release mechanism. The primary purpose of the pile testing is to measure the inertial response of piles in Auckland soils and to investigate how the soil stiffness decreases with increasing pile head excitation.

Andy Tai (PhD, recently examined successfully) *Thermomechanical modelling of sand*. The aim of this thesis is to develop a constitutive model of sand behaviour within the theoretical framework of thermodynamics. The main appeal of this modelling approach is that the theoretical basis of thermodynamics is well-established thus internal consistency within the model could be readily achieved. There is also the added advantage that we would be able to develop much deeper insight on the fundamental mechanics from the model outputs. This is in stark contrast with the traditional approach based on the theories of plasticity, which were originally developed to model the behaviour of metals. The theoretical results were interpreted against laboratory triaxial data for quartz sand and pumice sand

Anas Ibrahim (PhD, started February 2008): *Dynamic properties of Auckland residual soil under very small strain range*. This research focuses on the investigation of dynamic properties of undisturbed Auckland residual soil in the laboratory using improved small strain triaxial apparatus, bender element and multi-stage triaxial test with loading and unloading under the elastic range of strain. In addition, simulation of the small strain behaviour using PLAXIS is carried out.

Sam Harris (PhD, started October 2009): *The development of a site-specific warning system for rainfall induced landslides*. This research involves laboratory testing, numerical modelling and in-situ monitoring at site in Silverdale, adjacent to State Highway 1. Soil parameters are determined using standard laboratory tests and known mathematical relationships which are then used in saturated/unsaturated seepage finite element analysis in conjunction with limit equilibrium analysis to determine the factor of safety against slope failure due to rainfall events. These models are calibrated using field monitored data. The results will be integrated to develop site-specific warning system from which appropriate action can be implemented.

Claudia Keyser (PhD, submitted 2011) *The Geotechnical and Environmental Properties of Amended Biosolids*. Claudia has been studying the enhancement of the shear strength and stiffness of wastewater sludge using industrial by-products. The work concerns the sludge produced by Watercare Services waste treatment facilities at Mangere. A number of waste materials were investigated by carrying out consolidation and shear strength evaluation using a range of concentrations of the industrial additives. Fly ash was found to be the best all-round additive.

Lucas Hogan (PhD, started March 2010): *Characterisation and seismic response of New Zealand Bridges*. This research is split into three stages. Firstly, the categorisation of New Zealand bridge stock according to a range of construction characteristics, and definition of seismic hazard. Second, field testing of in-service bridges using forced and ambient vibration to capture the in-service dynamic characteristics of the bridge soil-foundation-structure system. Finally, using lessons learnt from field testing, the development of bridge computer models to: 1) replicate field testing results; 2) compare a range of soil-foundation-structure modelling approaches and complexities. The aim of this is to define modelling approaches accounting for non-linear soil-structure-foundation interaction in bridges that can be efficiently utilised in design.

Bilel Ragued (PhD, started March 2010): *Resilience of New Zealand Port Systems*. In collaboration with all port authorities in New Zealand, this research initially aims to develop a detailed overview of the current characteristics of New Zealand ports. Using this data, representative, or 'virtual' wharves will be defined that capture typical New Zealand characteristics. Field and analytical modeling will be carried out to determine the seismic response of wharves, accounting for soil-foundation-structure interaction. This information will be used in the development of fragility models for the prediction of damage and losses for given ground motion intensities.

Luke Storie (PhD, started September 2011) *Building foundation response during earthquake loading*. At this early stage Luke's intention is to investigate the performance of building foundations in the Christchurch, particularly those which appear, from ground level manifestations, not to have been affected by liquefaction. There are a large number of foundations in this category for a wide range of building heights and configurations. Given that so much good quality ground motion data is available the outputs from this research are expected to be a most informative.

Chris Van Houtte (PhD, about to commence) *The source properties of New Zealand earthquakes in the high frequency domain*. Chris will shortly begin a Ph.D in Engineering Seismology. He will likely study the source properties of earthquakes, particularly the Alpine and surrounding faults. Worldwide, engineering seismologists are currently very interested in understanding the high frequency part of ground motion. His topic will likely focus on attenuation of amplitude in the frequency domain, directivity effects (currently very little is known about directivity effects > 1Hz) and structural maturity of faults (a property determined from the age, slip rate, cumulative slip and length of long-term faults) on the high frequency part of ground motion.

MEs

Peter Algie (ME (part-time) started March 2011): *Analysis of the lateral load behaviour of piles in cohesionless soil*. This research is investigating the lateral load behaviour of piles in cohesionless soils with the eventual aim of handling cyclic loading in saturated sand with cyclic build-up in pore water pressure, particularly in a port and harbour setting.

Michelle Willis (ME (part-time) started March 2011): *Timber liquefaction piles*. This research investigates the performance of timber piles as a liquefaction countermeasure. OpenSees and OpenSeesPL are used to investigate the interaction of the soil-pile system, including slippage and gapping occurring at the soil-pile interface, grid spacing and different soil/pile properties. Assumptions used in existing design methods will be assessed, and design charts will be developed.

Elby Tang (ME (part-time) started March 2011): *Effectiveness of stone columns as a countermeasure for liquefaction-induced lateral spreading*. This research will assess the performance of stone columns as a countermeasure against liquefaction-induced lateral spreading. In particular, how the effects of densification of surrounding soils and drainage through the stone columns can be analysed using numerical modelling and how they affect the effectiveness of stone columns. Moreover, how 3D effects can be incorporated in a 2D model.

Marco Holtrigter (ME completed 2011): *A comparison between the flat dilatometer and the cone penetration test with the aid of artificial neural networks*. This study compares the DMT test with the more established Cone Penetration Test (CPT) at 10 sites in the upper North Island. The purpose of the study was to compare the results and interpretations of the CPT and DMT tests in general terms and also to undertake analysis of the data to investigate possible correlations between the two tests. The study shows promising results that suggest possible CPT-DMT correlations. However, further research is needed to validate or improve these correlations.

Final year BE projects:

Michael Tidbury and **Cecelia Lambert**: (BE final year project 2011) *Snap-back testing of piles embedded in Auckland residual clay*. Michael and Cecelia continued with the snap-back testing done by Lina Sa'don at the Pinehill site. The extended the range of results already completed on Lina's piles and came up with some important improvements in our snap-test procedure.

Russell Scoones and **Joseph Simpson**: (BE final year project 2011) *Effect of ground slope on the lateral load deformation behaviour of piles embedded in clay*. Russell and Joe addressed a problem that had been raised by a university professor in the US about the lateral stiffness of piles embedded in ground with a sloping ground surface. Using a non-linear 3D finite element software Joe and Russell showed the influence of ground slope for angles up to 30 degrees. They also demonstrated that a simple pile-head level-ground macroelement can predict the nonlinear lateral load behaviour of piles embedded in clay and also developed a way of handling the sloping ground.

Calvin and **Kevin Ng**: (BE final year project 2011) *PLAXIS modeling of embedded retaining walls with and without tieback support*. Calvin and Kevin investigated the performance of the PLAXIS two-dimensional finite element software at modeling vertical embedded retaining walls one side of which is excavated after the wall is installed. They covered both tied-back walls and also unsupported walls. Modelling with a range of embedment and excavation depths they were able to model system failure plotting the outward displacement of the top of the wall as the excavation depth was increased.

Nathan Hickman and **Brian Hill**: *Analysis of liquefaction in Christchurch*. This project attempts to quantify the liquefaction potential in Christchurch using simplified methods of evaluating liquefaction potential. Using available cpt data, maps showing calculated liquefaction potential indices indicating severity of liquefaction are produced and compared with actual liquefied zones. Explanations on why some sites that did not liquefy in the 4 September 2010 earthquake liquefied in 22 February 2011 earthquake are discussed.

David Bae and **Ray Gao:** (BE final year project 2011) *Modelling of earthquake ground response during the Canterbury earthquakes*. The purpose of this project is to study the dynamic response of Christchurch soils by simulating some of the strong motions that were recorded during the Darfield earthquake and Christchurch earthquake using effective stress ground response analysis program. Input parameters are obtained from cyclic undrained triaxial tests performed on soil samples taken from Christchurch and from boring data of sites adjacent to strong motion stations.

Jason Abraham and **Ryan Wyllie**: (BE final year project 2011) *Site Analysis of Auckland Soil Profiles*. As a result of the many volcanoes in the Auckland region, layers of volcanic rock exist at the near surface in many areas, overlying softer alluvial and sedimentary layers. This project studies the effect of these volcanics on surface ground motions using 1D site response analysis, to determine the NZS1170.5 design site class different layering characteristics correspond to.

Mohammed Al-Kubaisy and **Kavinda Widanapathirana:** (BE final year project 2011) *Quality assurance of basecourse:* The objective of this study is to investigate the variability of the components of a basecourse grading, using a sampling acceptance scheme to compare alongside TNZ standard (M/4). The data obtained (from experiments including sieve analysis and sand equivalent tests) is used for statistical analysis of assessing the quality of the aggregate. The analysis process for the acceptance of basecourse aggregate will examine various international schemes and compare with data from local quarries.

Melvin Angelo: (BE final year project 2011) *Geotechnical properties of the East Coast Bays Formation*: The main objective is to investigate the geotechnical properties of the ECBF within the Auckland area. The work focuses on collating data gathered from sites in Auckland to show the local variation of soft rocks within the lithologies of the ECBF, the similarities and differences of the geotechnical properties across the Auckland region and the significance to future projects in the ECBF.

Beau Goodwin and **Pak Chan**: (BE final year project 2011) *Triaxial testing of local rocks*: The objective of this study is to evaluate the influence of pore water pressure has on strength of soft rock with particular reference to the East Coast Bays Formation. A series of tests under undrained conditions with variable pore water pressures will be tested to examine the influence it has on the strength of the soft rock. Since majority of Auckland is formed by the geological formation of the East Coast Bays Formation, means that construction projects such as a Waterview tunnel will most likely to encounter the ECBF. Therefore this study on the ECBF is vital to understand it behaviour, properties and its performance during the construction of the project.

Chenle Zhu and **Sang Kim**: (BE final year project 2011) *Novel central drain for Rowe cell test*: The objective of this research is to investigate the validity of a Geotextile Reinforced Drain (GRD) that replaces the traditional method of Sand Drain (SD) drainage for Rowe cell radial consolidation tests. This will involve evaluating the validity of the GRD for a larger diameter Rowe cell and different types of soil in the Rowe cell radial consolidation tests.

Lessons Learnt: The Importance of Direct Communication with the 'Ultimate' Client

TWO RECENT EXAMPLES demonstrate the importance of a consulting engineer having direct communication lines with the 'ultimate' client.

Example 1

In the first example, a specialist geotechnical consultant carried out a site investigation to support land use consent for a four Lot subdivision. The use of the site investigation report was clearly qualified as being limited to this purpose. Other standard limitations about the nature and scope of the investigations were included in the report as was the recommendation that the soils consultant be advised if conditions were found to vary from those anticipated.

Further to subdivision of the proposed four Lots, the structural engineer for a purchaser of one of the Lots relied on the limited investigation report for the detailed design of the house foundations. This use of the report was outside the original scope and purpose. During construction ground conditions were found to vary from those inferred by the structural engineer from the report. A decision was then made to design and install more expensive foundations without any consultation with the geotechnical engineer. The structural engineer informed the client that the additional costs were the result of a 'faulty site investigation' and on this basis the 'ultimate' client sought to recover costs from the geotechnical consultant.

Example 2

The second example involves the same geotechnical specialist. The scope of site investigations for a beach house was severely limited due to restricted access for a drilling rig. Access allowed for only one borehole which was located outside the proposed building footprint. The investigation report prepared for the structural engineer as the Client was appropriately limited and qualified. As with the first example, conditions over the site were found to vary and the structural engineer designed and supervised a substantially more expensive foundation without reference to the geotechnical consultant. The structural engineer reported to the 'ultimate' client that the site investigation was deficient. The 'ultimate' client sought recovery of additional costs from the geotechnical consultant.

Conclusion

In neither case did the structural engineers explain to the 'ultimate' client the explicit risks of the limited site investigations. If the geotechnical consultant had been given the opportunity to directly communicate the risks to the 'ultimate' client, they would have understood their exposure and, if they wished, reduced the inherent risks by carrying out more detailed investigations. In both cases a pragmatic settlement was reached without admission of fault or liability.

Article prepared by a member of NZGS

CHRISTCHURCH POLYTECHNIC INSTITUTE OF TECHNOLOGY (CPIT)

The Bachelor of Engineering Technology (BEngTech) is a new 3 year engineering degree program with majors in Civil, Mechanical and Electrical engineering. The civil major of the BEngTech was offered by CPIT for the first time in 2011. Within each major, students may select a specialisation of their interest. CPIT is planning to offer a geotechnical specialisation within the civil major of BEngTech and is currently developing its capability in this area.

We value a close relationship with industry. To ensure that our specialisation is relevant and meets industry's needs we are seeking the following support and resources:

Teaching - seeking industry practitioners to strengthen our teaching capabilities such as part time teaching of specialist subject areas involving design and construction.

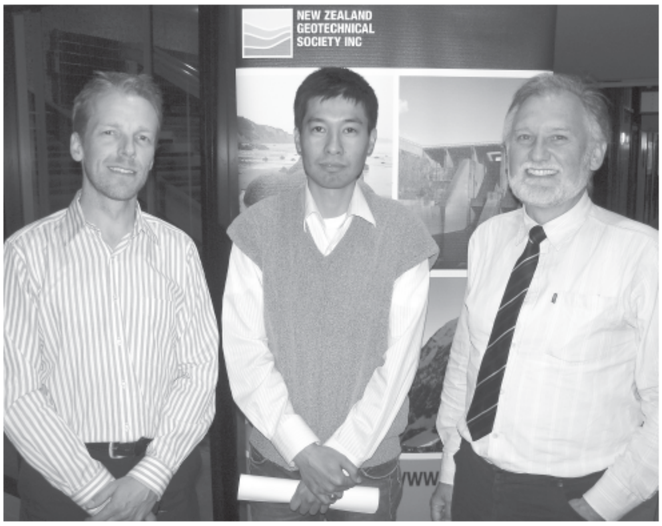
Equipment - seeking resources to support and complement CPIT's resources, such as allowing us the use of lab test equipment and, where possible, donating any equipment surplus to requirements.

Practical training - seeking opportunities for industry attachment for 2nd and 3rd year students in the geotechnical specialisation

Research projects - CPIT and industry collaboration for 3rd year student projects

AWARDS

NZGS SCHOLARSHIP



Left: Nick Harwood (Canterbury Branch Coordinator), Jawad Arefi (2011 NZGS Scholarship Recipient), Charlie Price (NZGS Ccommittee Member).

IN NOVEMBER 2010 the Management Committee agreed to initiate an NZGS Scholarship, up to a value of $10,000, for a selected Society member to undertake research consistent with the objectives of the Society. The Scholarship was made available to either a Student Member or Normal Member to undertake post-graduate research in geotechnical engineering or engineering geology (or a combination of both) in New Zealand. Numerous applications for the Scholarship were received.

A subcommittee headed by Dr CY Chin (Chair) and including Dr Sjoerd van Ballegooy, and Erica Cammack oversaw the short-listing of 4 applicants, who then made oral presentations to the subcommittee in Auckland.

NZGS takes pleasure in awarding the inaugural NZGS Scholarship to Jawad Arefi, to assist with his doctoral studies on the dynamic response of surface soils during earthquakes, and how to model these better – a topic aimed at contributing to improved modelling of seismic hazards in New Zealand. Jawad will be based out of the Civil Engineering Department at Canterbury University, and further details of his proposed research are outlined below.

Dr CY Chin will act as the Society's liaison with Jawad as he undertakes his research.

Ground Response Evaluation for Enhanced Seismic Hazard Assessment

Candidate: M. Jawad Arefi, Department of Civil Engineering, University of Canterbury
Supervisors: Associate Prof. Misko Cubrinovski, Prof. Jarg Pettinga, Dr. Brendon Bradley, Dr. Mizanur Rahman.

Abstract

The dynamic response of soils beneath a site has a significant effect on the ground motion hazard of engineered structures (Boore 2004). To understand such a complex response and mitigate its consequences, one must have both a fundamental understanding of dynamic nonlinear soil behaviour as well as mathematical models capable of predicting soil response in future possible earthquakes.

The aim of this research is to develop a better understanding of the dynamic response of local surficial soils, and to develop, compare and contrast methods of local soil response modelling. This aim will be achieved through the following objectives: (i) development of a relatively simple constitutive model with parameters to fit any desired set of G-γ (stress-strain) and h-γ (damping) curves over the relevant strain range; (ii) compare, contrast and provide recommendation on the appropriateness of different numerical methods for predicting site response for certain soil deposits; and (iii) develop improved site classification measures for incorporation in conventional seismic hazard analyses.

This research will therefore provide significant contributions in the understanding of the appropriateness of various modelling strategies in particular situations, and the development of improved soil classification for seismic hazard analyses.

Background

There have been extensive studies on understating and evaluating the dynamic behaviour of soils during seismic excitation. It is known that under large strong ground motions, soil behaves nonlinearly and this nonlinearity has been incorporated into site response analyses in different forms depending to the problem in hand and computational limitations.

Different methods of soil modelling are used to simulate seismic site response. Equivalent linear (EL) modelling is the simplest, but most commonly utilized approach in practice. This type of modelling iteratively uses an equivalent shear modulus and damping as a function of soil shear strain, and represents a simple approximation of actual nonlinear behaviour of soil. As it is linear, the computed strain returns to zero following ground shaking and hence permanent displacements and soil failure cannot be predicted. The small computational effort and the few and physically-intuitive input parameters has lead to the EL approach being widely used for small-strain and amplification studies. Alternatively, nonlinear (NL) modelling of soil has the obvious advantage that actual (nonlinear) stress-strain path during the cyclic loading is explicitly accounted for. Nonlinear models can be formulated in terms of total or effective stresses, the latter allowing modelling of the excess pore water pressure and liquefaction during earthquake shaking. The ability to evaluate the development of permanent displacement and addressing large strain levels and failure are the key advantages of NL modelling over EL models. However, the numerous parameters which must be determined for conducting nonlinear analyses is a drawback for employing such methods.

Numerical tools to conduct seismic site response analysis have developed tremendously over the last 30 years. Following the development of the EL program SHAKE (Schanbel et al, 1972), a number of nonlinear total stress models have been proposed for considering the effects of soil conditions and nonlinearity on ground motion (Matasovic, 2006; Hashash and Park, 2001; Li, 1992; Pyke, 2000; Borja et al. 2000, EPRI, 1993, Stewart et al. 2008). However, because most nonlinear total stress numerical codes use a Masing Rule-based constitutive model, they cannot adequately account for both modulus and damping characteristics as a function of shear strain simultaneously. A range of sophisticated elastic-plastic constitutive models for effective stress analyses and liquefaction problems have been also proposed and extensively verified (Cubrinovski and Ishihara, 1998; Iai, 1991; Elgamal, 2003). These methods are considered the most appropriate for analysis of cases when significant nonlinearity and deformations are expected but they are far too sophisticated and hence difficult to implement.

Selection of which seismic response method is appropriate for a particular problem requires a thorough knowledge of each methods limitations and assumptions. Many studies have tried to identify those limitations to investigate the effectiveness of each method or document the benefits of taking into account the nonlinear modelling for complex circumstances. However, many past studies have each focused on some particular aspect of nonlinear soil response or particular input parameter, and therefore there outcomes alone do not provide a holistic picture on the appropriateness of the different methods for a particular problem.

Even more simplified than the EL approach, conventional seismic hazard analyses presently classify soils into several discrete groups, rather than explicitly modelling soil response. Based on the aforementioned site response studies and the composition of such discrete soil classes (e.g. A-E in NZS1170.5) it is clear these 'crude' soil class definitions are a significant source of uncertainty in the resulting seismic hazard at the ground surface.

Scope and Objectives

The aim of this research is to develop a better understanding of the dynamic response of local surficial soils and develop, compare and contrast methods of local soil response modelling. This project therefore forms an integral part of a wider study to assess and characterise the geologic hazards affecting New Zealand. The specific objectives of the study are:

1. Develop a simple nonlinear stress-strain model for soils which can simulate any combination of G-g and h-g curves simultaneously in the strain range of interest
2. Systematically compare and contrast the appropriateness of various methods for modelling the seismic soil response of particular soil deposits
3. Develop improved site classification measures for incorporation in seismic hazard analyses

Methodology and Research Tasks

The research has different phases outlined below.

Phase 1: Developing a nonlinear soil stress-strain model to capture both shear modulus and damping curves

Several computer codes and constitutive models have been developed to perform nonlinear site response analysis. Each of these focuses on a particular aspect of soil behaviour, which may not be appropriate in certain conditions. Importantly at present, in nonlinear total stress analysis methods there is no constitutive model which enables users to fit the modulus reduction and damping curves of laboratory data simultaneously. Such a model is urgently needed for conducting nonlinear site response in the absence of significant pore water pressure development.

It is conventional in practice to only fit the modulus reduction curve to experimental data or optimize the fit of both modulus reduction and damping curve (Stewart, 2008). This problem occurs because the Masing constitutive model is primarily employed in site response problems. Many researchers have pointed out (e.g. Pyke, 2008;

Stewart, 2008) that Masing's unloading-reloading rule leads to over-damping at high strain and consequently to unrealistic results. Some researchers (e.g. Lo Presti, 2006; Wang, 1980) have proposed alternative models, but they do not provide a general solution to this problem. Therefore the aim is to develop a model which can simulate accurately both the modulus reduction and damping curves in one-dimensional problems and can easily be implemented in conventional site response codes.

A suitable computer code(s) will be adopted which have the potential to simulate both modulus reduction and damping curves simultaneously within total stress analyses methods.

Phase 2: Effects of different seismic response methods on predicted seismic soil response

The purpose in this phase is to carry out extensive computational analyses, to compare, contrast, and provide recommendations on the appropriateness of various methods of seismic response analyses for particular soil deposits.

Typically, site response analyses are performed using deterministic methods with given nonlinear soil properties. There is however potentially significant uncertainty in the soil properties as estimated from field and/or laboratory tests, and the representations of theoretical models at capturing 'true' soil behaviour. Such uncertainties can be accounted for by performing extensive analyses in which the soil model parameters are varied within definite lower and upper bounds. Using currently available data in literature, a comparison between equivalent linear and nonlinear total stress analyses for several representative soil profiles will be conducted accounting for such uncertainties. In order to do this, it requires selecting different soil profiles with varying geotechnical characteristics, strong motion records and establish a database comprising diverse scenarios and categorize them in several representative groups. This will include summarizing available data which already exist for Christchurch city after Darfield (2010) and Christchurch (2011) earthquakes.

The aim of the comparison is to establish clear criteria for the applicability of the equivalent linear approach, and identify conditions under which it will introduce significant errors. It is expected that under certain conditions the EL analyses may reduce the reliability of the output especially in the case of soft soils (Pyke, 2004) or where maximum shear strain amplitudes exceed 1%.

A similar comparative study will also be used to determine the appropriateness of the nonlinear total stress analysis as compared to the more general, yet more complex, seismic effective stress analysis. It is apparent that for the cases dealing with pore water generation and liquefaction problem, total-stress analysis is not capable to capture the nonlinearity of soil response. In the comparisons various ground response parameters will be considered including accelerations, displacements, shear strains and pore pressures where appropriate.

Phase 3: Improved soil classification for use in NZ seismic hazard analyses

Despite the importance of characterizing the nonlinear seismic response of soils, the treatment of current site effects in seismic hazard analysis is very simplistic. The aim of this phase is to combine the results of the other aspects of this project to develop an improved method of site soil classification to be used in seismic hazard analysis.

Comparisons will be made between the results of the analyses conducted in phases 1-2 and soil classifications used in seismic hazard analysis, both in New Zealand and overseas. Based on these results, as well as the geotechnical information which is available throughout much of New Zealand, recommendations for an improved site classification will be developed.

Outputs

The primary outputs from this research will be:

1. A simple constitutive model which allows a simultaneous match of both modulus reduction and damping relationships over a wide range of shear strains will be developed. The model will be limited to 1-D problems and total stress analysis.
2. A detailed understanding of the appropriateness of different methods of seismic response analysis (EL, nonlinear total-stress and nonlinear effective-stress) for different soil deposits and levels of nonlinearity will be gained, with a clear guidance for selecting the most appropriate method in particular applications. This will be in the form of a rational index of effectiveness and performance of different site response methods (equivalent linear, nonlinear total-stress and nonlinear effective-stress) with regard to simulation of effects of nonlinearity and uncertainties involved for specific scenarios.
3. An improved soil classification for use in conventional seismic hazard analyses will be suggested.

The above three key outcomes will lead to a more robust and consistent implementation of seismic site response within the overall procedures for assessment of seismic performance. Such guidance is likely to lead to a wider adoption and more appropriate use of available methods for site response analysis and an improved site classification for SHA.

Acknowledgement

Associate Professor Misko Cubrinovski and Dr. Brendon Bradley kindly agreed to supervise for this research and their motivating help and stimulating discussion to prepare this proposal is gratefully acknowledged.

References

Boore, D. M., 2004. Can site response be predicted? *Journal of Earthquake Engineering* 8, 1-41.

Cubrinovski, M., Rees, S. Effects of fines on undrained behaviour of sands, Geotechnical earthquake engineering and soil dynamics IV. GSP 181 ASCE.

Darendeli, M. B. 2001. Development of a new family of normalized modulus reduction and material damping curves, University of Texas at Austin, *PhD thesis.*

Hashash, Y.M.A. and Park D. 2001. Non-linear one-dimensional seismic ground motion propogation in the Mississipi embayment. *Engineering Geology*, Amsterdam, 62(1-3), 185-206

Ishibashi, I., 1992. Discussion to effect of soil plasticity on cyclic response, *Journal of Geotechnical Engineering*, ASCE, Vol. 118, No. 5, pp. 830-832

Kramer, S., 1996. Geotechnical Earthquake Engineering. Printice Hall.

Li, X.S., Wangand Z.L., Shen, C.K. 1992. SUMDES: a nonlinear procedure for response analysis of horizontally-layered sites subjected to multi-directional earthquake loading, Dept. of Civil Eng., Univ. of Calif. Davis.

Matasovic, N. 2006. D-MOD_2: A computer program for seismic response analysis of horizontally layered soil deposits, earthfill dams, and solid waste landfills. *User's manual*, GeoMotions, LLC, Lacey, Washington

Pyke, R. M. 2000. TESS: a computer program for nonlinear ground response analyses. TAGA Engineering Systems & Software. Lafayette. Calif.

Seed, H. B., and Idriss, I. M. 1970. Soil moduli and damping factors for dynamic response analyses. *Report EERC 70-10.* Earthquake Engineering Research Centre, University of California at Berkeley.

Schnabel, P. B., Lysmer, J., and Seed, H. B. 1972. SHAKE: a computer program for earthquake response analysis of horizontally layered sites, *Report EERC 72-12*, Earthquake Research Center, University of California, Berkely.

Vucetic, M. and Dobry, R. 1991. Effect of soil plasticity on cyclic response. Journal of Geotechnical Engineering, ASCE, Vol 117. No. 1. pp. 89-107.


calibration
SET 1

NZGS Student Awards

ONE OF THE objectives of NZGS is to encourage student participation in engineering geology, soil and rock mechanics and geotechnical engineering.

To foster this, full-time undergraduate or post-graduate tertiary students in New Zealand are invited to submit short abstracts to the Society, on an area of interest, to compete for a $1,000 Student Prize – in fact 2 prizes are usually awarded - one for the North Island and one for the South Island. However, with only one South Island submission this year the applicants were pooled and a national winner selected by a judging panel consisting of CY Chin, Gavin Alexander and Warwick Prebble. The top 2 abstracts could not be separated and as such 2 winners were declared – congratulations to Saskia de Vilder and Samuel Harris – their winning abstracts are presented below.

Saskia de Vilder An Engineering Geological Investigation of the Tutira Landslide Dam, Hawke's Bay, New Zealand.

THE TUTIRA LANDSLIDE dam is located in northern central Hawke's Bay, and has resulted in the formation of three lakes: Tutira; Waikapiro; and Orakai. It is the second largest landslide dam in the North Island, after Lake Waikaremoana, with an approximate landslide volume of 180x 106m^3, and a lake volume of 31x 106m^3. The rotational failure has an approximately 100m high, 600m long scarp, with a failure area of 0.45km^2. The landslide occurred approximately 7200 years ago, as determined by previous work using carbon dating techniques of lake-core sediments. The slope failure occurred in a Plio-Pleistocene sedimentary sequence of interbedded limestones, mudstones, and sandstones, known as the Petane Limestone Group. The aim of this investigation was to determine the factors that led to the initiation, and likely failure mode of the Tutira landslide dam. Pre-historic large landslides can be used as analogues to determine the hazard of possible large modern failures. Dams formed by landslides are often susceptible to breaching, posing a risk to downstream residents.

Traditional engineering geological field mapping (including the use of the Geological Strength Index) and terrestrial photogrammetry were used to characterize the lithology, rock mass conditions and discontinuities present in the headscarp. Terrestrial photogrammetry employs the same philosophy as aerial photograph analysis, with two photos of the head-scarp being taken from two different angles to create a 3D surface. This 3D surface was created in SiroVision, over which the images were draped. The models were geo-referenced, enabling discontinuity orientation information to be obtained from them. Terrestrial photogrammetry is an efficient method, which allows a large amount of discontinuity measurements to recorded from areas inaccessible using classical techniques. There was good correlation between the compass and photogrammetric discontinuity measurements, revealing three distinct joint sets at Tutira. The bedding dips at a shallow angle into the slope, and intersects with two vertical and orthogonal discontinuity sets, forming large sized blocks in the headscarp. The rock mass structure was described as blocky/distributed/seamy due to persistent bedding, and had good to fair

surface conditions. The combination of rock mass structure and surface conditions gives a GSI range of 45-60. Kinematic analysis was undertaken, and showed that the landslide could not have failed by simple sliding, wedge, or toppling failure at a pre-failure slope angle. At the present slope angle, a small concentration of poles fall within the toppling region. Laboratory strength testing was carried out on samples, and combined with Schimdt hammer data, and field estimates to determine the unconfined compressive strength (UCS) of the different lithologies. The cone indenter was used to determine an estimate of UCS for the mudstone lithology at Tutira, with point load tests were undertaken on a weathered limestone sample. Grain size analysis and Atterberg limits testing was carried out on the mudstone sample.

RocLab was used to determine the Mohr-Columb and Hoek-Brown strength criterion of the rock masses using the GSI, UCS and Mi estimate. The Hoek-Brown strength criterion was used as the basis for material properties in the computer models, as it gave a more conservative factor of safety estimate. Two models were created in the limit equilibrium method of slices modelling programme of SLIDE (RocScience software) – one with a simplified stratigraphy, and a more complex stratigraphic model. The simple lithologic model contains three layers, a strong limestone layer underlain by a weak mudstone and limestone layer respectively. The complex model contains several more layers of alternating weak mudstone and limestone, with the hard limestone layer at the top of the slope. The factor of safety for the simple model started at 2.017 (all values obtained using the Morgenstern and Price method), and 1.815 for the complex model. The Hawke's Bay is a region which experiences both intense precipitation storms, and frequent seismic activity, therefore high pore pressure and seismic loading are important parameters included in the models. Increasing the ru value of the limestone layers - the mudstone was considered impermeable, decreased the factor of safety value, but did not lead to slope failure. The peak ground acceleration of an MM intensity 9 earthquake had the effect of reducing the factor of safety to the verge of instability, with increasing ru value decreasing the value into the region of slope failure. . Alternative weakened rock mass strength models were also created to model the effect of material degradation on slope stability. The weak material property models have a lower factor of safety to begin with, and fail with increasing the ru value of the limestone layers. It is plausible that an earthquake combined with wet ground conditions may have triggered the Tutira landslide dam, or that progressive weakening of the rock mass was a factor which resulted in its eventual failure.

Saskia de Vilder
MSc Student, School of the Environment
University of Auckland.

Samuel Harris A Site Specific Warning System for Rainfall-Induced Landslides.

I. Introduction

Rainfall acts as a triggering mechanism for many landslides in New Zealand. These landslides cause several million dollars worth of damage annually; derailing trains [1] and causing fatalities [2]. In an effort to mitigate the cost of such landslides, a site specific warning system is being developed. The warning system relies on the use of water content sensors which are installed in an at risk slope. The selected site (Figure 1) which the warning system is being developed for is located in Silverdale, Northland. This slope was formed as part of a cut operation for the formation of State Highway One. The Northern Allochthon residual soil present at the site is renowned for its susceptibility to landslides, and a landslide occurred on the site in July 2008, following a period of heavy rainfall.

Fig. 1: The selected site. State Highway One lies at the toe of the slope

II. Methodology

Thirteen volumetric water content sensors were installed at various depths at the site. A tipping bucket rain gauge was installed to monitor rainfall events. These sensors were installed 45m away from the existing landslide. The sensors are used to capture the fluctuating water content of the soil due to rainfall events. An unsaturated/saturated 2D finite element model (FEM) (Figure 2) was developed which replicated this in situ fluctuating water content, using the site rainfall data as an influx. Once calibrated with the field monitored water content, a limit equilibrium analyses was undertaken at each time step in the FEM to determine the factor of safety (FOS) against slope failure. The entire model was then validated with the rainfall data which caused the slope failure in 2008. If modeled correctly, the FOS should reach unity at approximately the same time at which failure occurred. An artificial neural network (ANN) was then used to predict the FOS, using the sensor and site rainfall data as inputs. The ANN was trained using the data obtained from the limit equilibrium analyses. The next step in the development of the warning system is to develop

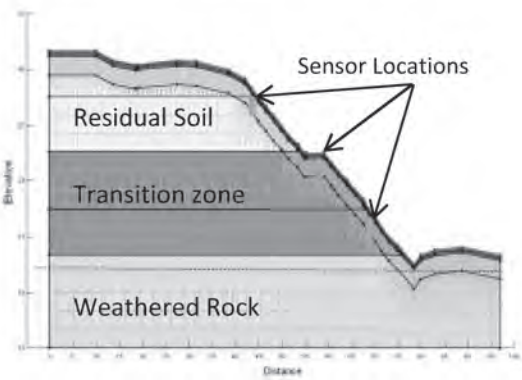


Fig. 2: The FE Mused. The red circles indicate the location of the sensors.

[1] NZPA. (2010). Manawatu rail line to be closed all week. The NewZealand Herald. Retrieved from http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10676486

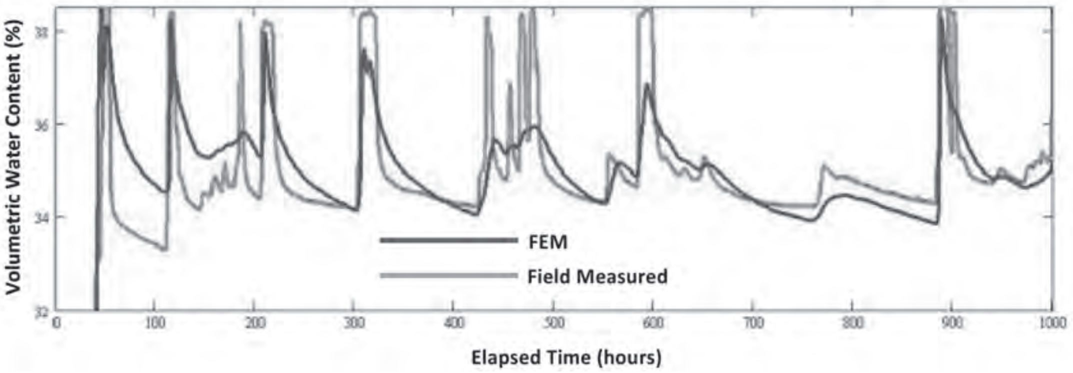


Fig. 3: The field measured water content compared with the FEM measured water content for a sensor located 0.5m deep at mid height of the slope. Elapsed time = 0 corresponds to the 19th of May 2010 at 10.00am.

an algorithm which can use the FOS predicted from the ANN as a basis to warn users of the warning system when failure is imminent. The users of the warning systemcan then take any necessary action, such as evacuating dwellings or closing roads.

3. Results and Discussion

Figure 3 compares the FEM measured water content, and field measured water content from a sensor located 0.5m deep at mid height of the slope. The general trend is well captured, however slight discrepancies between the two occur, particulary the degree of saturation reached and the drying paths following a rainfall event.

The 2008 rainfall record was applied to this FEM as an influx to the slope, and a limit equilibrium analyses was undertaken at each time step in the FEM. The results of this limit equilirbium analyses are shown in Figure 4. As seen, at each significant rainfall event there is a corresponding large and rapid decrease in the FOS. Following the rainfall event, the FOS begins to gradually recover. The FOS drops below unity at an elapsed time of approximately 5000 hours, however eyewitness reports state that movement occurred at an elapsed time of approximately 4400 hours [3]. This discrepancy could be because the reported movement was a precursor to complete failure of the slope, or from cumulative errors within the FEM and limit equilibriumanalyses.

The predicted FOS from the ANN is also shown in Figure 4. As observed there is a good agreement between the ANN predicted FOS and the FOS obtained from the limit equilibrium analyses. Currently the ANN only uses cumulative rainfall events recorded at the site as inputs to predicting the FOS. It is anticipated that if water content readings are used as inputs also, there will be less random spikes observed in the predicted FOS. The next step in the development of the warning systemis to create an algorithmwhich uses the ANN predicted FOS to from the basis of the warning system. Once completed, the water contents and rainfall data from a site can be input into a ANN, which then predicts the FOS of the site. The algorithm will then inform the user, based on the predicted FOS, of an expected minimumtime to failure of the slope. The user can then take any necessary action such as closing roads, thus completing the warning system.

4. Conclusion

A site specific warning system for rainfall induced landslides is being developed. FEM was undertaken to replicate fluctuating in situ water contents, using site rainfall records as an influx. Limit equilibrium analyses was then undertaken at each time step in the FEM to determine the FOS of the slope. An ANN was used to predict this FOS, using site data as inputs. This predicted FOS forms the basis of the warning system.

Samuel Harris
PhD Student, Department of Civil & Environmental Engineering,
University of Auckland.

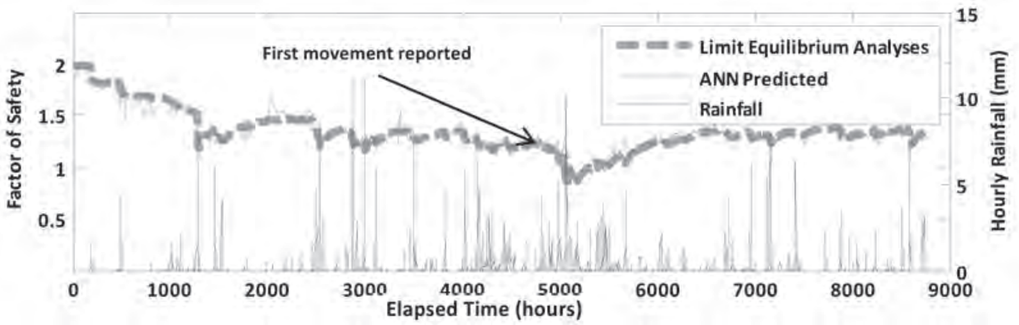


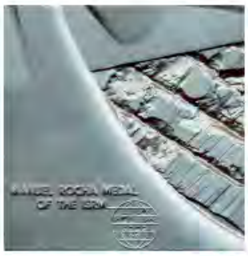
Fig. 4: A comparison of the limit equilibriumanalyses and the ANN predicted FOS using the 2008 rainfall data.

[2] NZPA. (2011). *Youth dies after landslide hits house. The NewZealand Herald.. Retrieved from http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10733041*
[3] *Transfield Services (NewZealand) Ltd. (2008). Auckland Motorways Maintenance Report.*

International Society for Rock Mechanics

ISRM

ROCHA MEDAL 2013



Since 1982 a bronze medal and a cash prize have been awarded annually by the ISRM for an outstanding doctoral thesis in rock mechanics or rock engineering, to honour the memory of Past President Manuel Rocha while stimulating young researchers.

In addition to the Rocha Medal award to the winning submission, one or two runner-up certificates may also be awarded.

An invitation is now extended to the rock mechanics community for nominations for the Rocha Medal 2013.

Full details on the Rocha Medal are provided in ISRM By-law No. 7.

Application

To be considered for an award the candidate must be nominated within two years of the date of the official doctorate degree certification.

Nominations shall be by the nominee, or by the nominee's National Group, or by some other person or organization acquainted with the nominee's work.

Nominations shall be sent electronically, addressed to the Secretary General, and shall contain:

- a one page curriculum vitae;
- a written confirmation by the candidate's National Group that he/she is a member of the ISRM;
- a thesis summary, written in English, with between 5,000 and 10,000 words, detailed enough to convey the full impact of the thesis and accompanied by selected tables and figures;
- one copy of the complete thesis
- one copy of the doctorate degree certificate;
- a letter of copyright release, allowing the ISRM to copy the thesis for purposes of review and selection only;
- an undertaking by the nominee to submit an article describing the work, for publication in the ISRM News Journal, in case of winning.

Application Deadline

The nomination must reach the ISRM Secretary General by 31 December 2011.

Past Recipients

1982	A.P. Cunha	PORTUGAL
1983	S. Bandis	GREECE
1984	B. Amadei	FRANCE
1985	P.M. Dight	AUSTRALIA
1986	W. Purrer	AUSTRIA
1987	D. Elsworth	UK
1988	S. Gentier	FRANCE
1989	B. Fröhlich	GERMANY
1990	R.K. Brummer	SOUTH AFRICA
1991	T.H. Kleine	AUSTRALIA
1992	A. Ghosh	INDIA
1993	O. Reyes W.	PHILIPPINES
1994	S. Akutagawa	JAPAN
1995	C. Derek Martin	CANADA
1996	M.P. Board	USA
1997	M. Brudy	GERMANY
1998	F. Mac Gregor	AUSTRALIA
1999	A. Daehnke	SOUTH AFRICA
2000	P. Cosenza	FRANCE
2001	D.F. Malan	SOUTH AFRICA
2002	M.S. Diederichs	CANADA
2003	L. M. Andersen	SOUTH AFRICA
2004	G. Grasselli	ITALY
2005	M. Hildyard	UK
2006	D. Ask	SWEDEN
2007	H. Yasuhara	JAPAN
2008	Z.Z. Liang	CHINA
2009	G. Li	CHINA
2010	J.C. Andersson	SWEDEN
2011	D. Park	REP. OF KOREA
2012	M.T. Zandarin	ARGENTINA

All relevant information can be obtained from the ISRM website, at http://www.isrm.net.

OBITUARY

Peter Taylor

PETER WHITAKER TAYLOR was born in 1925 and died in July this year. Peter obtained a BSc degree from the University of New Zealand in 1944 and a BE (Hons) degree from the University of New Zealand in 1945, having studied for three years at Auckland University College and completed the final year at Canterbury University College (as was the procedure in those days for engineering degrees). After graduation he was employed for a couple of years by the Auckland City Council and then took up a position with the Anglo-Iranian oil company. Whilst in Iran he had a terrible car accident which necessitated withdrawal to England and several bouts of plastic surgery, under Sir Harold Gillies, with an extended period of recuperation. During recovery he spent time as a Demonstrator in soil mechanics at Cambridge University, a position facilitated by Ken Roscoe (at that time leader of the soil mechanics group at Cambridge). Subsequently he worked for the then London County Council.

In 1953 Peter returned to NZ and took up a lecturing position with the School of Engineering out at Ardmore. He was promoted to Associate Professor in 1971 and full Professor in 1977. From 1977 to 1985 he was Head of the Department of Civil Engineering at the University of Auckland.

He was a gifted teacher highly regarded by generations of students for the quality and clarity of his lecture-room presentations. He had the knack of using just the right amount of simplification and yet preserving the core concepts of the material at hand. Peter's concern for the students under his tutelage was another hallmark of his teaching. He was a most successful Head of Department and respected by all for his sense of fair play and correct procedures and, consequently, is remembered with great affection by his past colleagues. These achievements were set in the midst of a life that had several significant challenges, the car accident in Iran, the suicide of both his parents (at different times), and the loss of his first wife at a relatively young age. That he overcame these hurdles while maintaining a balanced and positive outlook is a testament to the emotional strength of the man.

Alongside his teaching stands his legacy to the geotechnical profession in NZ. In 1964 there were two significant earthquakes, one in Japan at Niigata and the other in Alaska at Anchorage. These events initiated a flurry of research activity around the Pacific Rim, which continues to this day, and out of which has grown the discipline of Geotechnical Earthquake Engineering. Peter Taylor was in the thick of this development. He supervised a number of graduate students measuring the cyclic stress-strain response of soils. These data, combined with those from other university laboratories, contributed to the rapid development of new understandings of soil behaviour under earthquake excitation. Alongside supervising graduate students, several of whom worked with ingenious devices of his design, he completed a staff PhD. During the late 1950s and 1960s laboratory cyclic load testing at earthquake frequencies was a challenging undertaking. Peter Taylor had a flair for the development of the mechanical devices needed for this research; on more than one occasion he remarked that to do experimental work in soil mechanics one needed to be as much a mechanical engineer as a civil engineer. His research frequently broke new ground and yet was always of interest to the engineering profession. In the early 1980s he supervised two Masters Students doing experimental work on rocking foundations. Today, earthquake response of rocking foundations is a "hot" topic and his papers published more than 30 years ago are still cited. When structural design in NZ moved to LRFD procedures (Load and Resistance Factor Design) he demonstrated how geotechnical calculations could transition from the total factor of safety approach to LRFD.

Geotechnical engineering in New Zealand as we know it today was non-existent in the 1950s. Peter made important contributions to its development. In 1958 the first committee for soil mechanics was formed in New Zealand, Peter Taylor was a member of this and, until 1977, served on the committee that eventually became the Management Committee of the NZ Geotechnical Society. He was the Australasian Vice President of the

International Society for Soil Mechanics and Foundation Engineering between 1972 and 1977. He was also an official NZ delegate at the International Conferences on Soil Mechanics and Foundation Engineering in Paris (1961), Mexico City (1969), and Tokyo (1977). He also served on the Management Committee of the NZ Society for Earthquake Engineering from 1972 to 1977. Furthermore he was on the SANZ committee on seismic loading in 1976 and was a member of the Council of the Institution of Professional Engineers New Zealand from 1983 to 1985). He was a member of the Road Research Unit of the National Roads Board from 1965 to 1967 and again in 1974.

In 1984 he delivered the fourth NZ Geomechanics lecture entitled "Geotechnical Engineering: Education and Practice in New Zealand". He was a Life Member NZ Society for Earthquake Engineering, and a fellow of IPENZ, the ICE, and the ASCE. He received the Hume Prize in 1979 and the Freyssinet Award in 1979 from IPENZ.

In the 1950s facilities in New Zealand for laboratory testing of soil samples were very limited. In response to this Geotechnics Laboratory Ltd was established in 1959 by Ralph Tonkin, Nigel Smith and Peter Taylor. It soon became apparent that soil testing work needed to be closely integrated with the application of the results. Ralph Tonkin started, in parallel with Geotechnics Ltd., a consulting engineering practice in which he was joined by Don Taylor in 1961. From time to time Peter Taylor acted as a consultant to the practice of Tonkin and Taylor. Looking through Peter's CV it is apparent that he was consulted by many engineering practices involved with significant NZ developments.

Peter is survived by Sally, his second wife, and Francis, a son from his first marriage.

Prepared by:
Mick Pender with assistance from Terry Kayes, Don Taylor, Geoff Martin, John Hawley, Tam Larkin, John Blakeley and Peter Lowe.

CONFERENCE REPORTS

15th European Conference on Soil Mechanics and Geotechnical Engineering – Athens, Greece, 12-15 September 2011

THE 15TH INTERNATIONAL Conference on Soil Mechanics and Geotechnical Engineering was held in Athens from 12 to 15 September 2011. This was an ISSMGE conference which was very well organised and run by the local Hellenic Society for Soil Mechanics and Geotechnical Engineering.

The theme of the conference was 'The Geotechnics of Hard Soils - Weak Rocks', although there were many papers also covering softer soils. There were two Key Note Lectures, including a very interesting talk by Prof. Robert Mair on ground movements and their effects in tunnels and deep excavations. The paper presentations were grouped into 6 sessions of various general topics with discussion sessions on each topic in the afternoons. Much of the content was on tunnelling and deep excavations, with some interesting talks on the recent tunnelling for the Athens metro system. The topics of selection of soil parameters and modelling were also well covered, with discussions emphasizing the importance of the small strain modulus parameter and the decay of modulus with strain in numerical modelling.

Of particular interest was the way in which development is carried out in central Athens. The modern city of Athens is constructed over the ancient city and so every square inch of Athens is potentially an archaeological site. Every development in the city requires an archaeological dig and if a significant monument is found then it has to be exposed and protected. This means new buildings effectively end up with a basement level purely as an area for people to view the ruins. Foundations have to be designed around the ancient structures. This can have significant consequences. The National Bank of Greece's new building has several basement levels for carparking. The old city wall of ancient Athens was discovered below the site and the wall had to be preserved. This meant that the excavation for the basement carpark levels had to be constructed around and below the ancient monument with elaborate temporary support measures undertaken. As you can imagine this must have significantly delayed the whole construction program and substantially increased the cost of the project. Fortunately this project was completed prior to the global financial crisis!

It was also interesting to hear about the geotechnical engineering employed by the ancient Greeks around 4,000 to 5,000 years ago. Evidence has been found of the use of layers of animal hides as a form of soil reinforcement. Also piles constructed of stone block piers embedded below soft soils into more competent strata have been discovered. In the theme of this issue of Geomechanics News, the ancient Greeks also built many impressive retaining walls. The most impressive are those of the Acropolis, where stone block gravity walls of over 20m in height have existed for thousands of years. The higher walls are supported by buttresses, but the walls themselves are several metres thick at the base.

Above: Ancient Retaining Wall of the Acropolis (>20m in height)

The conference coincided with the 75th anniversary of the ISSMGE and there was an interesting talk about the history of the Society and it's aims for the future. It was announced that the Society is considering a name change to simply ISGE, i.e. proposing to drop the 'soil mechanics' term of the title with the hope of encompassing a wider base of the geotechnical community. This is proving to be a controversial change with many disapproving murmurs overheard from some delegates.

Overall the conference was very enjoyable. It was also great to catch up with Diego Marchetti at his DMT stand amongst many other interesting exhibitors. I have the full proceedings on CD should any one be interested.

Reported by:
Marco Holtrigter
Ground Investigation Ltd


THE COMPLETE PACKAGE
For the widest range of solutions to foundation and ground retention challenges in the country
right from the start : www.brianperrycivil.co.nz
Piling
Driven Piles
Cut-off Walls
Secant Walls
Marine Piling
Soldier Piles
CFA Piling
Bored Piles
Pile Testing
Sheet Piling
Diaphragm/Slurry Walls
Ground Improvement
Dynamic Compaction
Jet Grouting
Vibro Compaction
Vibro Replacement
Wick Drains
Anchoring
Anchors
Soil Nails
Mini Piles
BPC
BRIAN PERRY CIVIL
Foundations | Infrastructure | Environment
For access to the complete package contact:
Nick Wharmby 027 276 7722 / nickw@fcc.co.nz

retaining walls

IN THE JUNE 2011 issue of NZ Geomechanics News the editors called for members to submit a photo and brief description of any interesting retaining walls they had been involved with recently. The results are included in this Special Feature, which provides a summary of some of the current technologies being used, and challenges faced, when retaining land. The issue of retaining wall design is an especially topical one following the Christchurch Earthquakes, where many walls in the Port Hills were badly damaged or failed. Ironically, prior to last year's Darfield Earthquake a NZGS sub-committee had been formed and begun work on a set of guidelines for the seismic design of retaining walls. This work is now well advanced and the release of these guidelines will provide a valuable aid in the robust design of replacement walls in Canterbury.

Image courtesy of Brian Perry Civil and Dave Olsen.

Steel Soldier Pile Wall

Photo 3: Completed retaining wall (approximately 3m height of the wall is above ground).

THE SECTION OF North Island Main Trunk (NIMT) railway line between Pukerua Bay and Paekakariki, north of Wellington is known as North South Junction. This section of the NIMT presents significant constraints for train services due to a particularly steep section of the line, historical landslides and poor lines of sight. To improve reliability and flow of trains in the area, and to increase the existing speed limit from 25km/h to 70km/h, KiwiRail upgraded the North South Junction over Christmas 2010. The upgrade included:

- Realigning the existing track to ease tight curves,
- Lowering the inverts in four tunnels to accommodate larger freight containers,
- Constructing several hundred metres of retaining wall to retain the realigned track and slopes above, and
- The installation of significant rock fall mitigation measures including rock fall netting and catch fences.

The retaining walls designed for this project included shotcrete and anchor, and timber pole and steel soldier pile walls. Aurecon provided engineering services to KiwiRail for the design and construction of the walls. The wall discussed below is one of the soldier pile walls constructed from universal columns and timber laggings. It was built to retain the realigned track for approximately 70m length where the new formation extended close to or beyond the existing slope crest.

The UC sections were 10m long and driven at 1m to 1.2m centres. A number of issues were considered during the design and construction of this retaining wall including the following:

The retaining wall alignment ran along a steep slope with an angle of 35 to 40 degrees (Photo 1). The overall (global) stability and integrity of the wall was one of the major engineering challenges for the design.

The geology of the site was complex and comprised old side cast fill from the original railway

Photo 2: Retaining wall construction area.

Photo 1: Mid-construction photo showing the steep slopes above and below the retaining wall site.

line construction over 100 years ago, underlain by historical landslide and colluvium materials. Gravels and boulders were present in these materials.

Limited subsurface information was available at the design stage as it was not possible to carry out detailed geotechnical investigations at the site due to access, topography, health and safety and time constraints.

The design life of the wall was 100 years and the wall was required to withstand a significant live load from the railway line carrying heavy freight.

The site is adjacent to the sea so the wall will be exposed to a highly corrosive environment.

The steep slope and live railway corridor also presented difficulties in terms of mobilising and operating construction equipment and machinery.

The construction of the retaining wall also had to be completed within a very short timeframe, of two weeks, and without major disruptions to railway traffic.

To address the above issues and ensure an effective, efficient and practical retaining solution, driven 310 UC columns with timber laggings were selected as the most suitable retaining wall type (Photo 2 and 3). The wall construction was completed within the planned timeframe. A number of other options were also considered as discussed below:

(a) Soldier pile wall with augered holes: Augered piles could have been a potential solution, but augering of holes would require significantly more time to complete. The soils at the site were relatively loose, hole collapse was likely and boulders in the fill would have made excavation difficult.

(b) Gravity retaining wall: This type of wall imposes additional load on the existing steep slope and requires significant excavations into the slope adjacent to the live railway line.

(c) Tied back/anchored wall: This wall was considered a suitable option to resist the relatively heavy loads from the train surcharge and earth pressure. This option was not pursued due to the time to build and test, and long term maintenance concerns relating to the anchors under the rail line.

The retaining wall was designed to resist up to 5.5m of active earth pressure. 100mm thick timber laggings were provided between the piles. The design included a provision to add additional lagging in the event of future slips below the wall. A galvanised coating and an allowance for sacrificial steel thickness were provided to cope with the aggressive corrosive environment.

Bishal Subedi
Aurecon NZ Ltd

Piled and L-Shaped Walls

Above: The L-shape wall did not require piling through basalt

THE SITE WAS PARTICULARLY CHALLENGING:

- Greatly varying ground conditions
- Buildings on or over the boundary
- A very narrow site
- Deep excavations beside heavily loaded motorway lanes
- Major services such as 11,000v cables intersecting the work
- 250 stakeholders, 68 adjacent residential properties
- Traffic management and site access constraints

NEWMARKET TO GREENLANE RETAINING WALLS SOUTHERN MOTORWAY – AUCKLAND

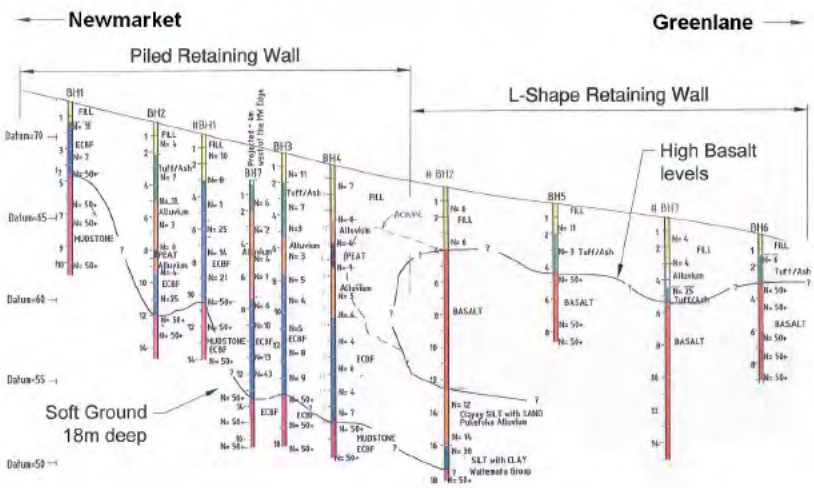
COMPLETED IN APRIL 2011, these retaining walls made the 4th lane possible between Newmarket and Greenlane on Auckland's southern motorway. The $13.8m NZTA project was designed by GHD consultants and constructed by Downer. Soil & Rock Consultants provided specialist geotechnical advice for temporary works and property condition surveys.

Two complete and fully designed options had been provided for the same retaining wall, a piled retaining wall and an L-shape retaining wall. The Contractor opted to construct both wall types since each one was particularly suited to a different end of the site.

The Newmarket end was suited to piling but too narrow for the L-Shape; the Greenlane end had sufficient width for the L-Shape but piling through the basalt would have been difficult.

Mark Hedley
Downer NZ Ltd

The piled retaining wall was suited to the deep, soft soils.



Geotechnical long section of the 500m section requiring retaining walls.
(Courtesy GHD Consultants)

Timber Pole with Concrete Waler Beam Wall

Photo 1: Tie back installation on steep slopes.

Photo 2: Steep coastal location.

KEY WALL DETAILS:

- Initial slip occurred as a result of July 2007 storm event.
- Very steep site with limited space within the property boundaries for construction of the wall.
- Complex ground water issues during heavy rain storms.
- Major slippage occurred the weekend before works were due to start, completely changing the landscape and necessitating a complete redesign (Feb 2008).
- Unstable layer just above the target basalt layer for anchor bonded length, causing issues with installation of anchors.
- Portions of the reinforced concrete ground beam inclined at around 40 degrees, requiring complete formwork which had to be installed progressively during the concrete placement.
- Tight budget in relation to the size/scale of wall required to remediate the site.

Photo 3: Difficult access and 40 degree inclined ground beam.

Craig Greenfield
Haigh Workman Civil & Structural Consultants

Geosynthetically Confined Soil Wall

THE PHOTOS ABOVE show a Geosynthetically Confined Soil (GCS®) wall constructed along a federal highway in the Rocky Mountains in the United States. Note the very large rock (>25t) which has fallen directly onto the wall from a height of over 30m. Despite this massive impact force, the overall integrity of the wall has remained intact with only minor local damage caused to the wall. Once the rock was broken up, using an hydraulic excavator, the wall was repaired within 2 days and the highway re-opened.

These walls operate on the principle of soil confinement as opposed to soil reinforcement. The internal geotextile layer spacing is very close – typically 200mm. This results in very high composite action between the soil and the confining geotextile. As a result of this confinement, dilation of the granular soil is inhibited and hence the failure mechanism is governed by the crushing strength of the backfill material as opposed to the maximum dilation angle.

Hiway GeoTechnical Ltd introduced this technology to New Zealand five years ago and since then have successfully designed and constructed over 70 walls based on this principle.

Andy O'Sullivan
Hiway GeoTechnical Ltd

Segmental Block Walls

ICB RETAINING WALLS Ltd has for many years offered a design and construct service.

During this time the ICB team has developed many design innovations for segmental block walls to add to the proven and familiar reinforced (MSE) soil model.

Walls are now designed using reinforced concrete and or ground anchors where a site is physically restricted and does not allow for the use of reinforced backfill.

Many recently built bridges with conventional pile construction have segmental block facades tied back behind the piles with special blended backfill.

As well, ICB can provide the latest in seismic design for segmental block retaining walls developed from recent earthquake simulations at American universities.

Chris Burke
ICB Retaining Walls Ltd

Above: Hobsonville Motorway. Completed in 2011: The clients choice for the 2 bridge abutments was a wavy faced segmental block with reinforced backfill, Constructed by ICB Retaining Walls Ltd for the main contractor HEB Contractors Ltd

Above left and left: Completed segmental block retaining wall.

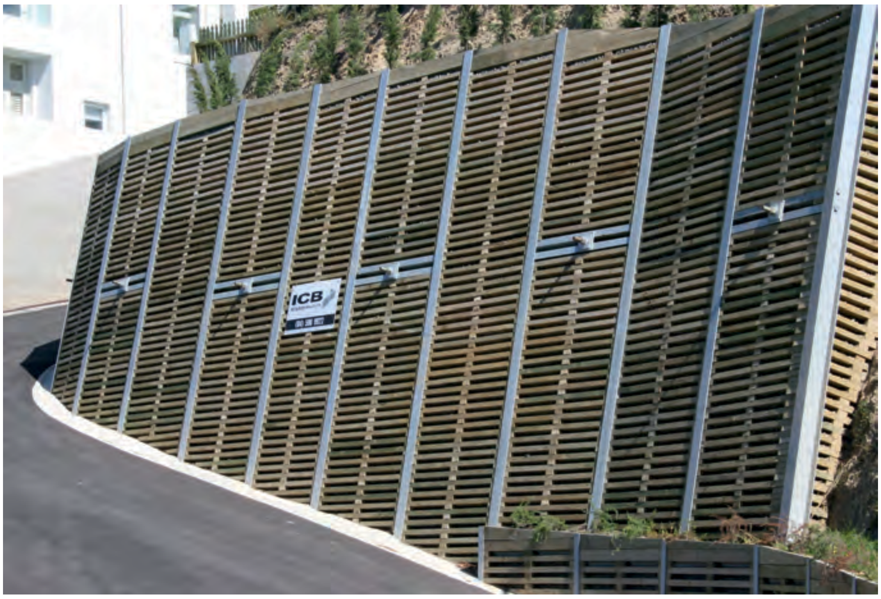
Steel Pile with Timber Lagging Walls

THE STEEL UB wall design offers a practical solution to sites where there is little room for excavation.

The properties of steel offering greater strength than timber, allows for better economy by spreading the centre of the beams and allows for a speedier construction time.

For walls with heavier loads or greater height, ground anchoring systems have been developed which can be installed while still maintaining a flush frontal plain to the face of the wall.

Chris Burke
ICB Retaining Walls Ltd



Completed Steel UB wall with pole in-fills.

Stonestrong Block Walls

Above: DART 2 Temporary access wall. Note some 50 lineal metres of wall 3.6 metres high were constructed over 3 days including excavation, block placement, geogrid and hardfill backfill. Wall construction plant included 12 tonne excavator and 5 tonne vibrating roller with blocks placed from below using a 20 tonne excavator. Note piling rig in background.

DART 2 PROJECT

DART 2 was one of the last major projects to be completed on the North Auckland Line (NAL) double tracking project undertaken by KiwiRail between 2008 and 2010. Project designers were Opus Consultants with the main contractor being Fulton Hogan.

Extending from just west of Kingdon Street in Newmarket through to Boston road in Mt Eden, works comprised double tracking the NAL through a steep and in places deeply incised corridor, formation lowering and widening to accommodate a new island railway platform at Grafton Station, replacement of Park Road and Khyber Pass road over rail bridges, extensive use of bored pile, Stonestrong gravity and driven sheet pile retaining walls to provide for required formation widths and rerouting of several significant truck sewer and storm water lines.

The original rail formation was built in the early 1870s and followed a (former) stream alignment that broadly ran between basalt lava flows from Mt Eden to the south butting up against tuff and volcanoclastic deposits from Outhwaite park and Domain

STONESTRONG BLOCK SOLUTIONS USED ON THE DART PROJECT INCLUDED:

- Construction of temporary rail platforms at Boston Road with the blocks recovered on decommissioning by KiwiRail and subsequently used for other walls within the rail network
- Permanent gravity retaining walls up to 4.5 metres high throughout the immediate "station box" area and a tiered MSE Tensar geogrid reinforced retaining wall 8.5 metres high supporting a vehicle access ramp on the adjacent St Peters College gymnasium development
- Permanent railway platform construction utilizing modified 24SF and 6SF plain face blocks
- Temporary construction access east of Park Road for piling rigs and crane plant to construct an in ground piled retaining wall.
- The original contractor's methodology for the temporary Park Road wall access comprised driven sheet pile retaining. Apart from the practical issues of driving sheet pile deep enough through thinly bedded basalt flows to provide sufficient cantilever fixity, site access for piling rigs and live rail operational requirements provided additional installation constraints. The Stonestrong alternative was constructed in stages during November and Christmas 2009 and utilized permanent retaining wall Stonestrong blocks used for temporary construction, rapid site excavation and construction of an MSE wall using Tensar RE580 geogrids and MR9 GAP 40 hardfill - which was subsequently reused in rail formation construction. The wall design allowed for construction plant live loads in excess of 40 tonnes and overall Stonestrong generated project savings were in excess of $500k. The temporary wall was removed during Easter 2010.

Completed Station, April 2010.

volcanoes to the north. Ground conditions change fairly rapidly along the alignment; solid basalt underlies the Kingdon Street crossing while several metres thickness of swamp and alluvial deposits are present immediately to the west of this. Somewhat variable ground conditions underlie the immediate Grafton station area including weathered tuff, thinly bedded basalt flows and a range of filled and made ground.

Stonestrong NZ was established in mid 2007 and currently operates casting facilities in Auckland, Christchurch and Brisbane. The company supplies vertical engineering solutions for a wide range of infrastructure and civil projects across NZ, Australia and the Pacific including PNG and New Caledonia.

The system consists of large modular precast hollow blocks suitable for gravity retaining walls up to 5 metres high and MSE solutions in excess of 15 metres using geogrids, polymeric strip or steel reinforcement components. Additional retaining solutions include narrow piled base structures and walls installed with integral tieback anchor blocks allowing for either drilled & grouted Reidbar anchors or alternatively helix screw anchors providing tensile capacity. Stonestrong structures can be fixed to the top of driven sheet piles for marine, erosion or seismic liquefaction confinement applications and there are a range of "pile through" system components suitable for bridge abutment pre construction as well as differential movement panels to allow for post construction structure settlement.

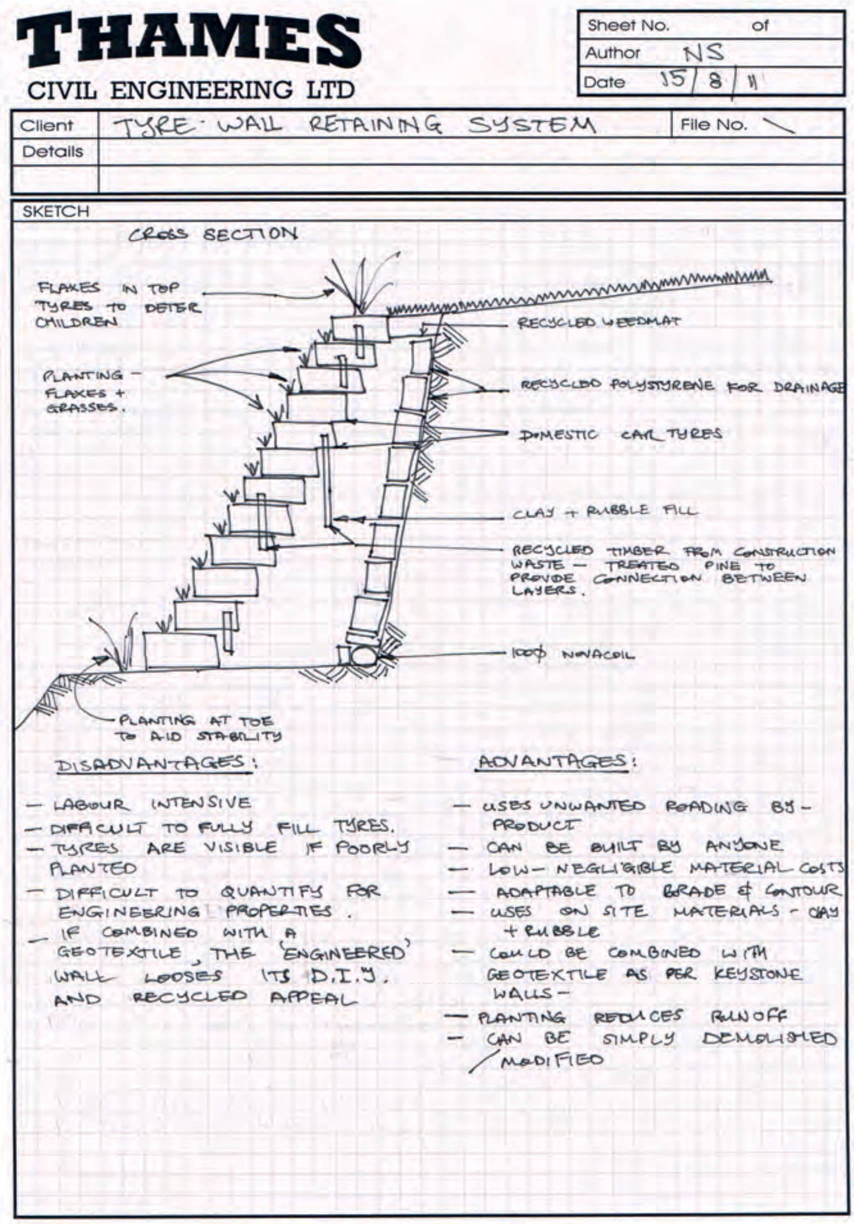
Blocks are fully designed precast elements in accordance with NZS 3101:2006 with a minimum 100 to 120 year design life. Blocks are internally backfilled with aggregate to provide additional retaining wall mass. Standard 24SF blocks have a built face area of 2.24m^2 and are easily installed at rates approaching 150m^2 per day. Further details are available at www.stonestrong.co.nz or 0800 820 8070.

Maurice Fraser
Fraser Geologics Ltd

Above: Station Box looking East towards Park Road, December 2009. Stonestrong upmain platform blocks being placed, note height of piled and shotcrete wall on LHS of photo

Recycled Tyre Wall

Above: Tyre placement with drainage and planting installed.



DESCRIPTION AND EXPLANATION:

The attached photos show a 'non-engineered' car tyre retaining wall, built by an engineer. The wall retains an old cut and fill area and a garden, and the main purpose is to stop minor surface frittering and slumping. The purpose of the planting is to make the tyres 'disappear' and to aid with stability by creating a root mass within and behind the wall.

The wall is constructed in layers, stretcher bond style, and laid back to suit the existing terrain (obviously the flatter the better). Each tyre is infilled with soil and rubble which can be excavated from the cut batter, so an excess of soil helps in construction. Upon completion, the upper layer was planted in flaxes to act as a child barrier and the remainder was planted in occasional flaxes and native grasses.

Initially, the selection of tyres was purely for simplicity - there was limited access for machinery or heavier materials. This was soon overtaken by the desire to make re-use of an unwanted product, and create a planted, 'green' structure. For a 5m long, 2.2m high, wall I used about 150 tyres (as well as other recycled products such as timber and polystyrene) which is well over my quota of car tyres since I started driving! Think global act local.

Niel Smith
Thames Civil Engineering Ltd

Above: Planting growing through tyre wall

Secant Pile Walls

LOCATION

As part of an infrastructure project in Auckland there is a requirement to install jacking and recovery pits to facilitate pipe-jacking of a 2m diameter gravity main. Vertical alignment and limitations on efficient jacking lengths necessitated the construction of 5No. access pits up to 19m deep. The pits were located along Roscommon Road in the central reserve with the associated space and working constraints due to the live carriageway and a number of services including a 300mm dia asbestos cement water main.

DESIGN

The individual site constraints resulted in different shaft types and configurations being adopted at different locations on the basis of practicality and cost. At two locations the excavation depth ground conditions and nature of the services enabled the use of king piles and timber lagging. However, the presence of a fragile water main and 33kV electrical cable adjacent to the excavation, unstable soils, high water table and excavation depth resulted in the selection of secant pile walls to form two of the shafts.

Jacking pit No.1 is located in the median strip of Roscommon Road. The ground conditions comprise a 1.5m cap of fill overlying Puketoka Formation deposits which are underlain by East Coast Bays Formation; these are summarised in the adjacent table:

Depth (m)	Strata	SPT 'N'
0.0 to 1.5	Clayey SILT	
1.5 to 10.0	Clayey / sandy SILT	0 to 5
10.0 to 12.5	Clayey / sandy SILT	10 to 15
12.5 to 16.5	Pumiceous sandy SILT	25 to 30
16.5 +	SANDSTONE	50+

The boreholes indicated that the ground water was at a depth of 6m with potentially high inflows through the sandstone.

The design of the pit had to provide clear internal dimensions of 10m x 6m at 18.3m excavation depth without significant deflection that could cause damage to the water main located within a metre of the wall. In addition, crane surcharges within 2m of the wall and an unreinforced zone for the break in of the TBM was required. The use of 750mm diameter secant piles was adopted with 150mm overlap with alternate piles being "hard" structural piles (30MPa concrete and 12 HD32) and "soft" piles (2MPa). The rectangular pit had a capping beam and 4No. waling frames to support the wall and minimise displacement.

Jacking pit No.2 is located 350m from No.1 but was required to be 8m wide. Whilst the loading and service constraints are present, the space available in this vicinity enabled the construction of an elliptical pit which was self supporting and thus did not require the waling frames. The secant pile design was based upon hoop stresses acting on the piled structure and resulted in all piles being constructed using 10MPa concrete and 6 HD25 in the"hard" piles to provide some vertical bending capacity should pile pile overlap be compromised.

CONSTRUCTION

The construction of secant piles to these depths would typically be carried out using conventional cased bored piles as this provides the best verticality tolerance and thus the greatest confidence that the pile overlap is achieved. The ICE Specification for Piles and Embedded Retaining Walls (SPERW 2007) provides well proven guidance in this area However, space constraints and the potential to damage the services during casing installation lead to the adoption of the CFA methodology. Even with the development of tooling from previous experience,

reference to SPERW 2007 highlighted that there was potential loss of pile overlap below 7m. The contingency was to shotcrete and, for the elliptical shaft install an in-situ waling.

The CFA piles were constructed with the small site area without damage to the services but the strength of the sandstone meant that the piles founded above excavation level in Pit No.1; adjustment of the waling frame and the pile structural capacity could accommodate this. Excavation of the pits revealed some misalignment of the piles which was expected based upon experience. This resulted in the need to break back some piles and in the Pit No.2 the installation of some cast in-situ concrete waler beams to maintain the integrity of the hoop compression stress pathways. The pits were successfully completed in time for the TBM mobilisation.

Photos: Secant retention piles used to create the access pits

Nick Wharmby
Brian Perry Civil

Deep Soil Mixed Walls

Figure 2: CSM Rig

A NEW METHOD of ground modification, cutter soil mixing (CSM), is being evaluated by NZTA for foundation enhancement of the SH16 Causeway Trial Embankment in Auckland. In the USA, CSM has been utilized for another application: support of deep excavations such as shafts, providing a more economical alternative to secant pile and diaphragm slurry walls.

CSM was first introduced in Europe by BAUER Maschinen GmbH and has seen use in Europe, Asia, and Canada. It was used in the USA on the Alternative Intake Project in northern California to construct 20- and 32-metre-deep watertight shafts in alluvial sands, silts, and clays.

CSM is an in situ soil-cement mixing process with the advantage of real-time monitoring of vertical alignment, which is not found with other soil-cement mixing processes. Pile or wall panel drift is a common problem with traditional soil-cement mixing for shaft depths exceeding about 20 metres. Utilizing an inclinometer mounted in the cutterhead assembly, CSM can achieve panel deviations of less than 0.5% of the panel depth, for depths exceeding 30 metres.

With CSM, rectangular panels are created by shearing the soil with mounted cutter wheels, which are attached to a stiff Kelly bar. During the shearing cycle, water is added in predetermined amounts to fluidize the material in place if it is predominantly cohesive, or bentonite is added with the water if the material is predominantly cohesionless. The addition of bentonite keeps the granular material in suspension, which facilitates mixing and keeps the granular material from collapsing. The cutter wheels typically rotate upwards towards each other, directing the soil cuttings towards shear blades that provide additional breakdown of the cuttings. The inclinometer provides the operator with real-time data for the x- and y-location of the cutterhead as it excavates. The operator can change the wheel rotation or 'crowd' the Kelly bar to assist in counteracting deviations of the head.

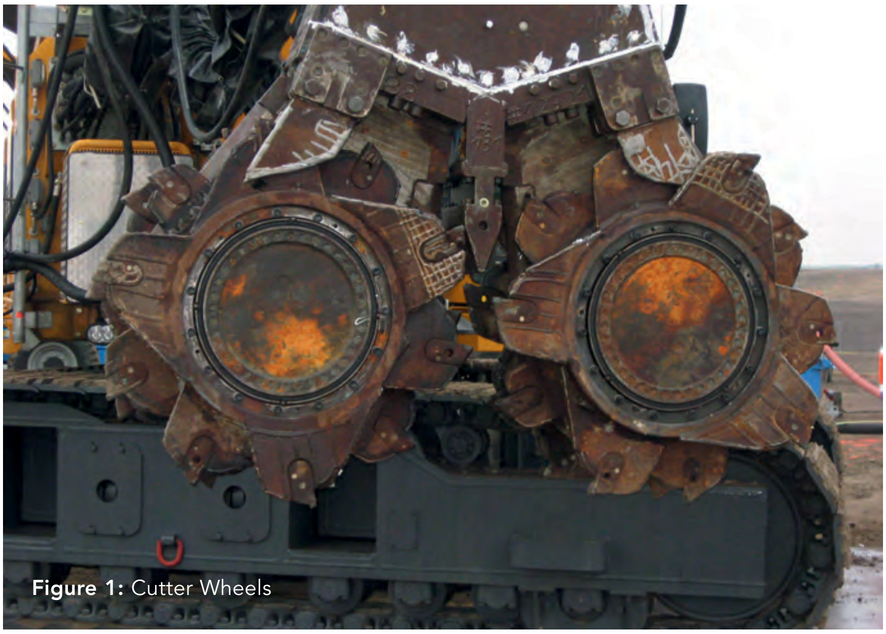


Figure 1: Cutter Wheels

After the soil is fluidized to the prescribed panel depth, cutterhead retraction begins. During retraction, a predetermined volume of cement grout per cubic metre of panel is mixed with the fluidized soil to form a soil cement mixture. To construct a shaft, panels are interlocked to form a contiguous ring of panels, similar to the way secant pile walls are interlocked. Primary alternating panels are typically constructed first and allowed to cure. Secondary overlapping panels are then cut into and between the primary panels to form continuously interlocking panels. Before curing, the panels can be reinforced with beams if necessary. After the shaft panels are cured, excavation of the soil within the shaft interior commences. Excavation can proceed under wet conditions or

Figure 3: Panel Shearing/Excavation

Figure 4: Completed CSM Shaft

dry conditions if a dewatering well is used inside the shaft.

The CSM method can be considered a hybrid of the soil-cement and slurry wall methods. It takes advantage of the economies inherent with in situ soil mixing and the robust support and watertight benefits of diaphragm slurry walls. The accuracy of individual panel installation at significant depths is a distinct advantage of CSM: it provides a high level of confidence that panels are sufficiently interlocked to provide continuous straight or circular walls.

Victor Romero and Norm Joyal
Jacobs Associates

Driven Timber Pile Wall

A TEMPORARY RETAINING wall for a 5.5m deep cut was constructed using this technique. The 5m cut had 20° slope surcharge. I developed this design along with the esteemed Grant Loney (T&T), with input from Andrew Langbein (T&T) – also very esteemed. Though they were sweating about my optimisation in this design.

We used non treated 350SED poles @ 1m centers, predrilled and driven to full depth prior to excavation on a 10% raking angle. Prior to driving the poles we installed and tested pull back anchors, which were later joined and inserted directly into the tops of the poles. After excavation we attached (with nail plates), a geotextile down the face of the poles to stop spalling and weathering. This temporary wall worked perfectly for 6 months. The poles are not recoverable.

Terry Donnelly
Contract Landscapes Ltd

KEY POINTS:
1 CHEAP
2 QUICK
3 EFFECTIVE

Terramesh Reinforced Soil Walls

INTRODUCTION

The first structure on record combining gabions with reinforced soil was built in Malaysia in 1979. This structure incorporated galvanised steel strips for soil reinforcement. This concept was further developed with the use of Maccaferri double twist steel wire mesh panels physically connected to the gabion facing to form the system we know today as Terramesh. The use of the Terramesh system for soil reinforcement is now accepted worldwide with the system independently reviewed and approved for use.

TERRAMESH WALLS IN NEW ZEALAND

Whilst the first gabion faced wall incorporating soil reinforcement technology was built in Malaysia, New Zealand engineers can take credit for designing and constructing the first Terramesh wall that makes use of the double twist galvanised and PVC coated steel mesh for soil reinforcement.

Birches dropout along State Highway 1 just south of Kaikoura was the site for the first Terramesh wall. This structure replaced a failed section of crib wall and was designed and built by the then Ministry of Works in 1987. The construction of additional Terramesh walls at Limestone dropout along State Highway 1 followed soon after. Since this time well over 200 Terramesh walls have built in New Zealand.

New Zealand offers designers and wall contractors many challenges including a wide range of climatic conditions and geological features. The recent earthquakes in Christchurch tested the boundaries of design and construction of all wall types including Terramesh. Whilst there were a few crib and timber pole walls that underwent unacceptable levels of movement a high proportion of walls including Terramesh walls in the Christchurch region performed well within the deformation limits laid out in the guidelines for ductile structures.

Numerous sites were inspected around the Christchurch region and all cases movement for Terramesh walls was observed to fall within the maximum allowable displacement of 200mm for ductile walls. Considering that the horizontal ground accelerations at most sites exceeded the design acceleration by a factor of 2 or more one could conclude that these walls far exceeded design expectations. In addition most of these walls were affected by both the main September 2010 and February 2011 events.

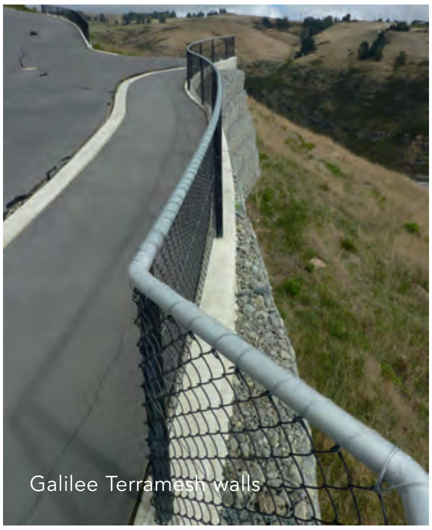
The recently constructed Terramesh walls along Galilee lane on the hill overlooking Moncks Bay showed very little to no movement after the September event however tension cracks in the pavements and behind the wall face were more noticeable after the February event with this location just over 3km from the epicentre.

Crack measurement that can be attributed to outward movement of the wall face varied in width from 1cm for low height walls of 2m or less to between 75mm to 150mm for walls of 4 to 5m in height. All walls were still adequately performing their intended function although the pavement requires resurfacing.

The Evans Pass road Terramesh wall was built in 2001 and when inspected the road had already had repairs. It was noted however that tensions cracks had formed in the grassed surface behind the gabions. A movement of up to 100mm was measure at this location. Although there was settlement of the rock within the gabion face, a feature of a number of the older walls, the structure itself was once again adequately performing the function of supporting the road above a residential area. This site was close to 4km from the epicentre of the February event and as a result the design ground acceleration was well below that experience in February.

It is not only earthquakes that need to be considered by engineers. State highway 94 from Te Anau to Milford is located in a very picturesque part of New Zealand but also in an area exposed to extreme weather conditions including high rainfalls resulting in frequent flooding and heavy snowstorms.


Failed timber pole wall


Galilee Terramesh walls


Evans Pass Rd Terramesh walls


Te Anau site during construction


10 year old Te Anau wall

The original road from Te Anau was constructed in the mid 1930's and proved to be quite challenging with snow, avalanches and flooding a frequent occurrence. The road now forms an important tourist route from Te Anau through the Homer tunnel to Milford Sound.

In the early 1990's this important tourist route was severely damage by flooding from the adjacent rivers and landslips. A number of sites where repaired using traditional gabion and Rockfall netting solutions. One of the sites, approximately 11.5km east of Homer Tunnel, presented a number of challenges due to the height of the slipped section and river bed load. The availability of rock and the harsh nature of the terrain were well suited to a Terramesh solution.

The ability of the structure to perform during high river flows, which can contain a high bed load as well as surface debris was of paramount importance. A concrete wall protecting the base of the Terramesh wall addressed the likely damage to the gabion mesh from river bed loads.

The 10m high Terramesh wall was inspected after 10 years of use and was observed to be in very good condition with no damage to the gabion facing from flood events. The whole wall was covered in lichen, mosses and other local plant species with the density greater in the downstream end of the wall.

No loss of rock had occurred with negligible internal rock settlement and subsequent deformation of the face. It was noticed that silts and sediments were being trapped between the rocks within the gabions providing a medium to support plant growth and increasing the resistance to internal rock movement.

CONCLUSION

We are approaching 25 years of Terramesh walls in New Zealand and we have seen how they can successfully perform in some very challenging conditions. The recent events in Christchurch have probably been the most dramatic for these walls with ground accelerations well in excess of those considered at the time of design. In most cases wall movement has been limited to the upper layers and well within acceptable design limits, with some bulging of gabions occurring due to settlement of the gabion rock.

Internationally, Terramesh walls have seen a rapid growth with the introduction of geogrids to increase the retained wall heights to well beyond 20m and the introduction of Green Terramesh having a face angle of 70° that can be vegetated.

Gordon Stevens
Maccaferri New Zealand Ltd

MSE Walls

THE MAIORO STREET Interchange project was undertaken as an early works project for NZTA prior to the Waterview project. It comprises the construction of the extension of Maioro Street which includes the Maioro Street Motorway Underpass and Maioro Street Rail Overbridge with approaches on fill embankments up to 10m high, and on and off ramps to SH20 which include cuts up to approximately 4m high and fills up to 10m high. Where geometry constraints precluded the use of battered slopes, retaining walls have been constructed.

The general site geology is Waitemata Group East Coast Bays Formation, consisting of firm to very stiff residual soils to approximately 6m overlying interbedded siltstone/ sandstone bedrock. However, more challenging conditions were encountered near a tributary of Oakley Creek which crossed beneath

the Maioro Street extension. The creek and surrounds have been impacted by two volcanic events; lava flows from the Mt Roskill eruption followed by the Mt Albert eruption. The current northern boundary of the creek is along the edge of the lava flow from Mount Albert that erupted about 30,000 years ago. The

Left and below:
Completed MSE walls

lava flowed over existing alluvial sediments, and blocked Oakley Creek valley causing alluvial deposits to build up behind the lava. The geology is, as a consequence of the eruptions and blockages, complex and remnant pockets of alluvium up to approximately 8m thick are present over parts of the site. Pockets of alluvium were present beneath the retaining wall footprints and were excavated and replaced with compacted engineered fill.

Two mechanically stabilized earth (MSE) walls with precast concrete panel facings, 180m and 130m long, support the fill embankments along the edges of SH20 for the on and off ramps and Maioro Street overbridge. They are up to 7m high with additional surcharged batter slopes. Where the walls reduce in height to less than 3m L cantilever with precast facing and poured concrete footings have been used. The bridge was supported on piles.

A second bridge has been constructed over the proposed rail corridor. Two retaining walls comprising bored piles with panels supports the bridge MSE walls with modular blocks facing support the abutment approaches. The overall wall lengths along the edges of the rail corridor, and are 170m and 88m long and the walls are up to approximately 8m high.

Yolanda Thorp
URS NZ Ltd

Geobeam Pavement Testing

CELEBRATING 50 YEARS 1959 - 2009

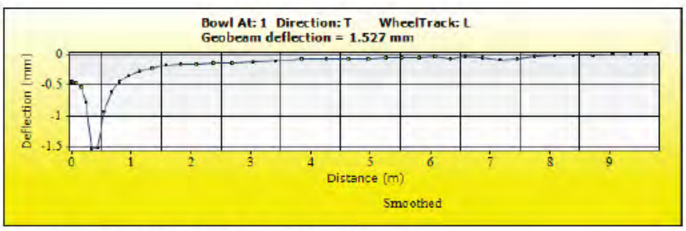
- Quality Control
- Investigation of Failures
- Rehabilitation Design
- Roading and Heavy Industrial Loadings

Measures and Calculates

- Maximum deflection of pavement with improved accuracy - better than a Benkelman Beam
- Deflection bowls
- Curvature function
- Composite modulus of pavement
- Subgrade modulus

Advantages

- Helps identify problem zones within the pavement
- Highly portable and can operate off different vehicles
- Records full deflection profile at approximately 10 mm intervals
- Utilises the latest wireless technology
- Operator observes real time deflection bowls
- Preliminary results available immediately on site
- Post processing available for layer moduli, residual life and pavement rehabilitation



To see a sample report in more detail visit:
www.geotechnics.co.nz / downloads / geobeam report

GEOTECHNICS LTD
23 Morgan Street, Newmarket, Auckland 1023
PO Box 9360
Newmarket, Auckland 1149, New Zealand

p. +64 9 356 3510
f. +64 9 356 3511
e. enquiries@geotechnics.co.nz
w. www.geotechnics.co.nz

GEOTECHNICS

TECHNICAL ARTICLES

Geology of the Auckland Urban Area – Revisiting Kermode (1992) and the Manukau Fault

Kevin J. Hind, Principal, Tonkin & Taylor Ltd, Auckland

Introduction

Covering an area of more than 1000km², Auckland is the largest urban area in New Zealand. Over recent decades, thousands of geotechnical investigations have been undertaken across the city in support of the construction of buildings, roads, pipelines and other infrastructure. Despite the large sum of money spent, few of these investigations have contributed in any meaningful way to the advancement of our knowledge of the city's geology. This reflects not only the limited extent of most investigations, but also the reality that even if useful geological information is obtained, it typically remains unrecognised within unpublished reports.

Maps published by GNS Science, together with a budget constrained drilling programme, typically form the cornerstone of routine geotechnical investigations in New Zealand. The standard source of geological information for the Auckland urban area is the 1:50,000 map and accompanying text of Kermode (1992). Developed from three decades of local work by Les Kermode, the map is an invaluable guide to the geology of Auckland.

However, Auckland's subdued topography and extensive surface modification mean that considerable uncertainty still exists with regard to some aspects of the local geology. Approaching its 20th anniversary of publication, Kermode (1992) also predates many of the larger geotechnical investigations that have been undertaken in Auckland.

An extensive geotechnical database developed as part of a confidential infrastructure project has provided an opportunity to revisit Kermode (1992). A number of significant observations were made. This article looks at just one of them – the Manukau Fault.

Geological Setting

The geology of Auckland is probably most notable for its extensive Quaternary monogenetic volcanic field. The majority of prominent volcanic centres are located on the isthmus, although they extend as far north as Takapuna (Lake Pupuke) and as far south as Wiri (McLaughlin Mountain). Although the vast majority of known volcanic centres occur on land, prominent volcanoes also occur in the outer Waitemata Harbour (Rangitoto and Browns Island) and the inner Manukau Harbour (Puketutu Island).

The basaltic volcanism erupted through the other prominent feature of Auckland's landscape – the Miocene-aged deepwater alternating sandstones and mudstones (flysch) which form the cliffs so characteristic of Aucklands extensive coastline. The third local geological element are the many and varied Pliocene to Holocene terrestrial and estuarine sediments collectively defined as the Tauranga Group. Occurring in areas of relatively low elevation and without any great physical distinction, the Tauranga Group generally goes unnoticed by all except those geotechnical practitioners tasked with the design of foundations and earthworks.

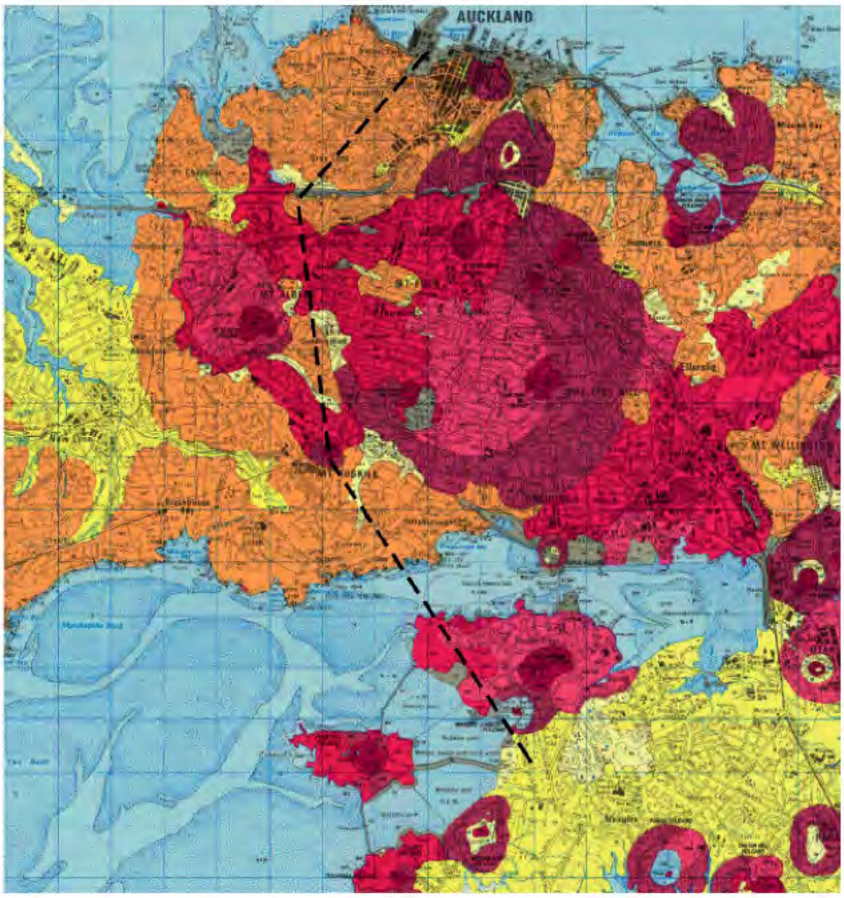
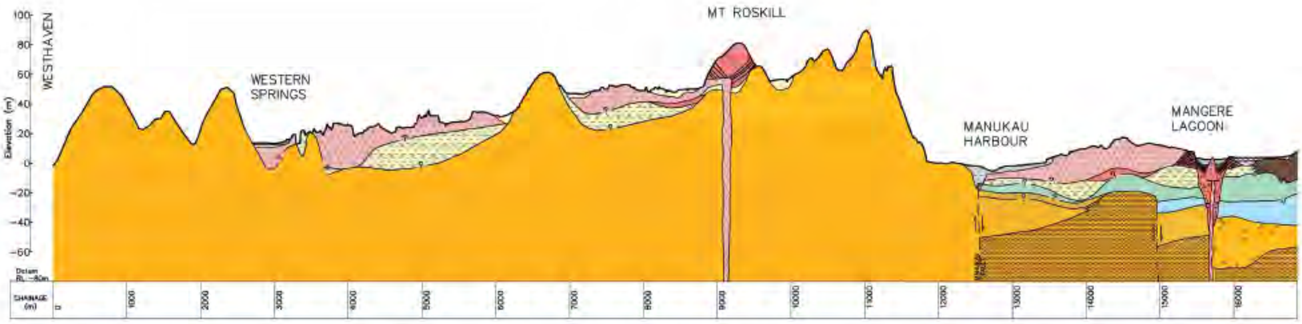


Figure 1: Geology of central Auckland as mapped by Kermode (1992). The location of the geological section presented as Figure 2 is indicated.



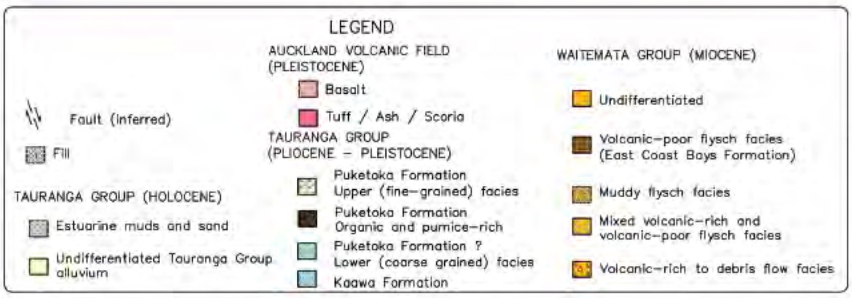


Figure 2: Geological model for the Auckland Isthmus and northern Manukau lowland)

Auckland is ultimately underlain by the greywackes of the Murihiku terrane (west) and Waipapa terrane (east). These primarily Jurassic-aged rocks outcrop only towards the eastern margins of Kermode (1992) and occur at a depth of several hundred metres below the central city.

Figure 1 presents the central part of Kermode (1992). A notable feature of this map is the significant difference in geology either side of the Manukau Harbour. North of the harbour the non-volcanic geology is dominated by the Waitemata Group flysch (East Coast Bays Fm), whereas south of the harbour the surface geology is dominated by the Tauranga Group, principally the Plio-Pleistocene Puketoka Fm.

A geological model developed across the Auckland Isthmus and northern Manukau lowland is presented in Figure 2. The model shows structural disassociation between the isthmus and the Manukau lowland, with the southern section having been downthrown relative to the northern section. Infilling of the downthrown block with post-Miocene marine, estuarine and terrestial sediments accounts for the difference in geology seen in Kermode (1992).

Structural Relationship between the Auckland Isthmus and Manukau Lowlands

It has long been recognised that the Auckland region includes a number of uplifted (horst) and downthrown (graben) blocks bounded by steep faults. The Manukau lowland is a regional-scale graben that has been downthrown relative to the Auckland Isthmus and Waitakere Ranges to the north and the Hunua Ranges to the east. The graben is bounded to the east by the Drury Fault and to the south by the Waikato Fault. The location of the western margin is unknown, although it is likely to exist off the coast of the Awhitu Peninsula.

The presence of a fault defining the northern margin of the Manukau lowland graben has been discussed by a number of workers. Kermode (1992) attributes Ballance (1965) with postulating the presence of the Manukau Fault. Although Ballance (1965) included a geology map (prepared by the N.Z.G.S) which showed the Manukau Fault off the northern shoreline of the Manukau Harbour, his paper does not actually mention the fault or its context.

The earliest reference to the Manukau Fault known to the author is Searle (1959) who described the Manukau lowland as "… a depressed earth-block, separated from the Auckland peninsula by the inferred Manukau fault …". Although Searle (1959) discusses the possibility that the Manukau Fault may lie within a line of boreholes drilled across the northern Manukau Harbour for the Western Interceptor siphon in the 1950's, he does not show the location of the fault on the accompanying geology map.

The N.Z.G.S. map and Searle's discussion on the location of the Manukau Fault were both presented in Searle (1981). As this is an updated version of Searle's seminal book on the geology of Auckland first published in 1964, credit for postulating the presence and location of the Manukau Fault probably lies with Searle (1964).

Based on detailed mapping along the entire northern Manukau Harbour, Geelan (1973) concluded that the northern Manukau Harbour was the northern limit of the Manukau graben, although he postulated that the Manukau Fault was not a single large structure but rather a 1km wide fault zone with a total displacement of between 100m and a 800m. The vertical displacement was therefore distributed across a number of structures within the fault zone, although one or more structures might be more important than the others.

Rather surprisingly, this potentially significant fault receives little attention from either of the published geology maps covering Auckland. Kermode (1992) states only that "The major inferred Manukau Fault postulated by Ballance (1965) has not been clearly confirmed by drilling or geophysics", whereas the 1:250,000 geology map of Auckland (Edbrook, 2001), does not mention the Manukau Fault at all.

Location of the Manukau Fault

The distribution of geological units on the isthmus, Waitakere Ranges and the Manukau lowland indicate that the Manukau Fault should be located somewhere in the Manukau Harbour. Furthermore, the significant elevation difference between the Hillsborough ridge and the Manukau Harbour indicates that the Manukau Fault is probably located close to the northern shoreline.

The N.Z.G.S geology map presented in Ballance (1965) places the Manukau Fault in a line between the southern tip of the Cornwallis Peninsula in the west and just offshore of Onehunga in the east (Figure 3). It is unknown whether this location was proposed by Searle, Ballance, N.Z.G.S or it was a collaboration.

Figure 3: Location of the Manukau Fault as indicted in Ballance (1965) and Searle (1981)

The location of the Manukau Fault near central Auckland, as postulated by Ballance (1965) and Searle (1981) is shown in Figure 4.

Boreholes and geophysical surveys dating from the late 1950's to 2011 have been used to develop the geological profiles across the Manukau Harbour shown on Figure 5. The data shows how the ECBF wave-cut platform located off the Hillsborough coast drops off steeply approximately 250m offshore from White Bluff (Figure 5, Section A-B). Searle (1959) noted that drilling records for the Western Interceptor boreholes describe the Waitemata Group adjacent to this drop-off as being shattered.

Publically available borehole data has been used to construct a geological section along SH20 as it approaches and crosses the Manukau Harbour. Presented in Figure 5 (Section C-D), the geology of this area is similar to Section A-B in that the upper surface of the Waitemata Group is near horizontal in the south but is significantly more elevated near the northern shore, suggestive of a possible location for the Manukau Fault.

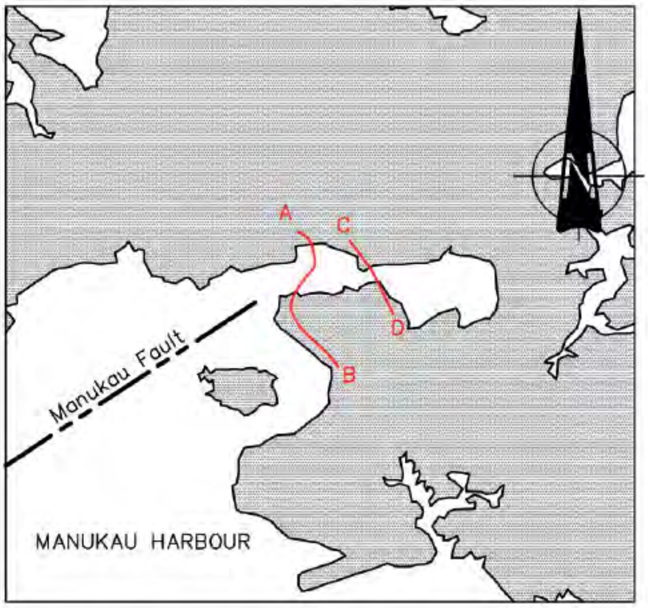


Figure 4: Postulated location of the Manukau Fault near central Auckland. Section lines A-B and C-D (Figure 5) are indicated.

In the absence of more detailed information, the Manukau Fault is shown on Figures 2 and 5 as a single major structure. However it is considered that a number of structures, each with a portion of the overall vertical displacement, are likely to be present.

An interesting feature of the geology beneath the Manukau Harbour is a paleovalley located above the inferred Manukau Fault (Figure 5, Section A-B). This appears to be the former channel of the ancestral Manukau River. Emplacement of the extensive lava field around Mangere Mountain during a Pleistocene low stand in sea level forced the Manukau River to flow around the edge of the lava, and possibly up against the footwall of the Manukau Fault. This channel was subsequently infilled with soft estuarine sediments as a result of the rise in sea level from the late Pleistocene to Holocene.

Other Block Faulting

Some small-scale block faulting is inferred in the geological model beneath the Manukau lowland (Figure 5, Section A-B). Based primarily on differences in the composition of the Waitemata Group flysch and the

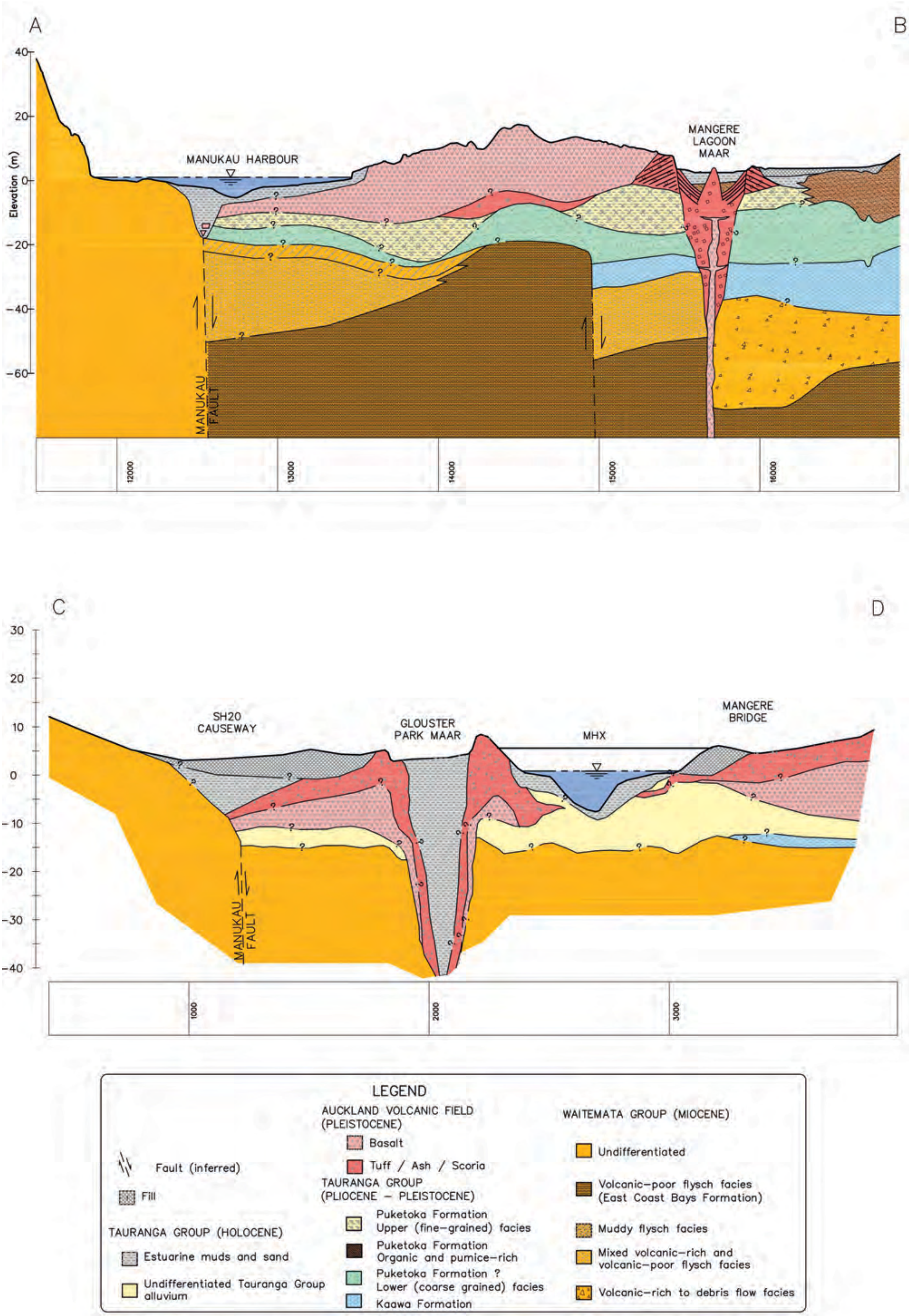


Figure 5: Geological sections across the northern Manukau Harbour showing the postulated position of the Manukau Fault.

elevation of the underlying Kaawa Fm sands, the presence of this faulting is very tentative, although the presence of a patchwork of small-scale horst and graben structures across the Manukau lowland has been well established from both boreholes and geophysical surveys (High, 1975; Allen, 1995).

Kenny (2008) postulated similar block structures across the Auckland Isthmus based on elevation differences between several flat-topped ridges, which Kermode (1992) postulated were the remains of a peneplanation surface. The (step-wise?) increase in elevation of the Waitemata Group ridges between Western Springs and the Hillsborough coast can be seen in Figure 2.

Conclusions

A review of recent and historic geotechnical data has offered an opportunity to reassess some aspects of the published geology of the Auckland Isthmus and Manukau lowlands.

The findings support earlier contentions that a major fault or fault zone is located in the northern Manukau Harbour. The assessment presented here indicates that the location of the fault presented by Searle (1964), Ballance (1965) and Searle (1981) is as good an estimate as we can currently have. Although the location of the Manukau Fault cannot be definitively proven at present, there seems little doubt that such a major structure or structural zone exists close to the northern shoreline of the Manukau Harbour.

Kenny (2008) considered it "logical to reinstate the Manukau Fault….just off the Hillsborough coastline". Here Kenny (2008) is reflecting on the absence of this major fault, which must exist in some form, from both Kermode (1992) and Edbrook (2001). Based on the information currently available, the author supports this proposition.

References

Allen, J.R. 1995: A geological model of the northern Manukau Lowlands. Unpublished MSc. Thesis, lodged in the Library, University of Auckland, Auckland, New Zealand.

Ballance, P. F. 1965: The geology and physiography of the Auckland District. Pp 8-19 in Kermode, L.O. (ed): Science in Auckland. 11th New Zealand Science Congress Handbook. 118p

Edbrook, S.W. (compiler) 2001: Geology of the Auckland area. Institute of Geological and Nuclear Sciences 1:250,000 geological map 3.

High, R. 1975: Aspects of upper Oligocene-Quaternary diastrophism in the Auckland Region (with special reference to the south Manukau area). Unpublished paper presented at Geological Society of New Zealand conference, Kaikoura. 22p.

Kenny, J. 2008: JAFfA – Just Another Fault for Auckland: Ongoing Investigation of faulting in Auckland. NZGS Newsletter 145.

Kermode, L.O. 1992: Geology of the Auckland urban area 1:50,000. Institute of Geological and Nuclear Sciences geological map 2.

Searle, E.J. 1959: The volcanoes of Ihumatao and Mangere, Auckland. N.Z.J. Geol. Geophys. 2: 870-888.

Searle, E.J. 1964: City of Volcanoes. A geology of Auckland. Paul's Book Arcade. 112p

Searle E.J. 1981: City of Volcanoes: A geology of Auckland. Revised by Mayhill, R.D. First published in 1964.

Design of Bridge Foundations in Soils Prone to Liquefaction –

Andy O'Sullivan, Senior Geotechnical Engineer, Hiway GeoTechnical Ltd. Andrew Holland, Senior Geotechnical Engineer AECOM, Hamilton

Introduction

The $ 45 million Hamilton Ring Road Upgrade Extension (HRRUE) project, which is currently being constructed by Downer New Zealand Ltd, will extend the Wairere Drive 4-lane configuration from Crosby Road to Ruakura Road.

AECOM were commissioned by Hamilton City Council to undertake the design of this section of the project. The site investigation revealed the presence of sensitive, potentially liquefiable layers at two locations, namely at the Carrs Road interchange (an overbridge and large retaining walls) and the East Coast Main Truckline Rail (ECMTR) Bridge.

AECOM carried out preliminary liquefaction assessments for both of these sites which indicated that excessive deformations were likely in a large seismic event. They concluded that some form of ground improvement would be required. A number of options were considered for ground improvement including stone columns and timber piles. However, given the sensitive nature of some of the materials and the close proximity to adjacent properties, AECOM invited Hiway GeoTechnical Ltd (HGT) to provide ground improvement options based on their Deep Soil Mixing (DSM) capability. HGT were subsequently engaged as a nominated subcontractor with Downer as the head contractor.

This article will outline the analysis carried out as part of the detailed design by HGT for the ground improvement works, including the steps taken to characterise the soils. In addition, the quality assurance (QA) and additional methods used to verify the design will be discussed.

Geology and Project Outline

The geological profile at the ECMTR Bridge consists of interbedded and intertonged layers of sandy SILTS and silty SANDS of the Hinuera Formation to a depth of over 30m. At the Carrs Road Interchange, the proposed main alignment intersects an ash hill. The geological profile here consists typically around 6m of ash or residually weathered ignimbrite, underlain by around 6-8m of moderately to highly sensitive, completely weathered (CW) ignimbrite. The sensitivity of the CW ignimbrite was observed during the site investigation when sections of the borehole core were recovered in a fully liquefied state and the CPT cone resistance was extremely low (q_c < 0.1MPa; Fr < 1%). A further complication is that at the Carrs Road interchange, the proposed main alignment will be in 6m of cut and will therefore rest on the CW ignimbrite layer.

The initial design for both locations was for the bridge decks to be supported fully on piles, with isolated MSE walls at the abutments. Ground improvements would be carried out underneath the abutments as required. In the case of the overbridge at Carrs Road, the bridge was a two-span structure with the central pier supported on driven pre-cast concrete piles. During the detailed design development phase, the design was changed to delete the abutment piles entirely and to rest the superstructure directly on the MSE walls (bankseats) relying on the ground improvement for support. This option produced considerable cost savings. As a result, the ground improvement needed to take account of the additional bridge deck loadings on the MSE walls, particularly under seismic excitation.

While the DSM method is well proven, with 1,000s of international case studies available, the simplified design methods (Porbaha et al) tend to be conservative, in the author's opinion, and do not adequately address fundamental design issues such as predicted displacements and generated shear stresses.

Therefore, for the project at Hamilton, the decision was made at an early stage of the detailed design to carry out a site specific, effective stress, time history analysis for each of the sites.

Geotechnical Assessment

While the project presented a number of geotechnical challenges, the two greatest challenges were deemed to be (a) the overall seismic response of the highly layered soils at the ECMTR bridge and (b) the characterisation of the completely weathered (CW) ignimbrite material at the Carrs Road interchange. In the case of the completely weathered ignimbrite, the characterisation required an understanding of the following:

(a) Complex mineralogy (allophanes and halloysites) hence the material has a very high water content (in excess of 100%)

(b) Susceptibility to structural collapse (based on site investigation observations where sections of core appeared to "liquefy" during investigation drilling)

(c) Determination of likely performance of material in unloading conditions (at Carrs Road the proposed alignment was in up to 6m of cut). While conventional soils in such a case would become over-consolidated, due to unloading, and hence stiffer and more pseudo-elastic, this needed to be balanced against the large increase in ratio between mean effective stress and mean total stress. This would increase the stress ratio and hence the potential risk of liquefaction under cyclic loading based on the conventional (CSR/CRR) approach.

(d) Determination of whether water content was fully held within clay structures and whether collapse of these structures (or partial collapse) under cyclic loading may result in sudden release of excess pore water pressure which in turn could lead to strain softening.

(e) Determination of volumetric characteristics of soil. (Determine whether the soil is dilative or contractive).

While the design was never intended to fully characterise these materials, sufficient understanding of the properties and their likely behaviour under cyclic loading was critical for the design.

Assessment of Performanace Under Seimic Loading

Geotechnical seismic design consists of three main steps namely:

(a) Susceptibility
(b) Triggering
(c) Deformation

A number of recognised laboratory tests exist, such as cyclic triaxial or direct simple shear tests, which are intended to determine the susceptibility of soils to liquefaction or strain softening under cyclic loading. In addition, some simplified methods such as those outlined in the NCEER (2001) report, outline in-situ methods of evaluation based on SPTs, CPTs and shear wave velocity (V_s). All of the published in-situ correlation methods are, however, based on conventional sedimentary, solid grained clean sands. Their application to weathered and alluvially re-worked materials derived from volcanic origin remains unproven.

Furthermore, their susceptibility to potential strength loss when disturbed during sample extraction, such as push tube installation, meant that any subsequent laboratory testing may not accurately capture the in-situ state of the soil. As a result, HGT opted to use the seismic dilatometer (sDMT) to provide additional interpretation of the in-situ strength parameters and stress state of the soil.

The Dilatometer (DMT) was developed by Prof Marchetti in the early 1980s, with the seismic module being added in more recent years. While no investigation technique can guarantee "zero" disturbance, the sDMT method is deemed to be the best available method for assessing in-situ ground conditions as the level of disturbance is considerably less than other in-situ methods such as CPTs or SPTs.

The sDMT method was described in detail in the December 2010 edition of the Geomechanics News (Holtrighter, O'Sullivan). Further information can be found on Prof. Marchetti's website www.marchetti-dmt.it It provides three independent parameters on which a liquefaction assessment can be based. These are:

- Shear Wave Velocity (v_s) – CRR/CSR (Andrus & Stokoe 2001)
- Dilatometer Modulus (E_D) - CRR/CSR (Tsai et al 2010)
- Horizontal Stress Index (k_D) - CRR/CSR (Tsai et al 2010)

Of these three, the Vs method is generally the most widely used and is included in the simplified (NCEER) method of liquefaction assessment. However, a review of the literature advises that the Vs method may be unconservative as, in lightly structured soils, the structure may degrade under cyclic loading.

Figures 1a and 1b below shows the comparison between all three methods for the sDMT tests at Carrs Road and also the ECMTR bridge. As the sDMT provides three separate methods for assessing liquefaction potential, it was decided that where any two of the three methods predicted the potential for liquefaction under the design seismic event, based on a CRR< CSR, that those layers would be categorised as being potentially susceptible to liquefaction and would require additional analysis. Note that in Figure 1a and 1b the material index (ID) based on the sDMT interpretation is also provided. This index is similar in principle to the material index (Ic) provided by CPTs. However with the sDMT, the classification is as follows:

$0 < I_D < 1.2$ – CLAY;
$1.2 < I_D < 1.8$ – SILT;
$1.8 < I_D$ – SAND

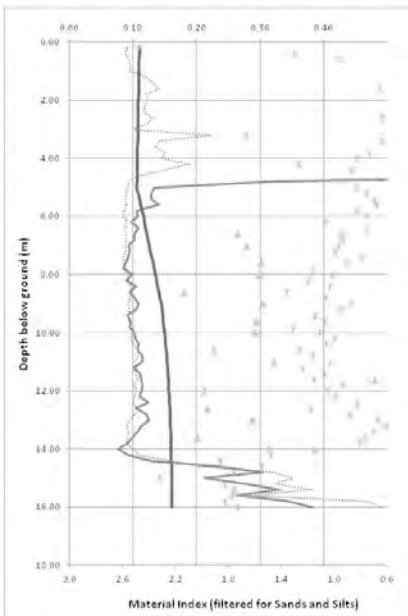


Figure 1a: CSR/CRR Graph for Carrs Road

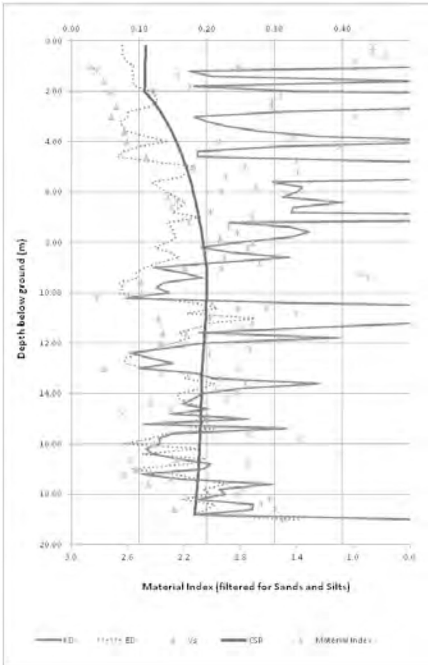


Figure 1b: CSR/ CRR Graph for ECMTR Bridge

As with CPT and SPT methods, the limitations that these methods have been developed for solid grained sedimentary, clean sands will also apply. However, the sDMT is better at determining the level of structure and stress state of the soil and hence the graphs in Figure 1a and 1b above should only be considered a "first cut" assessment.

A CRR<CSR does not necessarily imply that the soil will liquefy. First of all an assessment of in-situ stress state (position relative to steady state line) needs to be made. The difficulty with this is that steady state lines (state parameters) have not been published for either pumiceous sands or weathered ignimbrites. Indeed, it is unlikely that either soil will have steady state lines which are straight. Therefore an indirect approach needs to be adopted based on all of the available information. The initial approach was to examine the work carried out by Konrad, based on the previous work by Bean and Jeffries. Konrad proposed an interpretation of the DMT in terms of the state parameter (Ψ), whereby the DMT readings P1-P0 (ΔP) are plotted against mean effective stress (I_c). Konrad concluded that for a wide range of sands, the boundary line between contractive and dilative behaviour has the slope:

$\Delta P/I_c = 2.5$

Therefore sands with a value of ΔP versus $I_c < 2.5$ are classed as contractive and hence have a higher susceptibility to liquefaction whereas sands with a $\Delta P/I_c > 2.5$ are classed as dilative and are less likely to liquefy, although these may also be susceptible to cyclic mobility under cyclic loading.

Figures 2a & 2b below show the plots for Carrs Road and the ECMTR Bridge. Both graphs appear to indicate that the material will behave in a dilative manner and hence liquefaction (at least flow liquefaction) can be ruled out. However, further correspondence between the author and Prof Konrad and Prof Byrne (University of British Columbia) has concluded that this interpretation has some limitations as it does not fully cater for the installation effects of the DMT in the field. Hence it should only be used in conjunction with other assessment methods.

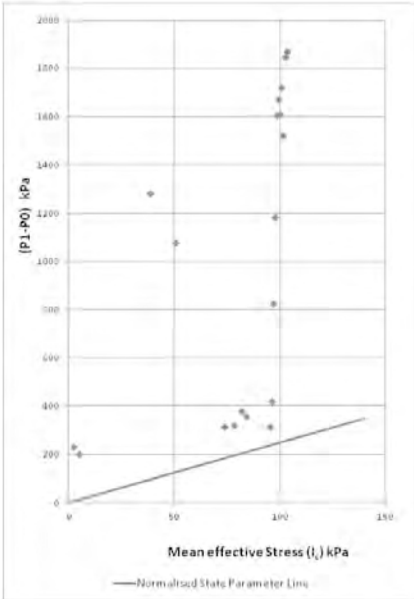


Figure 2a: DMT (ΔP) in relation to the Normalised State Parameter Line for Carrs Road

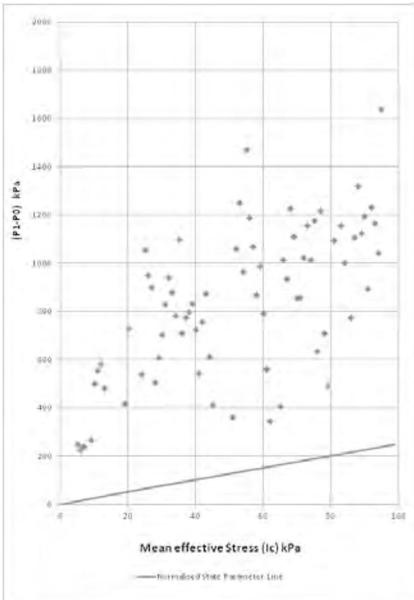


Figure 2b: DMT (ΔP) in relation to the Normalised State Parameter Line at the ECMTR Bridge

Further evidence of likely in-situ state can be obtained from the dynamic porewater pressure (u_2-u_0) response of the CPTs. In free draining granular materials, a positive u_2 may indicate loose and/or crushable behaviour and hence can provide an indication of whether the material is more likely to liquefy under cyclic loading. Figures 3a and 3b below show the dynamic porewater pressure response for the Carrs Road and ECMTR bridge sites plotted against the material index (I_D) obtained from the DMT. Soils with a material index greater than 1.8 are expected to behave in a drained manner under CPT installation. The graphs indicate that at neither site was significant dynamic pwp observed within the sandy layers.

Hence the conclusion for the sandy layers was that these were not likely to be liquefiable (flow liquefaction) based on a combination of the CSR/CRR assessment obtained from the sDMT (when filtered for sands) coupled with a review of the dynamic pwp response from the CPT.

For the remaining silts/clays, Boulanger and Idriss (2007) published an assessment of the susceptibility of fine grained materials to cyclic softening. Figure 4a and 4b shows the factor of safety plotted against depth for the Carrs Road and the ECMTR Bridge sites respectively.

Triggering Assessment

Thus far, the issue of susceptibility of the soils to potentially liquefy has been addressed. The next stage is to assess whether the liquefaction is likely to be triggered at each of the sites under the design earthquake magnitude.

As a first step, the potential degradation of the material under cyclic loading needed to be assessed. This was done by analysing the degradation of shear modulus (G/G_{max}) relationship. Both values can be obtained directly from the sDMT. The results for both sites are given in Figure 5 below.

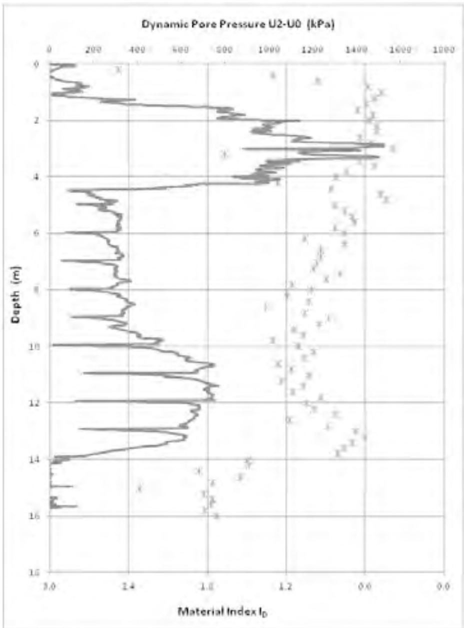


Figure 3a: Dynamic pwp response at Carrs Road against material index

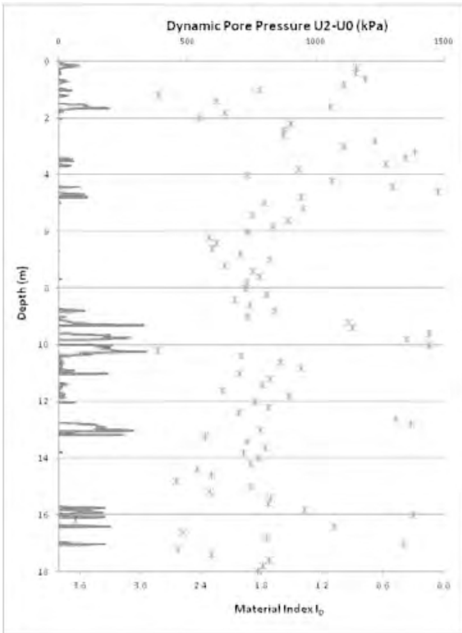


Figure 3b: Dynamic pwp response at ECMTR Bridge against material index

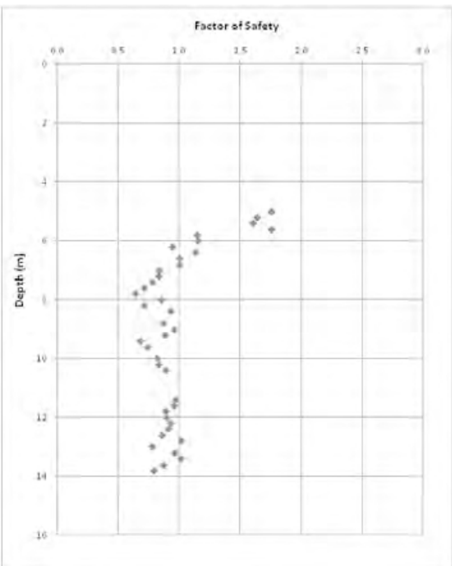


Figure 4a: FoS against strain softening for silts/clays at Carrs Road against material index

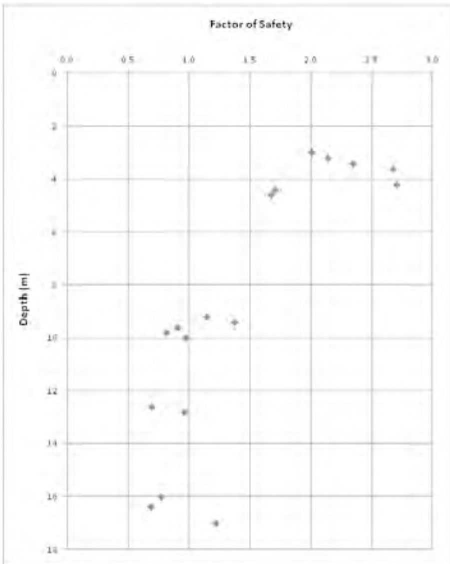


Figure 4b: FoS against strain softening for silts/clays at ECMTR Bridge against material index

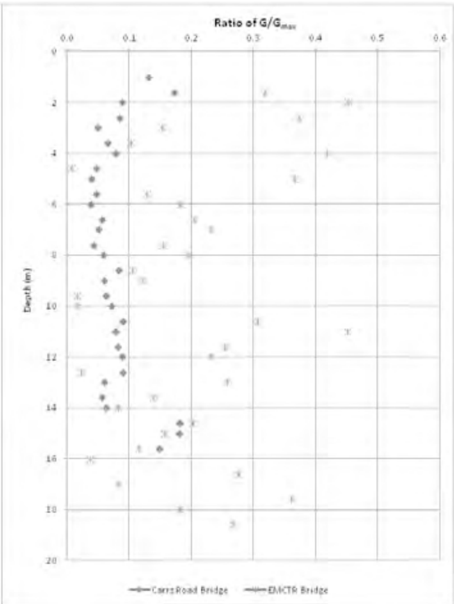


Figure 5: Plot of G/G_{max} against Depth

In the case of the completely weathered ignimbrite layer at Carrs Road, the ratio of G/Gmax was surprisingly uniform. The interpretation was that as the ratio was typically around 0.05, the material was sensitive and therefore that any soil structure (assumed from the high shear wave velocity readings) would quickly degrade. Therefore, when considering the unloading of this material, as the excavation for the main alignment progressed, the ratio of the unload/reload stiffness (E_{ur}) to the engineering strain stiffness (E_{50}) would remain high as the soil would reach a yield point at relatively low strain and behave in a plastic manner beyond this.

In the case of the ECMTR Bridge, a much lower E_{ur}/E_{50} ratio was assumed based on the higher G/G_{max} ratio and the lower initial shear wave velocity profile. However, the wide scatter in the ratio was also noted and this was compared to the borehole logs and CRR/CSR graphs developed.

The above was then used in conjunction with the plasticity index (PI), void ratio (e) and inferred OCR (cementation) to determine the damping (Rayleigh α and β) characteristics of the soil based on work by Ishibashi and Zhang as well as Vucetic and Dobry. This was particularly important for the ECMTR Bridge where the relatively thin, sensitive layers were present.

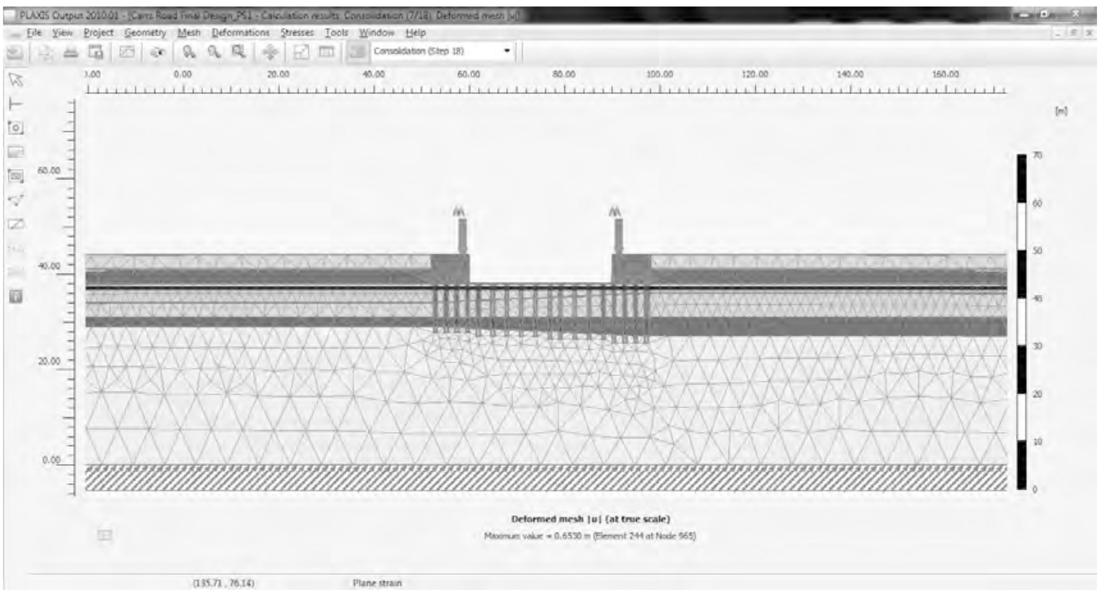
Once this assessment of the likely soil behaviour was completed, some simplified 1-D finite element models were developed to assess whether the anticipated damping (attenuation/amplification) for each soil layer was deemed correct. Two advanced constitutive soil models were considered for the analysis. These were:

(a) UBCSand model (after Park/Beatty/Byrne) and
(b) The HSsmall model (after Schanz/Vermeer)

Both models were applied to the critical layers and the most appropriate one chosen before the analysis progressed to the full-scale FE representations of the site geometry and geological profile. The finite element programme Plaxis 2010 2-D dynamic was used for the analysis.

Three corrected time history records were then run through each model. These were matched to the design response spectrum. The models were then used to determine whether potential strain softening would occur and to what extent, in each of the critical layers. Finally, it would also assess what the likely resultant deformations and stresses would be under the design seismic event (ULS).

Figure 6: FE model for Carrs Road Bridge showing DSM columns



Design of Deep Soil Mixed Ground Improvement

The deep soil mixing (DSM) method differs from other ground improvement methods, such as stone columns or vibro replacement, in that the design does not assume that significant densification takes place between the individual columns. Rather the stabilised 'block' effect is achieved by installing a grid of closely spaced DSM columns which are several hundred times stiffer than the surrounding natural soil.

Under significant loading, such as seismic excitation, stresses are taken up by the individual columns and not uniformly distributed through the overall block. The induced stresses and associated shear strains within the natural soil surrounding the columns are, therefore, significantly less than in an equivalent untreated soil block. Hence the soil does not undergo the same level of strain softening or reduction in effective stress associated with increases in pore pressure.

As deep soil mixing is a ground solidification method, whereby a cementitious binder is injected into the soil to form a structured soil column, an understanding of the intrinsic properties of the soil is essential.

The design needs to consider two aspects which are key to ensuring that the internal stability of the treated soil block is maintained under loading. These are:

(1) Whether the proposed DSM column spacing is sufficient to ensure that all of the soil mass is directly influenced by the columns (confinement)
(2) Whether the individual columns have sufficient shear and flexural strength to withstand the stresses induced under cyclic loading (ductility)

Understanding the relationship between the columns and the surrounding soil under cyclic loading is therefore crucial. The columns require the soil confinement to perform and take up the induced stresses. However, if the surrounding soil becomes stressed, this confinement may become critically reduced and the block will unravel.

Application in the Model

As DSM effectively constitutes a highly cemented soil, the individual columns are modelled as soil elements as opposed to structural (plate) elements. As described above, once the parameters have been determined, the key elements of the analysis are to ensure that the column spacing is sufficiently close that the columns are directly influencing all of the surrounding soil and that the individual columns retain sufficient shear and flexural stiffness under cyclic loading.

The models for each site were run both with and without ground improvement to compare the results. Figures 7 (a) and (b) below show the shear strain and shear stress results for a stress node mid-point between two DSM columns in one of the sensitive layers at the ECMTR bridge both with and without DSM columns installed.

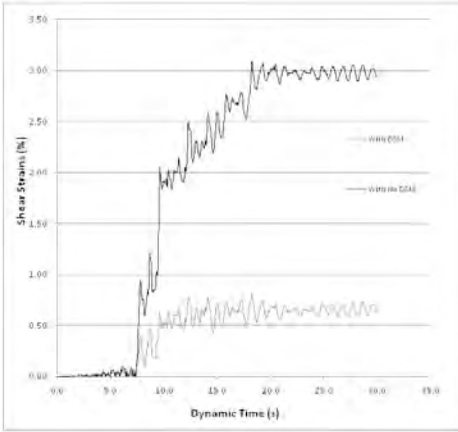


Figure 7a: Shear strain versus dynamic time

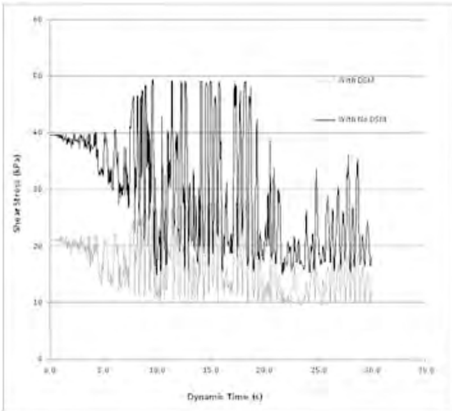


Figure 7b: Shear stress versus dynamic time

An examination of Figures 7a and 7b shows the very significant influence which the installation of the DSM columns has on the surrounding soil block. In the case of the shear strains, with no DSM columns installed, the layer undergoes two dramatic increases in non-recoverable shear strains of around 1% over consecutive cycles. Such a dramatic increase is likely to trigger the on-set of liquefaction in the layer. However, when the DSM columns are installed their influence inhibits the development of such large strains. The same can be seen in Figure 7b where the level of reverse shearing is dramatically attenuated (around 50%) at the furthest point from the DSM columns within the treated block.

Having assessed the stress ratio under seismic excitation for the soil, the next stage was to assess the stress levels in the individual DSM columns. Figure 8 shows the maximum mobilised shear stress under seismic excitation for the DSM columns at the ECMTR Bridge model.

The analysis shows that the maximum shear stress mobilised at any stress point in the DSM columns under the ULS earthquake was 620kPa with the capacity of the DSM columns being an equivalent of 780kPa. The vast majority of the DSM columns only had a maximum shear stress of around 400kPa.

Finally, the displacements were checked in the model. Two cases were run, namely with and without DSM

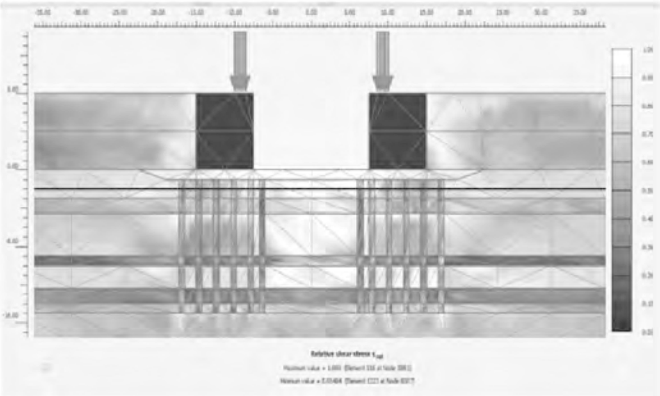


Figure 8: Maximum mobilised shear strength in DSM Columns at ECMTR Bridge.

ground improvement. The results for the total displacement at the base of the front face of the MSE wall at the Eastern Abutment at Carrs Road are shown in Figure 9 below. This shows that DSM was required to ensure that the required maximum displacement of 150mm under the ULS design earthquake was not exceeded. In the case of the DSM option, the vast majority of the displacement (138mm) was as a result of the MSE wall sliding forward on top of the DSM columns. Without the DSM, the displacement was as a result of development of a deeper seated mechanism through the CW ignimbrite layer. As a result, the MSE wall design, which was carried out separately by Reinforced Earth New Zealand, required a longer reinforcement strap length to ensure that the sliding mechanism identified was overcome.

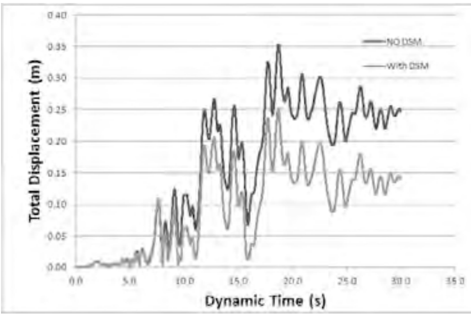


Figure 9: Comparison between total displacement predicted under ULS at base of Abutment with and without ground improvement (max. allowed 150mm)

Central Pier at Carrs Road Overbridge

At the Carrs Road Overbridge, it was initially planned to install a series of 450sq driven pre-cast concrete piles underneath the central pier. Given that the DSM rig was already on site, HGT proposed an alternative to the piles using DSM columns reinforced with a steel H-pile to provide additional bending capacity. Arup were engaged to verify the design for this element. Figure 10 below shows a photo of the installed H-piles. Capwap testing was carried out by T&T on the H-piles (310UC137), using a

Figure 10: DSM columns with 310UC piles installed for additional bending capacity at the Carrs Road central pier

6t drop hammer. The results were analysed by Arup using the GRLWEAP software package to verify that the design capacity was achieved.

On Site Quality Assurance

The design was verified on site through a series of daily Unconfined Compression Strength (UCS) tests carried out on wet grab samples taken from the DSM columns. These provided an indication of obtained strength and stiffness. The results of the obtained column strength are given in Figure 11.

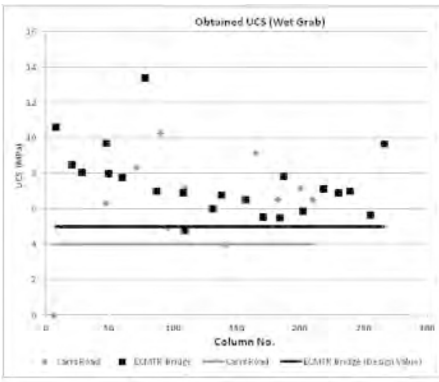


Figure 11: Graph of UCS results obtained from DSM column samples

In addition, a series of sDMT tests were carried out at both sites before and after installation of the DSM columns to verify whether any improvement effects had taken place between the DSM columns. The sDMT test positions were located 300, 600 and 900mm from the edge of one of the DSM columns within the treated soil block. The results, shown in Figure 12a and 12b below for the 300mm and 900mm offset at the ECMTR Bridge respectively, demonstrated that the installation effects of the DSM columns are very significant. This is interpreted as being as a result of the grout injection into the soil during the installation of the DSM columns. This leads to lateral (volumetric) expansion of the columns through the injection of grout which results in higher lateral

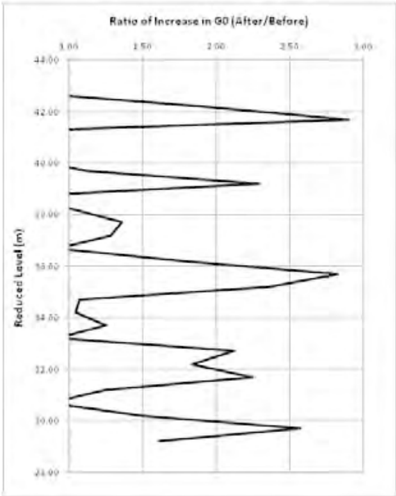


Figure 12a: Ratio of Increase in G_0 300mm outside DSM Column

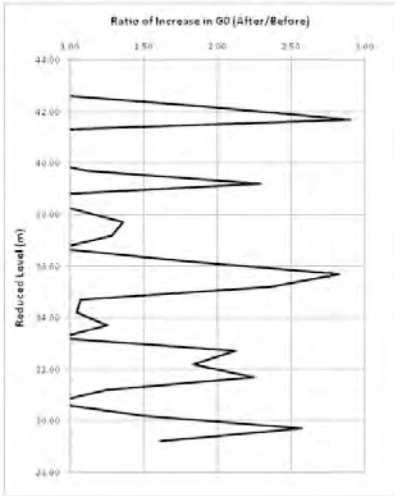


Figure 12b: Ratio of Increase in G_0 900mm outside DSM Column

confinement of the soil block (stress rotation). Notably, the greatest increase in G_0 was observed in the critical soil layers. The results were conducted independently and verified by Prof Marchetti.

Discussion and Conclusions

The biggest challenge faced during the detailed design was to characterise the soil in terms of performance under seismic loading. While laboratory tests were available, the nature of the materials makes sampling very difficult and hence the results need to be fully assessed. The combination of using side-by-side borehole logs, CPTs and sDMT proven invaluable in that each was able to provide clues as to the likely performance. Once the soil parameters had been established and the finite element models had been calibrated against the available information, then the remaining modelling was relatively straight forward.

The analysis and verification on site has proven that the DSM option was a good solution for the particular combination of factors at the site.

This project has highlighted the lack of research currently available on the engineering characteristics of pumiceous soils.

Acknowledgements

HGT would like to thank Hamilton City Council and the team at AECOM in Hamilton for the opportunity to present a case for a DSM-based ground improvement option at the site. HGT would also like to acknowledge the construction team at Downer, lead by Iain Fletcher and Stephen Delaney for working closely with us and assisting us throughout the project. HGT would like to thank the Geotechnical team at Arup in Sydney for their technical guidance and assistance throughout, in particular Sergei Terzaghi and James Dismuke. Finally HGT would like to thank Coffey Geotechnics, T&T, Opus laboratory and Ground Improvement for their assistance with the independent verification and QA sign-off work.

References

Porbaha A *"State of the Art in Deep Mixing Technology: Part IV, Design Considerations"*, Ground Improvement (2000) 3 pp. 111-125

Youd TL, Idriss IM, et al. *"Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils"* , J of Geotechnical and Geoenvironmental Engineering ASCE, Vol 127, No. 10, pp 817-833

Seed RB, Cetin KO et al. *"Recent Advances in Soil Liquefaction Engineering: A Unified and Consistent Framework"*, Keynote Address, 26th Annual Geotechnical Spring Seminar, Los Angeles Section of the GoeInstitute, American Society of Civil Engineers, HMW Queen Mary, Long Beach, California, April 30, 2003.

Holtrighter M, O'Sullivan A *"State of the Art Site Investigation Techniques – Introducing the Seismic Dilatometer (sDMT)"* NZGS Geomechanics News December 2010 (issue 80)

www.marchetti-dmt.it Website with database of key Dilatometer papers published over the past 30 years

Kung G T-C, Lee D-H, Tsai P-H *"Examination of Existing DMT-based Liquefaction Evaluation Methods by Side-by-Side DMT and CPT Tests"*, 5th International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, May 2010, San Diego, California.

Andrus RD, Stokoe KH, *"Liquefaction Resistance of Soils from Shear Wave Velocity"* J. Geotech. And Geoenviro. Eng. November 2000

Boulanger RW, Idriss IM *"Evaluation of Cyclic Softening in Silts and Clays"* J. Geotech. And Geoenviro. Eng. June 2007

Kramer S L, *"Geotechnical Earthquake Engineering"* 1996 Prentice-Hall

Plaxis 2-D 2010 Dynamic Manual, Plaxis

Byrne PM, Park SS, Beaty M *"Seismic Liquefaction: Centrifuge and numerical Modelling"*

Park SS, Byrne *"Practical Constitutive Model for Soil Liquefaction"*

GRLWEAP software, 2010 Pile Dynamics Ltd. www.pile.com

Ishibashi I, Zhang X *"Unified dynamic shear moduli and damping ratios of sand and clay"* Soils and Foundations Vol 33 No. 1 pp 182-191

Vucetic M and Dobry R *"Effect of Soil Plasticity on cyclic response"* J. Geotech Eng. ASCE Vol 117, No. 1 pp89-107

Fifty Years of the ISRM and Associated Progress in Rock Mechanics

– E.T.Brown – Senior Consultant, Golder Associates Pty Ltd, Brisbane

Abstract

The 12th Congress of the International Society for Rock Mechanics (ISRM) was held in Beijing, China, in October 2011 in the fiftieth year of the life of the Society which was established formally on 24 May 1962 in Salzburg, Austria. This paper which is a slightly revised version of one presented at the Congress (Brown, 2011), discusses the emergence of rock mechanics as a distinctive engineering and scientific discipline; the state and achievements of the discipline at the time the ISRM was founded in 1962; the events leading up to the formation of the Society; the development and achievements of the Society in the 50 years since 1962; and the progress made in the discipline of rock mechanics and rock engineering since that time.

1 Introduction

The 12th Congress of the International Society for Rock Mechanics (ISRM) fell in the fiftieth year of the life of the ISRM which was established formally on 24 May 1962 in Salzburg, Austria (Fairhurst, 2010). The Congress therefore provided an important opportunity for the Society to recall its foundation, reflect on its achievements and on the progress made in our discipline in the 50 years since its formation, and to look forward to the next 50 years.

This paper attempts the rather large and complex task of reviewing and synthesising the emergence of rock mechanics as a distinctive engineering and scientific discipline, the state and achievements of the discipline at the time the ISRM was founded in 1962, the events leading up to the formation of the Society, the development and achievements of the Society in the 50 years since 1962, and finally, the progress made in the discipline since that time. Although too young to have been involved in the work of the Society in its earliest years before the First Congress held in Lisbon in 1966, the writer has followed the developments discussed here with keen interest for about 48 of these 50 years. He is honoured and delighted to have been invited by the Society's President for 2007-2011, Professor John Hudson, to prepare and present his paper to the Congress (Brown, 2011). In a companion paper and lecture, Professor Hudson looked forward to the next 50 years of the Society and the discipline (Hudson, 2011).

Throughout this paper, the term rock mechanics will be used in the sense given in the ISRM Statutes: *"The field of rock mechanics is taken to include all studies relative to the physical and mechanical behaviour of rocks and rock masses and the applications of this knowledge for the better understanding of geological processes and in the fields of engineering"*. Thus, the term rock mechanics generally will be taken to include rock engineering, although on occasion, the two may be expressed independently as in the now commonly used term, rock mechanics and rock engineering.

2 The World in 1962

To begin, it is worth recalling what the world was like in 1962. In *world politics*, the Cold War was in full swing. The Premier of the then U.S.S.R, Nikita Kruschev, and the young President of the U.S.A., John F. Kennedy, were exercised over what became known as the Cuban missile crisis. Elsewhere, Harold Macmillan was the Prime Minster of the U.K., Charles de Gaulle was still the President of France, Jawaharlal Nehru was the Prime Minister of India and Chairman Mao Zedong was the leader of China. It has to be said that, at that time, the People's Republic of China was not at all well known to those living in what is usually referred to as "the West".

In culture – popular and otherwise – the American writer, John Steinbeck, won the Nobel Prize for Literature. There was an unhappy link to one of the life-long interests of the ISRM's Founder and First President, Professor Leopold Müller, when the world-famous Austrian violinist, Fritz Kreisler, died on 29 January. In popular music, The Beatles released their first recording and The Rolling Stones made their public debut. In the writer's favourite form of music – jazz – the pianist Herbie Hancock's tune Watermelon Man topped not only the jazz charts but the popular music charts as well for several weeks in 1962.

In sport, Brazil won the World Cup in football; the New York Yankees won the World Series in baseball; the American golfer, Arnold Palmer, won his second consecutive British Open and his third U.S. Masters titles; and an Australian, Rod Laver, won the Grand Slam in tennis.

In science and technology, the first observation of laser activity was reported; the first practical light emitting diode was produced; the world's first active telecommunications satellite, Telstar 1, was launched on 10 July; the felt-tipped pen came into being; and, although digital computing was in its infancy and the personal computer was still some years off, in a sign of things to come, the first computer game was developed for a PDP-1 computer.

3 The Emergence of Rock Mechanics as an Identifiable Discipline

The writer has argued previously that, by the early 1960s, the subject of rock mechanics, if it wasn't yet fully

Figure 1: The late Professor Leopold Müller, 1908-1988, founding President of the ISRM.

established, was well on its way to becoming established as an identifiable scientific and engineering discipline (Brown, 1999, 2002; Hood & Brown, 1999). The state of knowledge in the discipline in 1962 will be summarised in the next section. Here, it will be demonstrated that it was at least well on the way to becoming established through the appearance of specialist journals, conferences and societies.

From the mid-nineteenth century, publications on what we would now recognize as rock mechanics and rock engineering appeared in mining and engineering journals, in the publications of professional societies, and in reports of university and other research institutes in a number of countries (Obert & Duvall, 1967). In discussing what they refer to as the first stage of the development of rock mechanics, the Russian writers, Turchaninov et al. (1974) concluded that *"by the end of the 19th century, the basic patterns of deformation and fracture of rock in underground workings and on the surface had been studied, instrumented observations of the deformation of the surface had been made for the most important western European coal deposits, and the first practical rules had been suggested regarding the leaving of blocks of ore (safety pillars) and delineating the area of dangerous surface subsidence"*.

The first use of the term "rock mechanics" in English that the writer is aware of was in a paper published by Appleton (1944) in South Africa. The first issue of the first specialist journal devoted to rock mechanics and rock engineering, Geologie und Bauwesen, edited by Professor Josef Stini, was published in Vienna in 1929. Professor Leopold Müller who soon was to become the First President of the ISRM (Figure 1) succeeded Stini as editor in 1958, and in 1962 this journal changed its name to *Felsmechanik und Ingenieurgeologie* (*Rock Mechanics and Engineering Geology*). Further name changes to Rock Mechanics (Müller, 1969) and to the current *Rock Mechanics and Rock Engineering* were made in 1969 and 1983, respectively. The other major journal in the field, the *International Journal of Rock Mechanics and Mining Sciences*, was founded by Albert Roberts in the U.K. in 1963 with a primarily mining orientation (Roberts, 1963) which has disappeared with the efflux of time.

Since 1950, annual colloquia on rock mechanics had been held in Austria. In 1951, the First International Conference on Rock Pressure and Ground Support was held in Liège, Belgium. In 1958, the International Bureau of Rock Mechanics was established at the third International Strata Control Congress held in Leipzig in the then East Germany. From the early 1950s, systematic research in rock mechanics began in the U.S.A., and in 1956 the first of what soon became annual U.S. symposia on rock mechanics was held at the Colorado School of Mines. In 1962, the eighth ISRM President, Professor Charles Fairhurst, organised the 5th U.S. Symposium at the University of Minnesota (Fairhurst, 1963). In that year, the first Canadian Symposium on Rock Mechanics was held (Anon, 1963). And as well as there being publications in dedicated and more broadly-based journals and in the various conference proceedings, by the early 1960s books on rock mechanics had started to appear, notably Talobre's La Mécanique des Roches, published in Paris in 1957 (Talobre, 1957). A conference on the subject was also held in Paris in that year.

These few facts show clearly that, by 1962, the discipline of rock mechanics was identifiable and reasonably well established, at least in several parts of the world.

4 The State and Achievements of Rock Mechanics in 1962

The next question that might reasonably be asked is what were the concerns, the state of knowledge, and the achievements of the discipline of rock mechanics and rock engineering at that time? The short answer is that, with one vital deficiency, they were perhaps more advanced than might now be first supposed.

By 1962, many of the major concerns of the discipline had been clearly identified and were being investigated by both researchers and practitioners. For example, what is often referred to as the Austrian School of Rock Mechanics was well established. According to Müller (1979), as early as 1905, Albert Heim had recognized the distinction between rock material and the rock mass. The use of stereonets had been introduced by Schmidt (1925); methods of studying joint systems in rock masses had been developed by Stini in the 1920s (Stini, 1922) and subsequently extended by Müller himself (Müller, 1933, 1950, 1979); laboratory and large-scale field testing techniques were being used (e.g., Blanks & McHenry, 1945; Golder & Akroyd, 1954; John, 1962; Rocha et al., 1955); ground-support interaction concepts had been developed (Pacher, 1964; Rabcewicz, 1969); and limiting equilibrium methods were used to analyse the stability of blocks of rock in slopes and foundations (John, 1962; Terzaghi, 1962b).

Experimental investigations of the engineering properties of rocks were well underway in many parts of the world (Mayer, 1953; Obert et al., 1946). In fact, the mechanical testing of rock can be traced back at least to Coulomb and others in Europe in the mid-18th century (Coulomb, 1776; Heyman, 1972). From a perhaps more scientific, geological or geophysical rather than a rock engineering perspective, high pressure compression testing of rock material had been underway since the pioneering work of von Kármán (1911) and King (1912), followed by that of Griggs and Handin in the U.S.A. from the mid-1930s (Griggs, 1936; Handin, 1953). In Japan, Professor Kiyoo Mogi's large body of experimental work in this area was well underway by 1960 (Mogi, 1959, 2007) as was that of Dr Mervyn Paterson in Australia (Paterson, 1958, 1978). Also at a fundamental level, Professor John Jaeger's initial seminal work on the friction of rock joints and surfaces had been published (Jaeger, 1959, 1960). At the same time, large-scale field shear testing of rock discontinuities was being practiced in many parts of the world (John, 1962; Rocha et al., 1955).

Rock mechanics studies formed an important part of the investigation and design of dams and of tunnels for hydroelectric developments and other purposes (Jaeger, 1955, 1972). As early as 1951, Dr Charles Jaeger had submitted a proposal to the International Commission on Large Dams (ICOLD) "to create a sub-committee on rock mechanics" (Jaeger, 1972). Dr Klaus John later remarked that at the 7th ICOLD meeting held in Rome in 1961, "an increased emphasis on rock mechanics could be observed" (John, 1962). The ISRM's second President, Manuel Rocha, and his National Civil Engineering Laboratory in Lisbon, Portugal, was a world leader in that endeavour (Rocha, 1964; Rocha et al., 1955). And in Australia, from 1949, a team led by Tom Lang working on the monumental Snowy Mountains Hydro-electric Scheme, made significant contributions to the development of rock mechanics and rock engineering both nationally and internationally (e.g., Alexander, 1960; Brown, 1999; Lang, 1961; Moye, 1959; Pinkerton et al., 1961).

At that time, elastic stress analyses of underground excavations in rock were carried out using closed-form solutions such as those published by Terzaghi & Richart (1952). Photoelasticity was used for more complex excavation shapes (e.g., Hoek, 1963; Pinkerton et al., 1961), and an electric analogue solution was being developed in South Africa (Cook et al., 1966; Salamon et al., 1964). Digital computers and numerical methods of stress analysis such as the finite element method existed (Clough, 1960), but their serious application to rock engineering stress analyses was still a few years away (e.g., Goodman, 1966; Zienkiewicz & Cheung, 1964).

As part of this general effort, there was wide-spread interest in measuring the stresses in the Earth's crust (Judd, 1964; Terzaghi, 1962a). The Society's fourth President, Professor Pierre Habib of France, was involved in the development and application of the flat-jack method as early as 1950 (Habib, 1950; Habib & Marchand, 1952; Mayer et al., 1951). This method was also being used to measure the in situ moduli of rock masses (Habib, 1950), as were dynamic methods (Brown & Robertshaw, 1953; Evison, 1953). In 1958, one of the more important papers in the history of rock stress measurement, or estimation, as we now prefer to call it in the ISRM Suggested Methods, was published by Nils Hast in Sweden (Hast, 1958). By the early 1960s, a wide range of methods of rock stress measurement had been investigated and/or developed (see, for example, the papers in the proceedings of a 1963 conference edited by Judd (1964)). And, as has been discussed by Obert & Duvall (1967) and Hood & Brown (1999) in the context of mining rock mechanics, during the 1950s significant advances were made in the development of a range of instruments for other forms of field monitoring for rock engineering applications in both civil and mining engineering (e.g., Potts, 1957).

A significant program of research on rock mechanics as applied to deep-level hard rock mining and the associated problem of rock bursts, had been established in South Africa in 1953 (Hill, 1954, 1966). At around the same time, a similar problem was under investigation at the Kolar goldfield, India (Taylor, 1962-63). A number of towering figures in the history of our discipline, including two Müller Lecturers, Drs Neville Cook and Evert Hoek, made their initial theoretical and experimental contributions to the development of rock mechanics as part of the South African program. A central feature of that work was the experimental and theoretical study of the brittle fracture of rock using, among other things, modified Griffith crack theory (Cook, 1965; Cook et al., 1966; Hoek, 1964).

Importantly, as Hoek (2007) has argued, *"the early 1960s were very important in the general development of rock engineering world-wide because a number of catastrophic failures occurred which clearly demonstrated that, in rock as well as in soil, 'we were over-stepping the limits of our ability to predict the consequences of our actions' (Terzaghi and Voight, 1979)"*. Reference to just three of these failures will serve to make the point. In December 1959, the foundation of the Malpasset concrete arch dam in France failed with the resulting flood killing more than 400 people (Duffaut, 2011; Londe, 1987). A few weeks later in January 1960, the pillars at a coal mine at Coalbrook in South Africa collapsed with the loss of 432 lives (Bryan et al., 1964). And in October 1963, about 2500 people in the Italian town of Longarone were killed as a result of a landslide-generated wave that overtopped the Vaiont Dam (Müller, 1964). These three failures led to detailed investigations, much debate in the literature, the establishment of research programs, and the development and application of new methods of rock engineering investigation and analysis (see, for example, Bernaix, 1969; Jaeger, 1972; Londe, 1987; Londe et al., 1969; Müller, 1968; Müller-Salzberg, 1987; Salamon & Munro, 1967).

The examples and references given in the preceding paragraphs will make the essential points that by the early 1960s many of the major concerns of our discipline had been identified, many of the techniques that we use were in at least the early stages of their development, and significant advances had been made in the understanding of at least some areas of rock mechanics and in its application in rock engineering. But, as is still the case today, many significant questions remained unanswered. The most important of these, at least in the context of the ISRM, was Müller's implicit question, "what is the strength of a rock mass?" (Müller, 1967a). The background to this question and a masterly account of the progress made in answering it are given by Fairhurst (2010).

5 The Founding of the ISRM

Following a meeting of 16 men held in Professor Müller's home in Salzburg, Austria, in 1951, an Internationalen Arbeitsgemeinschaft für Geomechanik or International Working Group for Geomechanics, was established to study rock mechanics problems, essentially using the Austrian School approaches outlined above (Müller, 1967b). This group which was also known as the Salzburger Kreis or Salzburg Circle, remained largely Austrian – or at least European - until Professor Müller invited Professor Fairhurst to join at the 3rd U.S. Rock Mechanics Symposium held at the Colorado School of Mines in 1958 (Fairhurst, 2010). On 24 May 1962, Professor Müller officially registered the name of the Internationale Gesellschaft für Felsmechanik (International Society for Rock Mechanics) in Salzburg. The minutes of the Constitutional Meeting of the Society held in Salzburg on the following day lists 46 participants from Austria, Germany, Italy, Poland, U.K., U.S.A. and the former Yugoslavia. Under Professor Müller's dynamic leadership and with growing support from a number of other countries, particularly in Europe, the Society soon grew to become truly international.

As noted at the 11th ISRM Congress held in Lisbon in July 2007, the historic First Congress held in Lisbon in September 1966 was a major milestone and highlight in the early life of the Society and in the writer's own life (Brown, 2007). A total of 814 delegates from 40 countries attended that First Congress. In his Address given at the majestic Opening Ceremony, Professor Müller made this important statement (translated from the original German into English):

"Many experts agree with me that discontinuity and anisotropy are the most characteristic properties of the material rock and that the properties of jointed media depend much more upon the joints of the unit rock block system than upon the rock material. Therefore, any theoretical investigation of that material has to go its own ways, in the same way as the construction material of soil years ago suggested to soil mechanics its own methods, which differ greatly from the way of thinking of technical (or continuum) mechanics" (Müller, 1967a).

Thus, rock mechanics became recognized as being largely the study of the mechanics of discontinua as the writer's own PhD supervisor at that time, Professor Hugh Trollope, put it (Trollope, 1968; Trollope & Brown, 1965). That does not mean to say that theoretical continuum mechanics in the fields of both elasticity and plasticity did not, and does not, have application to rock mechanics and rock engineering. But it does mean that answering Professor Müller's implicit question about the strength of a rock mass requires consideration of the mechanics of a discontinuum.

An important development in the early life of the Society occurred in 1966 following the election of Manuel Rocha as our second President, when the Secretariat was established at the National Civil Engineering Laboratory (LNEC) in Lisbon, Portugal, with generous financial support provided by the Calouste Guggenheim Foundation. Since that time, our Society has been well-served by a succession of seven Secretaries-General provided by LNEC.

So by 1966, our discipline had been established, our International Society had been well and truly founded with a well-funded Secretariat in Lisbon, and our highly successful First International Congress had been held.

6 The Development & Achievements of the ISRM

The Statutes and By-laws by which the Society is governed have changed periodically over time since 1962, but the Society's essential *objectives and purposes* have remained:

- to encourage international collaboration and the exchange of ideas and information between rock mechanics practitioners;
- to encourage teaching, research, and the advancement of knowledge in rock mechanics; and
- to promote high standards for professional practice among rock engineers so that civil, mining and petroleum engineering works might be safer, more economic and less disruptive to the environment.

The *main activities* carried out by the Society in pursuit of these objectives are to:

- hold International Congresses at intervals of four years;
- sponsor a co-ordinated program of International Symposia, Regional Symposia and Specialised Conferences on topics in rock mechanics and rock engineering, organized by the National Groups of the Society;
- publish a News Journal to provide information about technology related to rock mechanics and up-to-date news on activities being carried out by the rock mechanics community;
- operate Commissions for studying scientific and technical matters of concern to the Society;

- award the Rocha Medal for an outstanding doctoral thesis, every year, and the Müller Award in recognition of distinguished service to the profession of rock mechanics and rock engineering once every four years; and
- cooperate with other international scientific associations.

The writer may be accused of bias, but he concludes that, over an extended period of time, the Society has been very successful in pursuing its objectives and purposes through these various activities, all of which have been carried out very effectively. In terms of the *objectives and purposes*, it is suggested that the Society has been demonstrably successful in pursuing at least the first two objectives. It might be argued that the third has been pursued and achieved perhaps more at an implicit, rather than at an explicit, level.

A number of the Society's activities have been very successful over the years. The excellent ISRM web-site maintained by the Secretariat indicates that, as well as 12 Congresses, beginning with a Symposium held in Madrid in October 1968, to date the Society has sponsored a total of 33 International Symposia, 68 Regional Symposia and two Specialised Conferences. The work of the various Commissions established since the time of the First Congress has brought great credit to the Society. Without wishing to minimise the contributions made by the other Commissions in the past, and those being made by the current Commissions, in the writer's opinion, one of the most impressive and lasting achievements of the Society has been the work of what is now the *Commission on Testing Methods*. That Commission began its life at the time of the First Congress in 1966 as the Commission on Standardization of Laboratory and Field Tests under the Chairmanship of Dr Don Deere of the U.S.A. It became the Commission on Testing Methods at the 4th Congress held in Montreux, Switzerland, in 1979.

A great many members of the Society have been associated with the quite detailed work of the Commission and its Working Groups over the last 45 years. However, it is believed that they will all agree that the contributions of two people have towered above those of all others – they are Dr John Franklin, who was Commission President from 1974 until 1987 when he became the Society's seventh President, and the 12th President, Professor John Hudson, who was Commission President from 1987 until 2006. The lasting contribution made by the Commission in developing a wide range of Suggested Methods for laboratory and field testing is reflected in what we call the 'Blue Book" edited by the current Commission President, Professor Resat Ulusay of Turkey, and John Hudson (Ulusay & Hudson, 2007).

Other achievements of the Society which address the objective of encouraging teaching and the advancement of knowledge in rock mechanics, have been the production of the ISRM slide collection, the introduction in recent years of the ISRM Lecture Tours and the Annual Technical and Cultural Field Trips, and the recent publication of the outcomes of the work of the Commission on Rock Engineering Design Methodology (Feng & Hudson, 2011). Many of the ISRM Lectures are now available on-line through the Society's web site. And the on-line Digital Library developed by the Secretariat "went live" in October 2010.

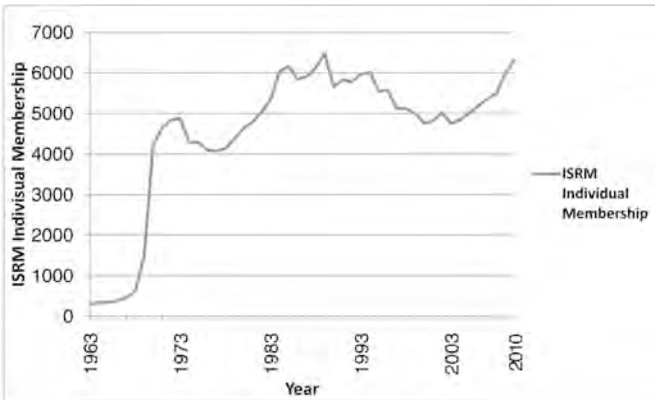


Figure 2: Total ISRM individual membership, 1963-2010.

Perhaps one disappointing feature of the Society's history is the relative stagnation at various times in individual membership numbers, both overall and in some of our six Regions of Africa, Asia, Australasia, Europe, North America and South America, and in some countries within those Regions. As shown in Figure 2, the total individual membership was only 383 at the time of the First Congress in 1966, but quickly grew to reach more than 4000 in 1970. It first passed 5000 in 1982 and 6000 in 1988, reaching a peak of 6470 in 1989. It then declined until about the year 2000 and then increased steadily to 6312 in 2010. Over the same period, the number of National Groups increased more steadily from 12 in 1966 to 48 or 49 in recent years.

In many ways, Europe has always been the numerical and financial mainstay of the Society. Figure 3 taken from the 2010 annual review shows the distribution in individual membership by Region from 2003 to 2010. As well as the high and increasing European membership shown by the yellow bars, this slide illustrates the increasing Asian membership shown in pink, mainly as a result of increases in membership in China and India.

In fact, the growth of rock mechanics in China has been a feature of the development of our Society and of our discipline over the last 25 to 30 years. The first 11 Chinese individual members joined the Society in 1979. China is now the Society's largest National Group with 558 members in 2010, followed closely by India. The writer's

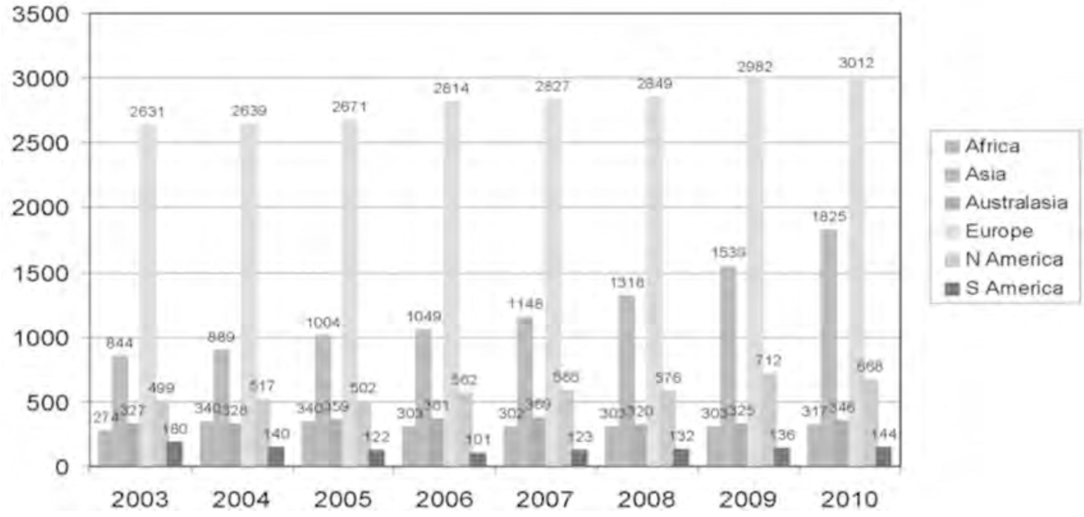


Figure 3: Individual ISRM Membership by Region, 2003-2010.

records and recollection suggest that China didn't really begin to participate in the work of the Society until about the time of the 5th Congress held in Melbourne in 1983 when 18 Chinese delegates attended. The numbers were small for the next two Congresses but then grew steadily until 54 Chinese delegates attended the 11th Congress held in Lisbon in 2007. Of course, a great many more Chinese delegates attended the recent 12th Congress!

In the 1983 to 1987 ISRM term of office, the Society had its first Chinese Vice-President in Professor Tan Tjong Kie. The first ISRM International Symposium to be held in China was held in Beijing in November, 1986. Interestingly, in a paper given to that Symposium, Chen et al. (1986) reported that a program of in situ stress measurement at the Three Gorges Dam area had been initiated by Professor Tan as early as 1958. Now the Society has its first Chinese President, Professor Xia-Ting Feng, who assumed the Presidency for the 2011 to 2015 term at the end of the 12th Congress.

The European, and particularly the English-speaking, influence in our Society is illustrated in a number of other ways, including by the list of Presidents shown in Table 1. Of the 13 ISRM Presidents to date, seven have been from European countries. Furthermore, another two of our Past Presidents, John Franklin and Charles Fairhurst, although North American when they became President, were both originally British.

Table 1: ISRM Presidents from 1962 to date.

Year	President (Country)
1962-1966	Leopold Müller (Austria)
1966-1970	Manuel Rocha (Portugal)
1970-1974	Leonard Obert (USA)
1974-1979	Pierre Habib (France)
1979-1983	Walter Wittke (Germany)
1983-1987	Edwin T Brown (UK)
1987-1991	John A Franklin (Canada)
1991-1995	Charles Fairhurst (USA)
1995-1999	Shunsuke Sakari (Japan)
1999-2003	Marc Panet (France)
2003-2007	Nielen van der Merwe (South Africa)
2007-2011	John A Hudson (UK)
2011-2015	Xia-Ting Feng (China)

The Society's major award, the Müller Award, has been awarded every four years since the first Award was made to Dr Evert Hoek at the Seventh Congress held in Aachen, Germany, in 1991. The list of Müller Award recipients given in Table 2 shows a similar European and English-speaking influence to the list of Presidents. It should be noted that all four of the North American recipients were born and educated in other countries. Furthermore, the 2007 recipient, although an Australian, actually worked in the United Kingdom for 12 years when he was most closely involved in rock mechanics and in the work of the Society. And, although he has lived in Norway for a great many years, the 2011 recipient is really an Englishman!

Annually since 1982, the Society has awarded the Rocha Medal for an outstanding doctoral thesis to honour the memory of its distinguished second President, Manuel Rocha. As might be expected, the 30 Rocha Medal recipients to date have been spread more evenly among the Society's Regions and National Groups than have been the Presidents and the Müller Award recipients with five of the Society's six Regions and 17 different National Groups being represented. Importantly, a number of the

Rocha Medal recipients have gone on to become senior and important figures in the discipline and in the Society.

Table 2: Müller Award recipients, 1991 – 2011.

Year	Award Recipient
1991	Evert Hoek (Canada)
1995	Neville G W Cook (USA)
1999	Herbert H Einstein (USA)
2003	Charles Fairhurst (USA)
2007	Edwin T Brown (Australia)
2011	Nicholas R Barton (Norway)

It can be concluded, therefore, that during the first 50 years of its life, the ISRM has pursued its stated objectives and purposes conscientiously by carrying out all of its main activities at least satisfactorily, with some being carried out to considerable effect.

7 Developements and Progress in Rock Mechanics

7.1 Scope

The task of making assessments of the main developments and the progress made in rock mechanics and rock engineering in the 50 years since the ISRM was established is a most challenging one. It is inevitable that any account such as that attempted here will reflect the writer's personal interests, knowledge and experience, and so, to at least some extent, will be idiosyncratic. It is also inevitable that, for much the same reasons, some important contributions made by some individuals and in some countries will be overlooked. In such cases, the writer offers his apologies. The references given for each of the advances listed under sub-headings 7.2 to 7.6 below are intended to provide examples of the significant contributions made to the various topics or techniques being discussed and are not intended to be either exhaustive or definitive. The references given are, quite simply, those known and available to the writer at the time of writing.

In making an assessment such as that reported here, it is first necessary to establish a framework within which the assessment will be made and the results summarised. The framework used here is the simplified general rock engineering process used by a number of authors (e.g., Brady & Brown, 2004; Hudson & Feng, 2007; Read & Stacey, 2009) as represented by the headings of sub-sections 7.2 to 7.6. This generalised process is necessarily simplified so that it can be adapted to apply to a wide range of rock engineering activities and applications. It should be emphasised that, in practice, the process is not linear but includes parallel activities and multiple feed-back loops. Figure 4 shows a rock mechanics modelling and rock engineering design flowchart which provides more detail of the design analysis stage of the overall process.

7.2 Site Investigation and Site Characterisation

Adequate site investigation and geological, geotechnical and hydro-geological site characterisation remains at the core of any successful rock engineering project. As was suggested in Section 4, the fundamentals and basic techniques of site investigation and site characterisation were established by the time the ISRM was founded. However, since that time, significant advances have been made in a number of relevant areas such as:

- drilling and borehole logging technologies, including core orientation methods and a range of geophysical logging techniques such as the Acoustic Televiewer (ATV) (Brown, 2007a; Takahashi et al., 2006);
- geophysical methods of site investigation, including seismic reflection, refraction and cross-hole tomography (Barton, 2006; Takahashi, 2004; Takahashi et al., 2006);
- methods of discontinuity data collection using photogrammetric, remote sensing, laser scanning and 3D digital imaging technologies (Gaich et al., 2007; Grobler et al., 2003; Read & Stacey, 2009; Slob et al., 2007);
- methods of carrying out and interpreting hydro-geological characterisation tests (Elsworth & Mase, 1993; Louis, 1974);
- modern rock mass classification schemes developed from the early 1970s (Barton, 2006; Barton et al., 1974; Bieniawski, 1976, 1989; Hoek, 1994; Marinos et al., 2007);
- understanding the statistics of discontinuity systems (Billaux et al., 1989; Dershowitz & Einstein, 1988; Priest, 2004; Priest & Hudson, 1981; Zhang et al., 2002) and the application of this knowledge in tools such as Discrete Fracture Network (DFN) simulations (Dershowitz, 1995; Rogers et al., 2010);
- the 3D representation of site geology, structures and geotechnical domains using engineering design and mine planning software (Beer, 2010); and
- methods of in situ stress estimation, although this process remains fraught with difficulty (Amadei & Stephansson, 1997; Fairhurst, 2003; Hudson et al., 2003).

For a range of reasons, one area of site investigation that has not developed to any great extent in the period since the early 1960s is in situ testing. Despite the range of tools now available to assist in the overall site investigation and site characterisation process, the writer's recent experience on some projects has been that basic core logging skills and the training provided for that important task sometimes leave much to be desired.

7.3 Rock and Rock Mass Properties

Key developments in the general area of estimating the

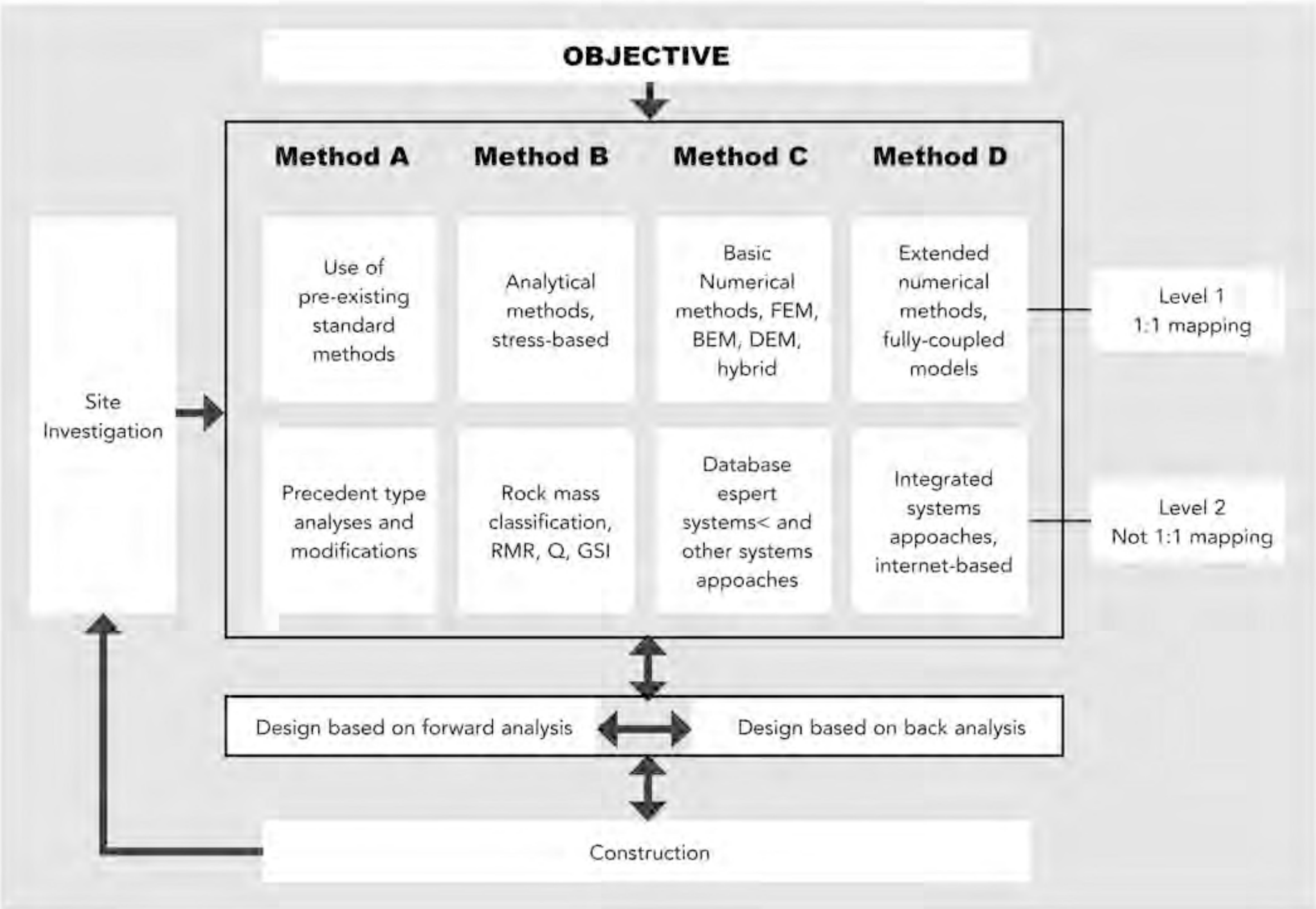


Figure 4: Flowchart of rock mechanics modelling and rock engineering design approaches (Feng & Hudson, 2004).

mechanical properties of rocks and rock masses in the last 50 years include:

- the study of the progressive breakdown of rock in laboratory tests and the development and use of servo-controlled testing techniques (Hudson et al., 1971; Martin, 1997; Wawersik & Fairhurst, 1970);
- the augmentation of these studies by the use of acoustic monitoring (Martin, 1997);
- the development and dissemination by the ISRM of a set of Suggested Methods for laboratory and field rock property tests (Brown, 1981; Ulusay & Hudson, 2007);
- the use of computerised methods of test control and automatic test data collection and analysis (Barla et al., 2007);
- the development and refinement of empirical methods of estimating rock material and rock mass strength and deformation properties (Hoek & Brown, 1980; Hoek & Diederichs, 2006; Suorineni et al., 2009);
- the introduction of fracture mechanics concepts and the development of related theory and methods of testing and analysis (Atkinson, 1987; Ulusay & Hudson, 2007; Zhou et al., 1986);
- the development of improved methods of direct shear testing of rock discontinuities under constant normal load (CNL) and constant normal stiffness (CNS) conditions and of improved understandings of the influence of surface roughness and infilling materials on the shear strengths and stiffnesses of artificial and natural discontinuities (Barla et al., 2007; Barton & Bandis, 1990; Goodman, 1989; Grasselli & Egger, 2003; Indraratna et al., 2010);
- improved fundamental understandings of fluid flow in single discontinuities and in discontinuous rock masses (Barton & de Quadros, 1997; Long & Witherspoon, 1985; Louis, 1974; Witherspoon et al., 1980); and
- the numerical modelling of the progressive fracture and break-down of rocks and rock masses using, in particular, Discrete Element Methods and bonded particle modelling (Potyondy & Cundall, 2004). A most significant development in this area has been the Synthetic Rock Mass model approach which has the potential to answer Müller's implicit question, *"what is the strength of a rock mass?"* (Fairhurst, 2010; Mas Ivars et al., 2011; Pierce et al., 2009).

Despite the advances that have been made, the sophisticated approaches being used for rock and rock mass property estimation on some rock engineering projects, and the wide-spread availability of the ISRM

Suggested Methods, the writer's experience has been that some practicing engineering geologists and geotechnical engineers do not have an adequate understanding of the purposes, complexities and requirements of good testing and rock property estimation programs. All too often, empirical approaches such as the Hoek-Brown rock mass strength criterion are treated as "black boxes" without adequate thought being given to the problem at hand (Brown, 2008; Kaiser & Kim, 2008). At the research level, some of the work being published, particularly in conference proceedings, appears to add little of value to the corpus of rock mechanics knowledge and to represent little more than "turning the handle".

7.4 Design Analysis

Methods of rock engineering design analysis have continued to develop during the last 50 years with an emphasis on numerical methods of stress and deformation analysis, but not to the exclusion of other approaches. For present purposes, it is convenient to adopt the classification of rock mechanics modelling approaches used by Feng & Hudson (2004, 2010) and illustrated in Figure 4.

In this classification, Level 1 methods are direct methods in which an explicit attempt is made to represent the geometry and mechanisms of the problem directly. They include the use of pre-existing standard methods, analytical methods, and basic and extended numerical methods. Level 2 methods are indirect methods in which the problem geometry and mechanisms are not represented explicitly. They include precedent type analysis, the use of rock mass classification schemes, basic systems methods and integrated systems approaches, possibly internet-based (Feng & Hudson, 2004; Hudson & Feng, 2007).

Of these eight approaches, pre-existing standard methods, analytical methods, precedent type analysis (but not of a formal type) and some early rock mass classification methods (but not the main methods used since the 1970s), were used before the early 1960s. Since that time, new and widely-used rock mass classification-based design methods have been introduced (Barton et al., 1974; Bieniawski, 1976, 1989; Hoek 1994; Marinos et al., 2007), and a wide range of basic and extended numerical methods have been developed and applied. There has been some further development of previously existing analytical (e.g., Diederichs & Kaiser, 1999; Sofianos et al., 1999) and empirical (e.g., Galvin et al., 1999; Hedley & Grant, 1972; Salamon & Munro, 1967) methods. In relatively recent years, artificial intelligence, expert systems, integrated intelligent, internet-based, neural network and other systems approaches have been developed and applied (e.g., Dershowitz & Einstein, 1984; Feng & An, 2004; Feng & Hudson, 2004, 2010).

As noted in Section 4 above, the application of *numerical methods*, specifically the finite element method, to rock engineering began in the early to mid-1960s. Since that time, the development and application of numerical methods of analysis has been a major feature of rock mechanics and rock engineering research and practice. A comprehensive review of the formulation of numerical methods and their application in rock mechanics and rock engineering was presented by Jing (2003). Jing's paper contained no less than 774 references to the published literature in the field to that date, but obviously does not deal with more recent developments. Here, it will be possible to refer to only a very small number of the great many important contributions made internationally to numerical modelling in rock mechanics and rock engineering.

The main numerical methods were developed originally for continuum applications but, from the 1960s, were adapted to allow for the discontinuous nature of rock masses (e.g., Goodman et al., 1968; Wittke, 1977), often treating them as equivalent continua. The fifth ISRM President, Professor Walter Wittke of Germany, made significant contributions to the rock engineering applications of the finite element method. Importantly, specific discontinuum methods of numerical analysis have been developed. In rock mechanics and rock engineering, these various methods have been applied mainly to stress and deformation analyses, but they have also been applied to the modelling of fracture processes and of fluid flow and heat transfer in rock masses. Following Jing (2003), the numerical methods that have been developed or adapted for rock mechanics and rock engineering applications may be classified as:

- Finite Element (FEM) and related methods, including meshless methods (Beck et al., 2009, 2010; Goodman et al., 1968; Wittke, 1977, 1990; Zienkiewicz, 1977);
- Finite Difference Methods (FDM) including the Finite Volume (FVM) approach, applied perhaps most notably in the well-known FLAC series of codes (Detournay & Hart, 1999; Hart et al., 2008; Itasca, 2011; Sainsbury, D.P. et al., 2011);
- Boundary Element Methods (BEM) using direct and indirect formulations (Beer & Watson, 1992; Brady, 1979, 1987; Crouch & Starfield, 1983);
- Discrete Element Methods (DEM) (Jing & Stephansson, 2007) including the explicit or Distinct Element Method (Cundall, 1971, 1987; Itasca, 2011), the implicit or Discontinuous Deformation Analysis Method (Shi & Goodman, 1985), key block theory (Goodman & Shi, 1985), DEM formulations for particle systems including bonded particle systems (Potyondy & Cundall, 2004), and quasi-static and dynamic lattice network models (Cundall, 2011; Cundall & Damjanac, 2009; Oñederra et al., 2009);
- hybrid or linked methods of a number of types (FEM/BEM, DEM/BEM, DEM/FEM – see, for

example, Beer & Watson, 1992; Brady, 1987; Elsworth, 1986; Lorig & Brady, 1982);
- DFN-based methods which may be combined with a number of the other methods (e.g., Beck et al., 2009; Pine et al., 2006; Rogers et al., 2010);
- coupled hydro-mechanical (Beck et al., 2010) and thermo-hydro-mechanical models (Detournay, 1995; Hudson et al., 2001; Stephansson et al., 1996); and
- inverse solution methods as used in back analysis in rock engineering (see Section 7.6 below).

Despite the significant advances that have been made, it must be recognised that the successful application of numerical methods in rock engineering design analyses depends to a great extent on the geotechnical models, the constitutive models and boundary conditions developed from the site characterisation data. Because of the difficulty of defining some of the input data deterministically, probabilistic or stochastic methods are often used to represent the rock mass geometry, the mechanical properties of rocks and rock masses, and in the analyses themselves (Einstein & Baecher, 1983; Priest & Brown, 1983). When formal probabilistic or stochastic methods are not used, a range of input data may be used in sensitivity studies. As Starfield & Cundall (1988) pointed out, rock mechanics problems are data-limited problems that cannot be modelled unambiguously.

As the numerical methods of design analysis outlined here were developed, high levels of expertise in the numerical methods themselves, and in their application in rock mechanics and rock engineering, were developed by a number of individuals and groups internationally. However, it has been the writer's experience that, despite the vast range of knowledge and experience that is now available in this field, the application of these methods in engineering practice often suffers because some analysts regard the computer codes used as "black boxes" and pay insufficient attention to the mechanics of the problems concerned, the input data and to the meaning or "believability" of the results obtained. Furthermore, there is a tendency to disregard features of a problem that are not catered for specifically in the software selected or available for use. Although the paper was written more than 20 years ago, the writer considers that many of those seeking to use modern numerical methods in rock engineering design analyses should pay greater attention to the guidance provided by Starfield & Cundall (1988), especially their warning that numerical modelling is an aid to thought rather than a substitute for thinking.

7.5 Excavation and Support and Reinforcement

7.5.1 Excavation

In the last 50 years, significant advances have been made in understanding the underlying mechanics and in developing the techniques and technologies associated with the two generic methods of rock excavation – drilling-and-blasting and mechanical excavation. In the 1950s and 1960s there was considerable research interest in the mechanics of percussive drilling, rock fragmentation by blasting and the mechanics of rock cutting, so much so that sessions on what came to be called rock dynamics were usually included in the programs of general rock mechanics symposia and conferences (e.g., Fairhurst, 1963). While these fundamental issues remain of concern to mainstream rock mechanics, it is the writer's impression that they have now become something of a special interest with their own specialist conferences, interest groups and societies having been established.

West (1988) traced the development of drilling and blasting and mechanical excavation technologies in the international tunnelling industry from the 1850s to the 1980s. The last 50 years have seen a range of developments in *drilling and blasting* technologies, many of them originating in Sweden. They include:
- integrated drilling systems with electronic controls and a range of drill support software for drill pattern design, navigation, automatic drilling and measurement while drilling (MWD) (Schunnesson, 2009);
- large diameter blast hole drilling for both surface and underground applications;
- new and improved explosive types for a variety of applications;
- electronic detonators;
- blast monitoring systems to improve blasting operations (McKenzie, 1987);
- blast vibration monitoring to assess environmental and other impacts (Dowding, 1985); and
- improved understanding of drilling and blasting processes through a range of industrial and research-level experimental, theoretical and computational studies (e.g., Furtney et al., 2009; Minchinton & Dare-Bryan, 2005; Ouchterlony & Moser, 2006).

Building on a range of previous studies, Hustrulid (2010) provides a detailed account of current blast design practice for development drifts in hard rock underground mining, while Williams et al. (2009) give an account of blasting practices, including controlled blasting, in large open pit mines.

In the area of *mechanical excavation*, new, larger and more powerful machines of a range of types have been developed for civil engineering and for soft rock mining, including coal mining, but not as yet with any great success for hard rock mining. The development of full-face tunnel boring machines (TBMs) can be traced back to the mid-19th century (West, 1988) but successful hard rock TBM tunnelling dates back only to the 1950s. The largest full-face tunnelling machines are now some 15 m in diameter and can excavate in a range of ground conditions including very strong rocks (Zhao & Gong, 2006). Rock mechanics-based data and methodologies are used in the selection of modern TBMs and in computer simulations of their performance (Barton, 2000; Gong & Zhao, 2009; Rojek et al., 2010; Zhao & Gong, 2006). As with excavation by drilling and blasting, improvements in the performance, automation and control of TBMs and other types of mechanical excavators such as road headers and longwall coal shearers, are being achieved through industrial and research-level experimental, theoretical and computational studies (e.g., Rojek et al., 2010; Pichler et al., 2010).

7.5.2 Support and reinforcement

Following Windsor & Thompson (1993), a distinction will be made between support and reinforcement, although the two are often treated together as in the term *ground support*. *Support* is the application of a reactive force to the surface of the excavation while *reinforcement* is a means of improving the overall rock mass properties from within the rock mass by techniques such as rock and cable bolts.

An essential concept in the mechanics of the support and reinforcement of underground excavations is ground-support interaction as represented in ground-support interaction diagrams. This concept had been developed by the Austrian School (Pacher, 1964; Rabcewicz, 1969) but has since been extended through the convergence-confinement method to which the 10th ISRM President, Marc Panet of France, made important contributions (Panet, 1993, 1995), and a wide range of linear and non-linear closed-form and numerical solutions for ground response curves and the characteristic curves for support and reinforcing elements and systems (e.g., Carranza-Torres & Fairhurst, 1999; Daemen, 1977). Despite the advances that have been made in incorporating ground support and its effects into numerical analysis codes (e.g., Itasca, 2011), as noted by Jing (2003), the numerical modelling of all aspects of support and reinforcement elements and systems, including their interfaces with the rock mass, still provides some challenges.

Considerable advances have been made in the development of support and reinforcement techniques and technology, including several new rock bolt types, for example, those with yielding or dynamic capabilities for use in rock burst prone environments (Falmagne & Simser, 2004; Ortlepp, 2007); cable bolts, particularly, but not exclusively, for application in the mining industry (Hutchinson & Diederichs, 1996; Windsor, 2004); shotcrete, particularly fibre-reinforced shotcrete and the wide-spread use of the wet mix process (Bernard, 2010); mesh and thin sprayed liners (Potvin et al., 2004); the corrosion protection of rock bolts, cable bolts and ground anchors (Windsor, 2004); the static and dynamic testing of support and reinforcement elements (Player et al., 2008); and understanding the corrosion process in rock bolts and cables in corrosive environments (Villaescusa et al., 2008). A range of design methods for support and reinforcement systems have now been developed (e.g., Barrett & McCreath, 1995; Barton et al., 1994; Hoek et al., 2008; Hutchinson & Diederichs, 1995; Pells, 2002) to replace, or be used in conjunction with, the largely empirical methods that were used earlier in the 50-year period and still find wide-spread use today.

7.6 Monitoring and Back Analysis

Monitoring the performance of mining and civil excavations in rock had been carried out for many years before the establishment of the ISRM in 1962, and had become an integral part of rock engineering practice through the observational method. Early monitoring used mechanical and optical, and then electrical, electro-optical, electronic and microseismic techniques (see, for example, Brady & Brown, 2004; Dunnicliff, 1988; Franklin & Denton, 1973; Kovari et al., 1979; Windsor, 1993). In open pit mining, for example, GPS, photogrammetry, laser scanning (LiDAR), radar and satellite imaging techniques and systems are now also used to monitor slope movements, in particular (Girard & McHugh, 2001; Hawley et al., 2009; Herrera et al., 2010; Sakurai et al., 2009).

Subsequently, the on-line acquisition, storage, processing, management, interpretation and reporting of rock engineering monitoring data followed the introduction of computer and digital technologies (Gilby & Socol, 2010; Kimmance, 1999). Figure 5 illustrates the components of a current instrumentation data management and monitoring system. The formalisation and power of these processes today and their potential to support well-informed decision making and risk management systems (e.g., Akutagawa, 2010; Dewynter et al., 2010; Hawley et al., 2009; Schubert, 2006) represents a great advance on the comparable processes available 50 years ago, although the purposes and principles of good monitoring programs remain essentially unchanged (e.g., Franklin, 1977; Kovari & Amstad, 1993). There can be little doubt that modern monitoring systems have contributed significantly to the rock engineering achievements to be outlined in Section 7.7 below.

One of the common objectives of monitoring formalised by the seventh ISRM President, Dr John Franklin of Canada, is to check the validity of the assumptions, conceptual models and values of rock mass properties used in design calculations (Franklin, 1977). Originally, and often still today, these checks were made, and values of rock mass properties and the in situ stresses estimated, using a process of trial and error or curve fitting using forward analyses based on the theory of elasticity. However, in the late 1970s and early 1980s, it was realised that it was possible to improve this process by developing and applying more formal back analysis techniques. These

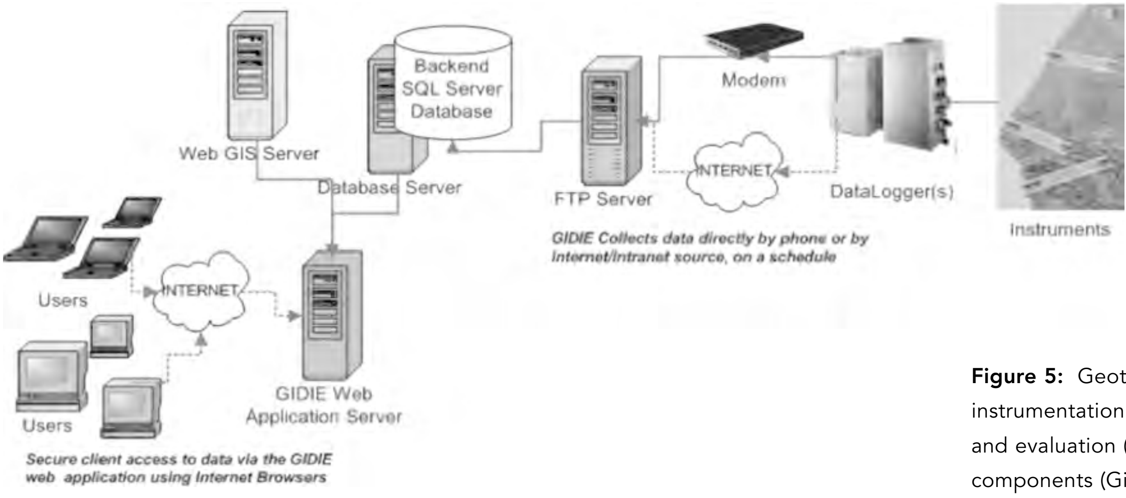


Figure 5: Geotechnical instrumentation data interpretation and evaluation (GIDE system components (Gilby & Socol, 2010)

techniques used essentially two approaches, the inverse and the identification or calibration methods (Gioda, 1980). In the earliest use of the inverse method in rock mechanics known to the writer, Kirsten (1976) used measured displacements in a slope and displacements calculated using the FEM to back calculate values of the elastic moduli.

The ninth ISRM President, Professor Shunsuke Sakurai of Japan, was heavily involved in the development of back analysis methods early in their history (Sakurai & Takeuchi, 1983) and subsequently (Sakurai & Akutagawa, 1995; Sakurai et al., 2009). Although formal back analysis methods were applied originally to 2D linear elastic problems, the theory was soon extended to the three dimensional and non-linear elasto-plastic problems encountered in rock engineering. A wide range of innovative techniques for solving the sets of non-linear equations involved have since been developed (Feng et al., 2004; Gioda & Sakurai, 1987; Sakurai, 1993).

Professor Sakurai has also emphasised the importance of monitoring the performance of excavations in rock for purposes other than the use of the measurement data in back analyses. For example, in order to assess the stability of tunnels from measured displacements, he proposed the concept of critical direct and shear strains, and on the basis of the critical strain, proposed hazard warning levels for the measured displacements as well as for the measured strains in tunnels Sakurai (1997, 1999). Hoek (2001) discusses a similar approach based on the normalised radial displacement at the tunnel boundary.

7.7 Rock Engineering Applications

Over the last 50 years, the pre-existing rock mechanics knowledge outlined in Section 4, and the further development of that knowledge outlined thus far in Section 7, have contributed to some remarkable rock engineering achievements in the general area of earth resources engineering (Fairhurst, 2011), including civil, mining, petroleum, energy resources and environmental engineering. Space limitations preclude reference to all but a very few of these achievements.

In *civil engineering*, the scale of rock engineering projects has steadily increased in terms of project dimensions, costs and environmental significance (Feng & Hudson, 2004). We might think, for example, of achievements such as the 62 m span cavern for the Olympic Ice Hockey stadium at Gjøvik, Norway (Barton et al., 1994); the helical underground car park for the Sydney Opera House, Australia, possibly the widest shallow-cover rock cavern in the world (Pells, 2002; Pells et al., 1991); the Three Gorges Dam and the associated ship locks and hydro-electric developments in China (Feng & Hudson, 2004; Liu et al., 2003a,b); and the long European alpine tunnels such as the Lötschberg and Gotthard base tunnels excavated under difficult conditions including squeezing and faulted ground and brittle rock under high stress at great depth (Hagedorn et al., 2007; Rojat et al., 2008).

In *mining engineering*, greater numbers of larger, deeper and more productive open pit mines with optimised slope angles have been designed and operated effectively using a range of advances in rock mechanics and rock slope engineering dating back to the seminal work of Hoek & Bray (1974) and earlier. Read & Stacey (2009) provide a detailed account of the state of this particular art. In underground metalliferous mining over the last 50 years, rock mechanics has contributed significantly to the mining of highly stressed, brittle, tabular orebodies in the deep-level gold mines of South Africa (Cook et al., 1966; Ryder & Jager, 2002), and to the development and implementation firstly of cut-and-fill and then of long hole open stoping and bench stoping methods (Brady & Brown, 2004;Villaescusa, 1996, 2008). Most importantly, the last 20 years has seen an increased emphasis on underground mass mining methods using highly productive and cost effective sub-level and block and panel caving methods at greater depths and in stronger rocks (Brown, 2007a, b; Chitombo, 2010). Caving processes and cave propagation are now being modelled successfully (Sainsbury, B.L. et al., 2011). In underground coal mining, larger and more productive longwall faces have been introduced as has longwall top coal caving to mine thicker seams, especially in China (Alehossein & Paulsen, 2010; Vakili & Hebblewhite, 2011).

Rock mechanics has become increasingly important in *petroleum engineering* since the 1970s as production has taken place from deeper and more difficult geological settings (Roegiers, 1999). Rock mechanics has contributed to the achievements of the petroleum and gas industry in areas such as geological and fracture modelling, including DFN modelling; seismic tomography and other geophysical techniques; borehole mechanics and wellbore stability; the measurement of in situ stresses; hydraulic fracturing and methods of enhanced oil recovery; poromechanics and coupled thermo-hydro-mechanical processes; the control of solids (generally sand) production; smart drilling including drilling deviated holes and drilling in deep water; and reservoir geomechanics (Detournay, 1995; Fjaer et al., 2008; Roegiers, 1999; Schutjens, 2009). Rock mechanics has also contributed to a number of other achievements in the exploitation of a range of energy resources, including hot, dry rock geothermal energy at depth (Thorsteinsson et al., 2008), the underground storage of oil and gas (You et al., 2006), and underground radioactive waste repository planning and design (Fairhurst, 2004; Hudson, 2010; Hudson et al., 2001), and the deep injection of solid and liquid wastes (Dusseault, 2010). Conversely, research in these areas, including through field trials, has contributed to basic and applied rock mechanics knowledge.

8 Conclusions

This necessarily brief overview of the development and achievements of the ISRM and of the discipline of rock mechanics and rock engineering in the 50 years since the ISRM was founded in 1962 shows clearly that much of significance has been achieved. New basic understandings and engineering tools have been developed to support an increasingly wide range of rock engineering applications. Many of the advances made in rock mechanics research, in the tools and techniques now available for data collection and analysis, and in the application of rock mechanics in engineering practice, have been enabled by modern digital computing, information and communications technologies. Others have drawn on advances made in other branches of science and technology. And during this first 50 years of its life, the ISRM has pursued its stated objectives and purposes conscientiously by carrying out all of its main activities at least satisfactorily, with some being carried out to considerable effect.

For those involved, the last 50 years has been an exciting, satisfying and possibly fortuitous time in which to have been involved in rock mechanics and the ISRM. However, increases in knowledge in our and other disciplines, and change and further development of our institutions and in society at large, are inevitable. From a rock mechanics and rock engineering perspective, the future remains full of promise, challenge and excitement.

9 Acknowledgements

The writer wishes to record his appreciation of the support and assistance of the following members of the international rock mechanics community in providing him with information and material used in the preparation of this paper: Nick Barton, David Beck, Pierre Berest, Pierre Duffaut, Maria de Lurdes Eusébio, Charles Fairhurst, Xia-Ting Feng, John Gilby, Nuno Grossmann, Pierre Habib, Evert Hoek, John Hudson, Luís Lamas, Italo Oñederra, Matt Pierce, Eda Quadros, Bre-Anne Sainsbury, David Sainsbury, Shun Sakurai, Penny Stewart and Walter Wittke. He also wishes to thank Rob Morphet and the management of Golder Associates, Brisbane, for their support during the preparation of this paper and Jillian Roche and Brooke Anderson for their skilful assistance in readying the paper for publication.

10 References

Akutagawa, S. 2010. On site visualisation as a new paradigm for field measurement in rock engineering. In K. G. Sharma, T. Ramamurthy, V. K. Kanjlia & A. C. Gupta (eds), *Advances in Rock Engineering, Proceedings ISRM International Symposium 2010 & 6th Asian Rock Mechanics Symposium*, New Delhi, 23-27 October, KN 34 - KN 45. New Delhi: Central Board of Irrigation & Power.

Alehossein, H. & Paulsen, B. A. 2010. Stress analysis of longwall top caving. *International Journal of Rock Mechanics & Mining Sciences*, 47(1): 30-41.

Alexander, L. G. 1960. Field and laboratory tests in rock mechanics. *Proceedings 3rd Australia-New Zealand Conference on Soil Mechanics & Foundation Engineering,* Sydney, 161-168. Sydney: Institution of Engineers, Australia.

Amadei, B. & Stephansson, O. 1997. *Rock Stress and its Measurement*, 512 p. Dordrecht: Kluwer.

Anon, 1963. *Proceedings Rock Mechanics Symposium*, McGill University, Montreal, 7-8 September, 1962, 218 p. Ottawa: Mines Branch, Department of Mines & Technical Surveys.

Appleton, E. 1944. Scientific research: fundamentals of its application to rock mechanics. *South African Mining & Engineering Journal,* 55(1): 519-520.

Atkinson, B.K. (ed.) 1987. *Fracture Mechanics of Rock*, 534 p. London: Academic Press.

Barla, G., Barla, M., Camusso, M. & Martinotti, M. E. 2007. Setting up a new direct shear testing apparatus. In L. Ribeiro e Sousa, C. Olalla & N. F. Grossmann (eds), *Proceedings 11th Congress, International Society for Rock Mechanics*, Lisbon, 9-13 July, 1: 415-418. Leiden: Taylor & Francis.

Barrett, S. V. L. & McCreath, D. R. 1995. Shotcrete support design in blocky ground: towards a deterministic approach. *Tunnelling & Underground Space Technology*, 10(1): 79-89.

Barton, N. 2000. *TBM Tunnelling in Jointed and Faulted Rock*, 172 p. Rotterdam: Balkema.

Barton, N., 2006. *Rock Quality, Seismic Velocity, Attenuation and Anisotropy*, 729 p. London: Taylor & Francis.

Barton, N. & Bandis, S. C. 1990. Review of predictive capabilities of JRC-JCS model in engineering practice. In N. R. Barton & O. Stephansson (eds), *Rock Joints, Proceedings International Symposium on Rock Joints*, Loen, 4-6 June, 603-610. Rotterdam: Balkema.

Barton, N., By, T. L., Chryssanthakis, P., Tunbridge, L., Kristiansen, J., Løset, F., Bhasin, R. K., Westerdahl, H. & Vick, G. 1994. Predicted and measured performance of the 62 m span Norwegian Olympic Ice Hockey Cavern at Gjøvik. *International Journal of Rock Mechanics &*

Mining Sciences, 31(6): 617-641.
Barton, N. & de Quadros, E. F. 1997. Joint aperture and roughness in the prediction of flow and groutability of rock masses. In K. Kim (ed.), *Linking Science to Rock Engineering, Proceedings 36th U.S. Rock Mechanics Symposium & ISRM International Symposium*, New York, 29 June – 2 July, 2: 907-916. New York: Columbia University.
Barton, N., Lien, R. & Lunde, J. 1974. Engineering classification of rock masses for the design of tunnel support. *Rock Mechanics*, 6(4): 189-236.
Beck, D. A., Fillery, B. & Reusch, F. 2010. 3d hydro-mechanical simulation of faulted open pit slopes. Proceedings 44th U.S. *Rock Mechanics Symposium & 5th U.S. - Canada Rock Mechanics Symposium*, Salt Lake City, 27-30 June, Paper ARMA-425, 6p (on CD-ROM).
Beck, D. A., Pfitzner, M. J., Arndt, S. M. & Fillery, B. 2009. Estimating rock mass properties and seismic response using higher order, discontinuous, Finite Element models. In M. Diederichs & G. Grasselli (eds), *Rock Engineering in Difficult Conditions, Proceedings 3rd Canada - U.S. Rock Mechanics Symposium & 20th Canadian Rock Mechanics Symposium*, Toronto, 9-15 May, 12 p (on CD-ROM).
Beer, G. (ed.) 2010. *Technology Innovation in Underground Construction*, 504 p. Leiden: CRC Press/Balkema.
Beer, G. & Watson, J. O. 1992. *Introduction to Finite and Boundary Element Methods for Engineers*, 509 p. Chichester: John Wiley.
Bernaix, J. 1969. New laboratory methods of studying the mechanical properties of rock. *International Journal of Rock Mechanics & Mining Sciences*, 6(1): 43-90.
Bernard, S. (ed.) 2010. *Shotcrete: Elements of a System, Proceedings 3rd International Conference on Engineering Developments in Shotcrete*, Queenstown, 15-17 March, 310 p. Leiden: CRC Press/Balkema.
Bieniawski, Z. T. 1976. Rock mass classifications in rock engineering. In Z. T. Bieniawski (ed.), *Proceedings Symposium on Exploration for Rock Engineering*, Johannesburg, 1-5 November, 1: 97-106. Cape Town: Balkema.
Bieniawski, Z. T. 1989. *Engineering Rock Mass Classification*, 251 p. New York: John Wiley.
Billaux, D., Chiles, J. P., Hestir, K. & Long, J. 1989. Three-dimensional statistical modelling of a fractured rock mass – an example from the Fanay-Augères Mine. *International Journal of Rock Mechanics & Mining Sciences*, 26(3-4): 281-299.
Blanks, R. F. & McHenry, D. 1945. Large triaxial testing machine built by Bureau of Reclamation. *Engineering News Record*, 135(6): 171-172.
Brady, B. H. G. 1979. A direct formulation of the boundary element method of stress analysis for complete plane strain. *International Journal of Rock Mechanics & Mining Sciences*, 16(4): 235-244.
Brady, B. H. G. 1987. Boundary element and linked methods for underground excavation design. In E. T. Brown (ed.), *Analytical & Computational Methods in Engineering Rock Mechanics*, 164-204. London: Allen & Unwin.
Brady, B. H. G. & Brown, E. T. 2004. *Rock Mechanics for Underground Mining*, 3rd edn, 628 p. Dordrecht: Kluwer.
Brown, E. T. (ed.) 1981. *Rock Characterization, Testing and Monitoring – ISRM Suggested Methods*, 211 p. Oxford: Pergamon Press.
Brown, E. T. 1999. Rock mechanics and the Snowy Mountains Scheme. In *The Spirit of the Snowy Fifty Years On, Proceedings 1999 Invitation Symposium, Australian Academy of Technological Sciences & Engineering*, Cooma, 23-24 November, 89-101. Melbourne: Australian Academy of Technological Sciences & Engineering.
Brown, E. T. 2002. Rock mechanics in Australia. *International Journal of Rock Mechanics & Mining Sciences*, 39(5): 529-538.
Brown, E. T. 2007a. *Block Caving Geomechanics*, 2nd edn, 696 p. Brisbane: JKMRC.
Brown, E. T. 2007b. Rock mechanics – the basic mining science: challenges in underground mass mining. In L. Ribeiro e Sousa, C. Olalla & N. F. Grossmann (eds), *Proceedings 11th Congress, International Society for Rock Mechanics*, Lisbon, 9-13 July, 3: 1335-1347. Leiden: Taylor & Francis.
Brown, E. T. 2008. Estimating the mechanical properties of rock masses. In Y. Potvin, J. Carter, A. Dyskin & R. Jeffrey (eds), *Proceedings 1st Southern Hemisphere International Rock Mechanics Symposium*, Perth, 16-19 September, 1: 3-22. Perth: Australian Centre for Geomechanics.
Brown, E. T. 2011. Fifty years of the ISRM and associated progress in rock mechanics. In Q. Qian & Y. X. Zhou (eds), *Harmonising Rock Engineering and the Environment, Proceedings 12th Congress, International Society for Rock Mechanics*, Beijing, 16-21 October, 1: (in press). Leiden: CRC Press/Balkema.
Brown, P. D. & Robertshaw, J. 1953. The in-situ measurement of Young's Modulus for rock by a dynamic method. *Géotechnique*, 3(7): 283-286.
Bryan, A., Bryan, J. G. & Fouché, J. 1964. Some problems of strata control and support in pillar workings. *The Mining Engineer*, 123(41): 238-266.
Carranza-Torres, C. & Fairhurst, C. 1999. The elasto-plastic response of underground excavations in rock masses that satisfy the Hoek-Brown failure criterion. *International Journal of Rock Mechanics & Mining Sciences*, 36(6): 777-809.
Chen, Y., Liu, Y., Zhang, M. & Chen, R. 1986. A preliminary study of in-situ stress field in the Three-Gorge Dam area. *Proceedings International Symposium on Engineering in Complex Rock Formations*, Beijing, 3-7 November, 149-162. Beijing: Science Press.
Chitombo, G. P. 2010. Cave mining – 16 years after Laubscher's 1994 paper "cave mining – state of the art". In Y. Potvin (ed.), *Caving 2010, Proceedings 2nd International Symposium on Block & Sublevel Caving*, Perth, 20-22 April, 45-61. Perth: Australian Centre for Geomechanics.
Clough, R. W. 1960. The finite element method in plane stress analysis. *Proceedings 2nd A.S.C.E. Conference on Electronic Computation*, Pittsburgh, September, 345-378.
Cook, N. G. W. 1965. The failure of rock. *International Journal of Rock Mechanics & Mining Sciences*, 2(4): 389-403.
Cook, N. G. W., Hoek, E., Pretorius, J. P. G., Ortlepp, W. D. & Salamon, M. D. G. 1966. Rock mechanics applied to the study of rockbursts. *Journal, South African Institute of Mining & Metallurgy*, 66(10): 436-528.
Coulomb, C. A. 1776. Essai sur une application des régles de maximis et minimis à quelques problèmes de statique, relatives à l'architecture. *Mémoires de Mathématique et de Physique, l'Académie Royale des Sciences*, 7: 343-382.
Crouch, S. L. & Starfield, A. M. 1983. *Boundary Element Methods in Solid Mechanics*, 322 p. London: Allen & Unwin.
Cundall, P. A. 1971. A computer model for simulating progressive, large-scale movements in blocky rock systems. In *Rock Fracture, Proceedings International Symposium on Rock Mechanics*, Nancy, 4-6 October, 1: Paper II-8.
Cundall, P. A. 1987. Distinct element models of rock and soil structure. In E. T. Brown (ed.), *Analytical & Computational Methods in Engineering Rock Mechanics*, 129-163. London: Allen & Unwin.
Cundall, P. A. 2011. Lattice method for modelling brittle, jointed rock. In D. P. Sainsbury, R. D. Hart, C. L. Detournay & M. J. Nelson (eds), *Continuum and Distinct Element Numerical Modeling in Geomechanics – 2011, Proceedings 2nd International FLAC/DEM Symposium*, Melbourne, 14-16 February, 11-19. Minneapolis: Itasca International Inc.
Cundall, P. A. & Damjanac, B. 2009. A comprehensive 3D model for rock slopes based on micromechanics. In Slope Stability 2009, *Proceedings 3rd International Symposium on Rock Slope Stability*, Santiago, 9-11 November, 10 p (on CD-ROM).
Daemen, J. J. K. 1977. Problems in tunnel support mechanics. *Underground Space*, 1(3): 163-172.
Dershowitz, W. 1995. Interpretation and synthesis of discrete fracture orientation, size, shape, spatial structure and hydrologic data by forward modelling. In L. R. Myer, N. G. W. Cook, R. E. Goodman & C-F. Tsang (eds), *Proceedings Conference on Fractured & Jointed Rock Masses*, Lake Tahoe, 3-5 June 1992, 579-586. Rotterdam: Balkema.
Dershowitz, W. S. & Einstein, H. H. 1984. Applications of artificial intelligence to problems of rock mechanics. In C. H. Dowding & M. M. Singh (eds), Rock Mechanics in Productivity & Protection, *Proceedings 25th U.S. Symposium on Rock Mechanics*, Evanston, 25-27 June, 483-494. New York: A.I.M.E.

Dershowitz, W. S. & Einstein, H. H. 1988. Characterizing rock joint geometry with joint system models. *Rock Mechanics & Rock Engineering*, 21(1): 21-51.

Desseault, M. B. 2010. Deep injection disposal: environmental and petroleum geomechanics. In K. G. Sharma, T. Ramamurthy, V. K. Kanjlia & A. C. Gupta (eds), Advances in Rock Engineering, *Proceedings ISRM International Symposium 2010 & 6th Asian Rock Mechanics Symposium*, New Delhi, 23-27 October, KN 21 - KN 33. New Delhi: Central Board of Irrigation & Power.

Detournay, C. & Hart, R. (eds) 1999. FLAC and Numerical Modeling in Geomechanics, *Proceedings International FLAC Symposium*, Minneapolis, 1-3 September, 528 p. Rotterdam: Balkema.

Detournay, E. 1995. Coupled thermo-hydro-mechanical processes in rock mechanics, with applications to the petroleum industry. In T. Fuji (ed.), *Proceedings 8th Congress, International Society for Rock Mechanics*, Tokyo, 25-29 September, 3: 1061-1068. Rotterdam: Balkema.

Dewynter, V., Magne, S., Rougeault, S., Ferdinand, P., Vallon, F., Avallone, L., Vacher, E., de Broissia, M., Canepa, C. & Poulain, A. 2009. Optical fiber sensing cable for underground settlement monitoring during tunnelling. In G. Beer (ed.), *Technology Innovation in Underground Construction*, 163-188. Leiden: CRC Press/Balkema.

Diederichs, M. S. & Kaiser, P. K. 1999. Stability of large excavations in laminated hard rock masses: the voussoir analogue revisited. *International Journal of Rock Mechanics & Mining Sciences*, 36(1): 97-117.

Dowding, C. H. 1985. *Blast Vibration Monitoring and Control*, 297 p. Englewood Cliffs: Prentice-Hall.

Duffaut, P. 2011. What modern rock mechanics owe to the Malpasset Arch Dam failure. In Q. Qian & Y. X. Zhou (eds), *Harmonising Rock Engineering and the Environment, Proceedings 12th Congress, International Society for Rock Mechanics*, Beijing, 16-21 October, (in press). Leiden: CRC Press/Balkema.

Dunnicliff, J. 1988. *Geotechnical Instrumentation for Monitoring Field Performance*, 577 p. New York: John Wiley.

Einstein, H. H. & Baecher, G. B. 1983. Probabilistic and statistical methods in engineering geology. *Rock Mechanics & Engineering Geology*, 16(1): 39-72.

Elsworth, D. 1986. A hybrid boundary element-finite element analysis procedure for fluid flow simulation in fractured rock masses. *International Journal for Numerical & Analytical Methods in Geomechanics*, 10(6): 569-584.

Elsworth, D. & Mase, C. R. 1993. Groundwater in rock engineering. In J. A. Hudson, E. T. Brown, C. Fairhurst & E. Hoek (eds), *Comprehensive Rock Engineering*, 1: 201-226. Oxford: Pergamon Press.

Evison, F. F. 1953. The seismic determination of Young's modulus and Poisson's ratio for rocks in situ. *Géotechnique*, 6(3): 118-123.

Fairhurst, C. (ed.) 1963. *Proceedings Fifth Symposium on Rock Mechanics*, University of Minnesota, Minneapolis, May 1962, 726 p. Oxford: Pergamon Press.

Fairhurst, C. 2003. Stress estimation in rock: a brief history and review. *International Journal of Rock Mechanics & Mining Sciences*, 40(7-8): 957-973.

Fairhurst, C. 2004. Nuclear waste disposal and rock mechanics: contributions of the Underground Research Laboratory (URL), Pinawa, Manitoba, Canada. *International Journal of Rock Mechanics & Mining Sciences*, 41(8): 1221-1227.

Fairhurst, C. 2010. First Vienna-Leopold-Müller Lecture: What is the strength of a rock mass? *Progress in answering Müller's (implicit) question. Proceedings 5th Colloquium, Rock Mechanics – Theory & Practice*, Vienna, 26-27 November 2009, *Mitteilungen für Ingenieurgeologie und Geomechanik*, Band 9: 87-110.

Fairhurst, C. 2011. Grand challenges in Earth Resources Engineering – and some implications for rock mechanics and rock engineering. In D. P. Sainsbury, R. D. Hart, C. L. Detournay & M. J. Nelson (eds), *Continuum and Distinct Element Numerical Modeling in Geomechanics – 2011, Proceedings 2nd International FLAC/DEM Symposium*, Melbourne, 14-16 February, 3-10. Minneapolis: Itasca International Inc.

Falmagne, V. & Simser, B. P. 2004. Performance of rockburst support systems in Canadian mines. In E. Villaescusa & Y. Potvin (eds), *Ground Support in Mining & Underground Construction, Proceedings 5th International Symposium on Ground Support*, Perth, 28-30 September, 313-318. Leiden: Balkema.

Feng, X-T. & An, H. 2004. Hybrid intelligent method optimization of a soft rock replacement scheme for a large cavern excavated in alternate hard and soft rock strata. *International Journal of Rock Mechanics & Mining Sciences*, 41(4): 655-667.

Feng, X-T. & Hudson, J. A. 2004. The ways ahead for rock engineering design methodologies. *International Journal of Rock Mechanics & Mining Sciences*, 41(2): 255-273.

Feng, X-T. & Hudson, J. A. 2010. Specifying the information required for rock mechanics modelling and rock engineering design. *International Journal of Rock Mechanics & Mining Sciences*, 47(2): 179-194.

Feng, X-T. & Hudson, J. A. 2011. *Rock Engineering Design*, 464 p. Leiden: CRC Press/Balkema.

Feng, X-T., Zhao, H. & Li, S. 2004. A new displacement back analysis to identify mechanical geo-material parameters using integrated intelligent methodology. *International Journal for Numerical & Analytical Methods in Geomechanics*, 28(11): 1141-1165.

Fjaer, E., Holt, R. M., Horsrud, P., Raaen, A. M. & Risnes, R. 2008. *Petroleum Related Rock Mechanics*, 2nd edn, 514 p. Amsterdam: Elsevier.

Franklin, J. A. 1977. Monitoring of structures in rock. *International Journal of Rock Mechanics & Mining Sciences*, 14(4): 163-192.

Franklin, J. A. & Denton, P. E. 1973. The monitoring of rock slopes. *Quarterly Journal of Engineering Geology*, 6(3-4): 259-286.

Furtney, J. K., Cundall, P. A. & Chitombo, G. P. 2009. Developments in numerical modeling of blast induced fragmentation: updates from the HSBM project. In J. A. Sanchidrián (ed.), *Rock Fragmentation by Blasting – FragBlast 9, Proceedings 9th International Symposium on Rock Fragmentation by Blasting*, Granada, 13-17 September, 335-342. Leiden: CRC Press/Balkema.

Gaich, A., Pötsch, M. & Schubert, W. 2007. Rock mass characterization for tunneling and mining using 3D images. In L. Ribeiro e Sousa, C. Olalla & N. F. Grossmann (eds), *Proceedings 11th Congress, International Society for Rock Mechanics*, Lisbon, 9-13 July, 2: 1019-1024. Leiden: Taylor & Francis.

Galvin, J. M., Hebblewhite, B. K. & Salamon, M. D. G. 1999. University of New South Wales pillar strength determinations for Australian and South African mining conditions. In C. Mark, K. A. Heasley, A. T. Iannocchione & R. J. Tuchman (eds), *Proceedings 2nd International Workshop on Coal Pillar Mechanics & Design*, Vail, 6 June, NIOSH IC 9448, 63-71. Pittsburgh: U.S. Department of Health & Human Services.

Gilby, J. & Socol, M. 2010. Geotechnical instrumentation data management. In K. G. Sharma, T. Ramamurthy, V. K. Kanjlia & A. C. Gupta (eds), Advances in Rock Engineering, *Proceedings ISRM International Symposium 2010 & 6th Asian Rock Mechanics Symposium*, New Delhi, 23-27 October, Paper 124, 7p (on CD-ROM). New Delhi: Central Board of Irrigation & Power.

Gioda, G. 1980. Indirect identification of the average elastic characteristics of rock masses. In P. J. N. Pells (ed.), *Structural Foundations on Rock, Proceedings International Symposium*, Sydney, 7-9 May, 65-73. Rotterdam: Balkema.

Gioda, G. & Sakurai, S. 1987. Back analysis procedures for the interpretation of field measurements in geomechanics. *International Journal for Numerical & Analytical Methods in Geomechanics*, 11(6): 555-583.

Girard, J. M. & McHugh, E. L. 2001. Emerging technologies and the future of geotechnical instrumentation. In D. Elsworth, J. P. Tinucci & K. A. Heasley (eds), *Rock Mechanics in the National Interest, Proceedings 38th U.S. Symposium on Rock Mechanics*, Washington D.C., 5-7 July, 1: 445-450. Lisse: Balkema.

Golder, H. Q. & Akroyd, T. N. W. 1954. An apparatus for triaxial-compression tests at high pressures. *Géotechnique*, 4(4): 131-136.

Gong, Q. M. & Zhao, J. 2009. Development of rock mass characteristics model for TBM penetration rate prediction. *International Journal of Rock Mechanics & Mining Sciences*, 46(1): 8-18.

Goodman, R. E. 1966. On the distribution of stresses around circular tunnels in non-homogeneous rocks. *Proceedings 1st Congress, International Society for Rock Mechanics*, Lisbon, 25 September – 1

October, 2: 249-255. Lisbon: LNEC.

Goodman, R. E. 1989. *Introduction to Rock Mechanics, 2nd edn*, 562 p. New York: John Wiley.

Goodman, R. E. & Shi, G-H. 1985. *Block Theory and its Application to Rock Engineering*, 338p. Englewood Cliffs: Prentice-Hall.

Goodman, R. E., Taylor, R. L. & Brekke, T. L. 1968. A model for the mechanics of jointed rock. *Journal, Soil Mechanics & Foundations Division*, A.S.C.E., 94(SM3): 637-659.

Grasselli, G. & Egger, P. 2003. Constitutive law for the shear strength of rock joints based on three-dimensional surface parameters. *International Journal of Rock Mechanics & Mining Sciences*, 40(1): 25-40.

Griggs, D. T. 1936. Deformation of rocks under high confining pressures. *Journal of Geology*, 44: 541-577.

Grobler, H. P., Poropat, G. & Guest, A. R. 2003. Photogrammetry for structural mapping in mining. Technology Roadmap for Rock Mechanics, *Proceedings 10th Congress, International Society for Rock Mechanics*, Johannesburg, 8-12 September, 1: 431-436. Johannesburg: Southern African Institute of Mining & Metallurgy.

Habib, P. 1950. Détermination du module d'élasticité des roches en place. *Annales de l'Institut Technique du Bâtiment et des Travaux Publics*, No 145, September: 27-35.

Habib, P. & Marchand, R. 1952. Mesures des pressions de terrains par l'essai de vérin plat. *Suppléments aux Annales de l'Institut Technique du Bâtiment et des Travaux Publics, Série Sols et Foundations*, No 58, October: 967-971.

Hagedorn, H., Rehbock-Sander, M. & Stadelmann, R. 2007. Gotthard Base tunnel: rock burst phenomenon during construction of a multifunctional section in a fault zone area. In L. Ribeiro e Sousa, C. Olalla & N. F. Grossmann (eds), *Proceedings 11th Congress, International Society for Rock Mechanics*, Lisbon, 9-13 July, 2: 917-920. Leiden: Taylor & Francis.

Handin, J. 1953. An application of high pressure geophysics: experimental rock mechanics. *Transactions, American Society of Mechanical Engineers*, 75: 315-324.

Hart, R. D., Detournay, C. L. & Cundall, P. A. (eds), 2008. *Continuum and Distinct Element Modeling in Geo-Engineering, Proceedings 1st FLAC/DEM Symposium*, Minneapolis, 25-27 August, 698 p. Minneapolis: Itasca Consulting Group Inc.

Hast, N. 1958. The measurement of rock pressure in mines. *Sveriges Geologiska Undersokning*, Series C, 52(3).

Hawley, M., Marisett, S., Beale, G. & Stacey, P. 2009. Performance assessment and monitoring. In J. Read & P. Stacey (eds), *Guidelines for Open Pit Slope Design*, 327-379. Melbourne: CSIRO Publishing.

Hedley, D. G. F. & Grant, F. 1972. Stope and pillar design at the Elliot Lake uranium mines. *Canadian Institute of Mining & Metallurgy Bulletin*, 65(723): 37-44.

Herrera, G., Tomás, R., Vicente, F., Lopez-Sanchez, J. M., Mallorquí, J. J. & Mulas, J. 2010. Mapping ground movements in open pit mining areas using differential SAR interferometry. *International Journal of Rock Mechanics & Mining Sciences*, 47(7): 1114-1125.

Heyman, J. 1972. *Coulomb's Memoir on Statics*, 212p. Cambridge: Cambridge University Press.

Hill, F. G. 1954. An investigation of the problem of rockbursts; an operational research project. Part I. The approach to the problem and analyses of the rockbursts that have occurred on the ERPM during the years 1948-1953. *Journal, Chemical, Metallurgical & Mining Society of South Africa*, 55(October): 63-83.

Hill, F. G. 1966. Preface to "Rock Mechanics applied to the study of rockbursts". *Journal, South African Institute of Mining & Metallurgy*, 66(10): 435.

Hoek, E. 1963. Experimental study of rock-stress problems in deep level mining. *Experimental Mechanics*, 3: 177-194.

Hoek, E. 1964. Fracture of anisotropic rock. *Journal, South African Institute of Mining & Metallurgy*, 64(10): 501-518.

Hoek, E. 1994. Strength of rock and rock masses. *ISRM News Journal*, 2(2): 4-16.

Hoek, E. 2001. Big tunnels in bad rock. The 36th Karl Terzaghi Lecture. *Journal of Geotechnical & Geoenvironmental Engineering, A.S.C.E.*, 127(9): 726-740.

Hoek, E. 2007. The development of rock engineering. In *Practical Rock Engineering*. Available at http://Rocscience.com/hoek/pdf/1_The_development_of_rock_engineering.pdf .

Hoek, E. & Bray, J. W. 1974. *Rock Slope Engineering*, 309 p. London: Institution of Mining & Metallurgy.

Hoek, E. & Brown, E. T. 1980. *Underground Excavations in Rock*, 527 p. London: Institution of Mining & Metallurgy.

Hoek, E., Carranza-Torres, C., Diederichs, M. S. & Corkum, B. 2008. Integration of geotechnical and structural design in tunnelling. *Proceedings University of Minnesota 56th Annual Geotechnical Engineering Conference*, Minneapolis, 29 February, 1-53.

Hoek, E. & Diederichs, M. S. 2006. Empirical estimation of rock mass modulus. *International Journal of Rock Mechanics & Mining Sciences*, 43(2): 203-215.

Hood, M. & Brown, E. T. 1999. Mining rock mechanics, yesterday, today and tomorrow. In G. Vouille & P. Berest (eds), *Proceedings 9th Congress, International Society for Rock Mechanics*, Paris, 25-28 August, 3: 1551-1576. Lisse: Balkema.

Hudson, J. A. 2010. Underground radioactive waste disposal: the rock mechanics contributions. In K. G. Sharma, T. Ramamurthy, V. K. Kanjlia & A. C. Gupta (eds), *Advances in Rock Engineering, Proceedings ISRM International Symposium 2010 & 6th Asian Rock Mechanics Symposium*, New Delhi, 23-27 October, KN 3 - KN 20. New Delhi: Central Board of Irrigation & Power.

Hudson, J. A. 2011. The next 50 years of the ISRM and anticipated future progress in rock mechanics. In Q. Qian & Y. X. Zhou (eds), *Harmonising Rock Engineering and the Environment, Proceedings 12th Congress, International Society for Rock Mechanics*, Beijing, 16-21 October, 1: (in press). Leiden: CRC Press/Balkema.

Hudson, J. A., Brown, E. T. & Fairhurst, C. 1971. Optimizing the control of rock failure in servo-controlled laboratory tests. *Rock Mechanics*, 3(4): 217-224.

Hudson, J. A., Brown, E. T., Fairhurst, C. & Hoek, E. (eds) 1993. *Comprehensive Rock Engineering*, 5 Vols. Oxford: Pergamon Press.

Hudson, J. A., Cornet, F. H. & Christiansson, R. 2003. ISRM Suggested methods for rock stress estimation – Part 1: Strategy for rock stress estimation. *International Journal of Rock Mechanics & Mining Sciences*, 40(7-8): 991-998.

Hudson, J. A. & Feng, X-T. 2007. Updated flow charts for rock mechanics modelling and rock engineering design. *International Journal of Rock Mechanics & Mining Sciences*, 44(2): 174-195.

Hudson, J. A., Stephansson, O., Andersson, J., Tsang, C-F. & Jing, L. 2001. Coupled T-H-M issues relating to radioactive waste repository design and performance. *International Journal of Rock Mechanics & Mining Sciences*, 38(1): 143-161.

Hustrulid, W. 2010. Some comments regarding development drifting practices with special emphasis on caving applications. In Y. Potvin (ed.), Caving 2010, *Proceedings 2nd International Symposium on Block & Sublevel Caving*, Perth, 20-22 April, 3-43. Perth: Australian Centre for Geomechanics.

Hutchinson, D. J. & Diederichs, M. S. 1996. *Cablebolting in Underground Mines*, 406 p. Richmond, B.C.: Bitech Publishers.

Indraratna, B., Oliveira, D. A. F. & Brown, E. T. 2010. A shear-displacement criterion for soil-infilled rock discontinuities. *Géotechnique*, 60(8): 623-633.

Itasca, 2011. *FLAC Ver 6.0, FLAC3D Ver 4.0, FLAC/Slope Ver 6.0, UDEC Ver 5.0 & 3DEC Ver 4.1* Minneapolis: Itasca Consulting Group Inc. (See www.itascacg.com/home.php.)

Jaeger, C. 1955. Present trends in the design of pressure tunnels and shafts for underground hydro-electric power stations. *Proceedings, Institution of Civil Engineers*, 4(2): 116-174.

Jaeger, C. 1972. *Rock Mechanics and Engineering*, 417 p. Cambridge: Cambridge University Press.

Jaeger, J. C. 1959. The frictional properties of joints in rock. *Geofisica Pura e Applicata*, 43(Part 2): 148-158.

Jaeger, J. C. 1960. Shear fracture of anisotropic rocks. *Geological Magazine*, 97: 65-72.

Jaeger, J. C. 1971. Friction of rocks and stability of rock slopes. *Géotechnique*, 21(2): 97-134.

Jing, L. 2003. A review of techniques, advances and outstanding issues in numerical modelling for rock mechanics and rock engineering. *International Journal of Rock Mechanics & Mining Sciences*, 40(3):

283-353.

Jing, L. & Stephansson, O. 2007. *Fundamentals of Discrete Element Methods for Rock Engineering: Theory and Applications*, 545 p. Amsterdam: Elsevier.

John, K. W. 1962. An approach to rock mechanics. Journal, *Soil Mechanics & Foundations Division, A.S.C.E.*, 88(SM4): 1-30.

Judd, W. R. (ed.) 1964. State of Stress in the Earth's Crust, *Proceedings International Conference*, Santa Monica, 13-14 June 1963, 732 p. New York: American Elsevier.

Kaiser, P. K. & Kim, B-H. 2008. Rock mechanics challenges in underground construction and mining. In Y. Potvin, J. Carter, A. Dyskin & R. Jeffrey (eds), *Proceedings 1st Southern Hemisphere International Rock Mechanics Symposium*, Perth, 16-19 September, 1: 23-38. Perth: Australian Centre for Geomechanics.

Kármán, T. von, 1911. Festigkeitsversuche unter allseitigem Druck. *Zeitschrift Verein Deutscher Ingenieure*, 55: 1749-1757.

Kimmance, J. P. 1999. Geographical information system application to construction and geotechnical data management on large projects. In C. F. Leung, S. A. Tan & K. K. Phoon (eds), *Proceedings 5th International Symposium on Field Measurements in Geomechanics*, Singapore, 1-3 December, 151-156. Rotterdam: Balkema.

King, L. V. 1912. On the limiting strength of rocks under conditions of stress existing in the earth's interior. *Journal of Geology*, 20: 119-138.

Kirsten, H. A. D. 1976. Determination of rock mass elastic moduli by back analysis of deformation measurements. In Z. T. Bieniawski (ed.), *Proceedings Symposium on Exploration for Rock Engineering*, Johannesburg, 1-5 November, 1: 165-172. Cape Town: Balkema.

Kovari, K. & Amstad, C. 1993. Decision making in tunnelling based on field measurements. In J. A. Hudson, E. T. Brown, C. Fairhurst & E. Hoek (eds), *Comprehensive Rock Engineering*, 4: 571-606. Oxford: Pergamon Press.

Kovari, K., Amstad, C. & Köppel, J. 1979. New developments in the instrumentation of underground openings. In A. C. Maevis & W. A. Hustrulid (eds), *Proceedings 1979 Rapid Excavation & Tunneling Conference*, Atlanta, 18-21 June, 1: 817-837. New York: A.I.M.E.

Lang, T. A. 1961. Theory and practice of rockbolting. *Transactions, Society of Mining Engineers of A.I.M.E.*, 220: 333-348.

Liu, J., Feng, X-T., Ding, X-L., Zhang, J. & Yue, D-M. 2003a. Stability assessment of the Three Gorges Dam foundation, China, using physical and numerical modeling – Part I: physical model tests. *International Journal of Rock Mechanics & Mining Sciences*, 40(5): 609-631.

Liu, J., Feng, X-T. & Ding, X-L. 2003b. Stability assessment of the Three Gorges Dam foundation, China, using physical and numerical modeling – Part II: numerical modeling. *International Journal of Rock Mechanics & Mining Sciences*, 40(5): 633-652.

Londe, P. 1987. The Malpasset Dam failure. Engineering Geology, 24(1-4): 295-329.

Londe, P., Vigier, G. & Vormeringer, R. 1969. Stability of rock slopes, a three-dimensional study. *Journal, Soil Mechanics & Foundations Division, A.S.C.E.,* 95(SM1): 235-262.

Long, J. & Witherspoon, P. 1985. The relationship of the degree of interconnection to permeability in fracture networks. *Journal of Geophysical Research*, 90(B4): 3087-3098.

Lorig, L. J. & Brady, B. H. G. 1982. A hybrid discrete element-boundary element method of stress analysis. In R. E. Goodman & F. E. Heuze (eds), Issues in Rock Mechanics, *Proceedings 23rd U.S. Symposium on Rock Mechanics,* Berkeley, 25-27 August, 628-636. New York: A.I.M.E.

Louis, C. 1974. Rock hydraulics. In Müller, L. (ed.), *Rock Mechanics*, (Course held at CISM, Udine, Italy), 300-387. Vienna: Springer-Verlag.

McKenzie, C. K. 1987. Blasting in hard rock: techniques for diagnosis and modeling for damage and fragmentation. In G. Herget & S. Vongpaisal (eds), *Proceedings 6th Congress, International Society for Rock Mechanics*, Montreal, 30 August – 3 September, 3: 1425-1431. Rotterdam: Balkema.

Marinos, P. G., Marinos,V. & Hoek, E. 2007. The Geological Strength Index (GSI): a characterization tool for assessing engineering properties of rock masses. In C. Mark, R. Pakalnis & R. J. Tuchman (eds), *Proceedings International Workshop on Rock Mass Classification for Underground Mining*, Vancouver, 31 May, NIOSH IC 9498, 87-94. Pittsburgh: U.S. Department of Health & Human Services.

Martin, C. D. 1997. Seventeenth Canadian Geotechnical Colloquium: the effect of cohesion loss and stress path on brittle rock strength. *Canadian Geotechnical Journal*, 34(5): 698-725.

Mas Ivars, D., Pierce, M. E., Darcel, C., Reyes-Montes, J., Potyondy, D., Young, R. P. & Cundall, P. A. 2011. The synthetic rock mass approach for jointed rock mass modelling. *International Journal of Rock Mechanics & Mining Sciences*, 48(2): 219-244.

Mayer, A. 1953. Les propértiés mécaniques des roches. Géotechnique, 3(8): 329-338.

Mayer, A. 1963. Recent work in rock mechanics. *Géotechnique*, 13(2): 99-118.

Mayer, A., Habib, P. & Marchand, R. 1951. Mesure en place des pressions de terrains. *Proceedings Conference Internationale sur les Pressions de Terrains et le Soutènement dans les Chantiers d'Exploration*, Liège, 24-28 April, 217-221.

Minchinton, A. & Dare-Bryan, P. 2005. The application of computer modelling for blasting and flow in sublevel caving operations. *Proceedings 9th AusIMM Underground Operators' Conference*, Perth, 7-9 March, 65-73. Melbourne: Australasian Institute of Mining & Metallurgy.

Mogi, K. 1959. Experimental study of deformation and fracture of marble (1). On the fluctuation of compressive strength of marble and relation to the rate of stress application. *Bulletin, Earthquake Research Institute, University of Tokyo*, 37: 155-170.

Mogi, K. 2007. *Experimental Rock Mechanics*, 361 p. London: Taylor & Francis.

Moye, D. G. 1959. Rock mechanics in the investigation and construction of T.1 underground power station, Snowy Mountains, Australia. *Geological Society of America Engineering Geology Case Histories*, No 3: 13-44.

Müller, L. 1933. Untersuchungen über statistische Kluftmessungen. *Geologie und Bauwesen*, 5(4): 185-255.

Müller, L. 1950. Der Kluftkörper. *Geologie und Bauwesen*, 18(1): 52-60.

Müller, L. 1964. The rock slide in the Vajont Valley. *Rock Mechanics & Engineering Geology,* 2: 148-212.

Müller, L. 1966. Der progressive bruch in geklufteten median. *Proceedings 1st Congress, International Society for Rock Mechanics*, Lisbon, 25 September – 1 October, 1: 679-686. Lisbon: LNEC.

Müller, L. 1967a. Address to the Opening Session. *Proceedings 1st Congress, International Society for Rock Mechanics*, Lisbon, 25 September – 1 October, 1966, 3: 80-83. Lisbon: LNEC.

Müller, L. 1967b. Address to the Closing Session. *Proceedings 1st Congress, International Society for Rock Mechanics*, Lisbon, 25 September – 1 October, 1966, 3: 90-92. Lisbon: LNEC.

Müller, L. 1968. New considerations of the Vajont slide. *Rock Mechanics & Rock Engineering*, 6(1): 1-91.

Müller, L. 1969. New editorial system. *Rock Mechanics*, 1(1): 1-4.

Müller, L. 1979. Josef Stini: contributions to engineering geology and slope movement investigations. In B. Voight (ed.), *Rockslides and Avalanches*, 2: 95-109. Amsterdam: Elsevier.

Müller-Salzburg, L. 1987. The Vajont catastrophe - a personal view. *Engineering Geology*, 24(1-4): 423-444.

Obert, L. & Duvall, W. I. 1967. *Rock Mechanics and the Design of Structures in Rock*, 650 p. New York: John Wiley.

Obert, L., Windes, S. L. & Duvall, W. I. 1946. Standardized tests for determining the physical properties of mine rock. *U.S. Bureau of Mines Report of Investigation* 3891.

Oñederra, I., Chitombo, G. P., Cundall, P. A. & Furtney, J. K. 2009. Towards a complete validation of the lattice scheme in the Hybrid Stress Blasting Model (HSBM). In J. A. Sanchidrián (ed.), Rock Fragmentation by Blasting – FragBlast 9, *Proceedings 9th International Symposium on Rock Fragmentation by Blasting*, Granada, 13-17 September, 343-351. Leiden: CRC Press/Balkema.

Ortlepp, W. D. 2007. Dynamic capacity in cable anchors and rockbolts. In *Cave Mining, 1st International Symposium on Block & Sub-level Caving*, Cape Town, 8-10 October, 405-419. Johannesburg: Southern African Institute of Mining & Metallurgy.

Ouchterlony, F. & Moser, P. 2006. Likenesses and differences in the fragmentation of full-scale and model-scale blasts. *Fragblast-8, Proceedings 8th International Symposium on Rock Fragmentation by*

Blasting, Santiago, 7-11 May, 207-220. Santiago: Editec.
Pacher, F. 1964. Deformationsmessungen im Versuchstollen als Mittel zur Erforschung des Gebirgsverhaltens und zur Bemessung des Ausbaues. *Rock Mechanics & Engineering Geology*, Suppl IV, 149-161.
Panet, M. 1993. Understanding deformations in tunnels. In J. A. Hudson, E. T. Brown, C. Fairhurst & E. Hoek (eds), *Comprehensive Rock Engineering*, 1: 663-690. Oxford: Pergamon Press.
Panet, M. 1995. *Calcul des Tunnels par la Methode de Convergence-Confinement.* Paris: Press de l'Ecole Nationale des Ponts et Chausses.
Paterson, M. S. 1958. Experimental deformation and faulting in Wombeyan marble. *Bulletin, Geological Society of America*, 69: 465-476.
Paterson, M. S. 1978. *Experimental Rock Deformation – The Brittle Field*, 254 p. Berlin: Springer-Verlag.
Pells, P. J. N. 2002. Developments in the design of tunnels and caverns in the Triassic rocks of the Sydney region. *International Journal of Rock Mechanics & Mining Sciences*, 39(5): 569-587.
Pells, P. J. N., Poulos, H. G. & Best, R. J. 1991. Rock reinforcement and design for a shallow large span cavern. In W. Wittke (ed.), *Proceedings 7th Congress, International Society for Rock Mechanics*, Aachen, 16-20 September, 2: 1193-1198. Rotterdam: Balkema.
Pichler, J., Lammer, E. & Bertignoll, H. 2010. Innovative roadheader technology for safe and economic tunnelling. In G. Beer (ed.), *Technology Innovation in Underground Construction*, 315-333. Leiden: CRC Press/Balkema.
Pierce, M., Gaida, M. & DeGagne, D. 2009. Estimation of rock block strength. In M. Diederichs & G. Grasselli (eds), Rock Engineering in Difficult Conditions, *Proceedings 3rd Canada - U.S. Rock Mechanics Symposium*, Toronto, 9-15 May, Paper 4360 (on CD-ROM).
Pine, R. J., Coggan, J. S., Flynn, Z. N. & Elmo, D. 2006. The development of a new numerical modelling approach for naturally fractured rock masses. *Rock Mechanics & Rock Engineering*, 39(5): 395-419.
Pinkerton, I. L., Andrews, K. E., Bray, A. N. G. & Frost, A. C. H. 1961. The design, construction and commissioning of Tumut 1 Power Station. *Journal, Institution of Engineers, Australia*, 33(7-8): 235-252.
Player, J., Thompson, A. & Villaescusa, E. 2008. Dynamic testing of reinforcement systems. In T. R. Stacey & D. F. Malan (eds), *Proceedings 6th International Symposium on Ground Support in Mining & Civil Engineering Construction*, Cape Town, 30 March – 3 April, 597-622. Johannesburg: Southern African Institute of Mining & Metallurgy.
Potts, E. L. J. 1957. Underground instrumentation. *Quarterly, Colorado School of Mines*, 52(3): 135-182.
Potvin, Y., Stacey, D. & Hadjigeorgiou, J. (eds) 2004. *Surface Support in Mining*, 416 p. Perth: Australian Centre for Geomechanics.
Potyondy, D. O. & Cundall, P. A. 2004. A bonded-particle model for rock. *International Journal of Rock Mechanics & Mining Sciences*, 41(8): 1329-1364.
Priest, S. D. 2004. Determination of discontinuity size distributions from scanline data. *Rock Mechanics & Rock Engineering*, 37(5): 347-368.
Priest, S. D. & Brown, E. T. 1983. Probabilistic stability analysis of variable rock slopes. *Transactions, Institution of Mining & Metallurgy, Section A: Mining Industry,* 92: A1-12.
Priest, S. D. & Hudson, J. A. 1981. Estimation of discontinuity spacing and trace length using scanline surveys. *International Journal of Rock Mechanics & Mining Sciences*, 18(3): 183-197.
Rabcewicz, L. 1969. *Stability of tunnels under rock load. Water Power*, 21(6-8): 225-229, 266-273, 297-304.
Read, J. & Stacey, P. (eds) 2009. *Guidelines for Open Pit Slope Design*, 496 p. Melbourne: CSIRO Publishing.
Roberts, A. 1963. Editorial. *International Journal of Rock Mechanics & Mining Sciences*, 1(1): 3-4.
Rocha, M. 1964. Mechanical behaviour of rock foundations in concrete dams. *Transactions, 8th International Congress on Large Dams*, Edinburgh, 1: 785-832.
Rocha, M., Serafim, J. L., Silveira, A. & Neto, J. R. 1955. Deformability of foundation rocks. *Proceedings 5th International Congress on Large Dams*, Paris, R75, 3: 531-559. Paris: Editions Science et Industrie.
Roegiers, J-C. 1999. The importance of rock mechanics to the petroleum industry. In G. Vouille & P. Berest (eds), *Proceedings 9th Congress, International Society for Rock Mechanics*, Paris, 25-28 August, 3: 1525-1549. Lisse: Balkema.
Rogers, S., Elmo, D., Webb, G. & Catalan, A. 2010. A discrete fracture network based approach to defining in situ, primary and secondary fragmentation distributions for the Cadia East panel cave project. In Y. Potvin (ed.), *Caving 2010, Proceedings 2nd International Symposium Block & Sublevel Caving*, Perth, 20-22 April, 425-439. Perth: Australian Centre for Geomechanics.
Rojat, F., Labiouse, V., Kaiser, P. K. & Descoeudres, F. 2008. Brittle rock failure in the Steg lateral adit of the Lötschberg base tunnel. *Rock Mechanics & Rock Engineering*, 42(2): 341-359.
Rojek, J., Oñate, E., Labra, C., Kargl, H. & Akerman, J. 2010. Optimizing rock cutting through computer simulation. In G. Beer (ed.), *Technology Innovation in Underground Construction*, 299-314. Leiden: CRC Press/Balkema.
Ryder, J. A. & Jager, A. J. (eds) 2002. *Rock Mechanics for Tabular Hard Rock Mines*, 489 p. Johannesburg: SIMRAC.
Sainsbury, B. L., Sainsbury, D. P. & Pierce, M. E. 2011. A historical review of the development of numerical cave propagation simulations. In D. P. Sainsbury, R. D. Hart, C. L. Detournay & M. J. Nelson (eds), *Continuum and Distinct Element Numerical Modeling in Geomechanics – 2011, Proceedings 2nd International FLAC/DEM Symposium*, Melbourne, 14-16 February, 23-36. Minneapolis: Itasca International Inc.
Sainsbury, D. P., Hart, R. D., Detournay, C. L. & Nelson, M. J. (eds) 2011. *Continuum and Distinct Element Numerical Modeling in Geomechanics – 2011, Proceedings 2nd International FLAC/DEM Symposium*, Melbourne, 14-16 February, 852 p. Minneapolis: Itasca International Inc.
Sakurai, S. 1993. Back analysis in rock engineering. In J. A. Hudson, E. T. Brown, C. Fairhurst & E. Hoek (eds), *Comprehensive Rock Engineering*, 4: 543-569. Oxford: Pergamon Press.
Sakurai, S. 1997. Lessons learned from field measurements in tunnelling. *Tunnelling & Underground Space Technology*, 12(4): 453-460.
Sakurai, S. 1999. Interpretation of field measurements in tunnelling practice. In G. Vouille & P. Berest (eds), *Proceedings 9th Congress, International Society for Rock Mechanics*, Paris, 25-28 August, 3: 1517-1523. Lisse: Balkema.
Sakurai, S. & Akutagawa, S. 1995. Some aspects of back analysis in geotechnical engineering. In L. Ribeiro e Sousa & N. F. Grossmann (eds), *Eurock '93 - Safety & Environmental Issues in Rock Mechanics, Proceedings International Symposium*, Lisbon, 21-24 June 1993, 1133-1140. Rotterdam: Balkema.
Sakurai, S., Farazmand, A. & Adachi, K. 2009. Assessment of the stability of slopes from surface displacements measured by GPS in an open pit mine. In G. Deák & Z. G. Agioutantis (eds), *Sustainable Exploitation of Natural Resources, Proceedings 3rd International Seminar ECOMINING – Europe in 21st Century*, Milos Island, Greece, 4-5 September, 239-248.
Sakurai, S. & Takeuchi, K. 1983. Back analysis of measured displacement of tunnels. *Rock Mechanics & Rock Engineering*, 16(3): 173-180.
Salamon, M. D. G. & Munro, A. H. 1967. A study of the strength of coal pillars. *Journal, South African Institute of Mining & Metallurgy*, 68(2): 55-67.
Salamon, M. D. G., Ryder, J. A. & Ortlepp, W. D. 1964. An analogue solution for determining the elastic response of strata surrounding tabular mine excavations. *Journal, South African Institute of Mining & Metallurgy*, 65(2): 115-137.
Schmidt, W. 1925. Gefügestatistik. *Tschermaks Mineralogische und Petrographische Mitteilungen*, 38: 392-423.
Schubert, W. 2006. The role of on-site engineering in underground projects. In C. F. Leung & Y. X. Zhou (eds), Rock Mechanics in Underground Construction, *Proceedings ISRM International Symposium 2006 & 4th Asian Rock Mechanics Symposium*, Singapore, 8-10 November, 71-82. Singapore: World Scientific Publishing Co.
Schunnesson, H. 2009. Modern tools and equipment for tunnelling and drifting. In P. Dight (ed.), Proceedings *1st International Seminar on Safe & Rapid Development Mining*, Perth, 6-7 May, 139-148. Perth: Australian Centre for Geomechanics.

Schutjens, P. 2009. Book review: Petroleum Related Rock Mechanics, 2nd edn, 2008. *International Journal of Rock Mechanics & Mining Sciences*, 46(8): 1398-1399.

Shi, G-H. & Goodman, R. E. 1985. Two dimensional discontinuous deformation analysis. *International Journal for Numerical & Analytical Methods in Geomechanics*, 9(6): 541-556.

Slob, S., Hack, H. R. G. K., Feng, Q., Röshoff, K. & Turner, A. K. 2007. Fracture mapping using 3D laser scanning techniques. In L. Ribeiro e Sousa, C. Olalla & N. F. Grossmann (eds), *Proceedings 11th Congress, International Society for Rock Mechanics*, Lisbon, 9-13 July, 1: 299-302. Leiden: Balkema.

Starfield, A. M. & Cundall, P. A. 1988. Towards a methodology for rock mechanics modelling. *International Journal of Rock Mechanics & Mining Sciences*, 25(3): 99-106.

Stephansson, O., Jing, L. & Tsang, C-F. (eds) 1996. *Coupled Thermo-Hydro-Mechanical Processes of Fractured Media*, 596 p. Amsterdam: Elsevier.

Stini, J. 1922. *Technische Geologie*, 789 p. Stuttgart: Ferdinand Enke.

Suorineni, F. T., Chinnasane, D. R. & Kaiser, P. K. 2009. A procedure for determining rock-type specific Hoek-Brown brittle parameter s. *Rock Mechanics & Rock Engineering*, 42(6): 849-881.

Takahashi, T. 2004. ISRM Suggested Methods for land geophysics in rock engineering. *International Journal of Rock Mechanics & Mining Sciences*, 41(6): 885-914.

Takahashi, T., Takeuchi, T. & Sassa, K. 2006. Suggested Methods for borehole geophysics in rock engineering. *International Journal of Rock Mechanics & Mining Sciences*, 43(3): 337-368.

Talobre, J. 1957. *La Mécanique des Roches*, 444 p. Paris: Dunod.

Taylor, J. T. M. 1962-63. Research on ground control and rockbursts on the Kolar Goldfield, India. *Transactions, Institution of Mining & Metallurgy, Section A: Mining Industry*, 72: 317-338.

Terzaghi, K. 1962a. Measurement of stresses in rock. *Géotechnique*, 12(2): 105-124.

Terzaghi, K. 1962b. Stability of steep slopes on hard unweathered rock. *Géotechnique*, 12(4): 251-270.

Terzaghi, K. & Richart, F. E. 1952. Stresses in rock about cavities. *Géotechnique*, 3(2): 57-90.

Terzaghi, R. D. & Voight, B. 1979. Karl Terzaghi on rock slides: the perspective of a half-century. In B. Voight (ed.), *Rockslides and Avalanches*, 2: 111-133. Amsterdam: Elsevier.

Thorsteinsson, H., Augustine, C., Anderson, B. J., Moore, M. C. & Tester, J. W. 2008. The impacts of drilling and reservoir technology advances on EGS exploitation. *Proceedings 33rd Workshop on Geothermal Reservoir Engineering*, Stanford University, 28-30 January, Stanford Geothermal Program Publication SGP-TR-2008, 14 p.

Tincelin, E. 1952. Mesures des pressions de terrains dans les mines de fer de l'est. *Annales de l'Institut Technique du Bâtiment et des Travaux Publics, Série Sols et Foundations*, No 58, October: 972-990.

Trollope, D. H. 1968. The mechanics of discontinua or clastic mechanics in rock problems. In K. G. Stagg & O. C. Zienkiewicz (eds), *Rock Mechanics in Engineering Practice*, 275-320. London: John Wiley.

Trollope, D. H. & Brown, E. T. 1965. Pressure distributions in some discontinua. *Water Power*, 17(8): 310-313.

Turchaninov, I. A., Iofis, M. A. & Kasparyan, E. V. 1979. *Principles of Rock Mechanics*, 493 p. Translated from Russian by A. L. Peabody; translation edited by W. A. Hustrulid. Rockville, MD: Terraspace.

Ulusay, R. & Hudson, J. A. (eds) 2007. *The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring:* 1974-2006, 628 p. Ankara: ISRM Turkish National Group.

Vakili, A. & Hebblewhite, B. K. 2010. A new cavability assessment criterion for Longwall Top Coal Caving. *International Journal of Rock Mechanics & Mining Sciences*, 47(8): 1317-1329.

Villaescusa, E. 1996. Excavation design for bench stoping at Mount Isa mine, Queensland, Australia. *Transactions, Institution of Mining & Metallurgy, Section A: Mining Industry*, 105: A1-10.

Villaescusa, E. 2008. Geotechnical considerations for planning and design of open stopes. In H. Schunnesson & E. Nordlund (eds), MassMin 2008, *Proceedings 5th International Conference & Exhibition on Mass Mining*, Luleå, 9-11 June, 341-352. Luleå: Luleå University of Technology.

Villaescusa, E., Hassell, R. & Thompson, A. G. 2008. Development of a corrosivity classification for cement grouted cable. In T. R. Stacey & D. F. Malan (eds), *Proceedings 6th International Symposium on Ground Support in Mining & Civil Engineering Construction*, Cape Town, 30 March – 3 April, 461-476. Johannesburg: Southern African Institute of Mining & Metallurgy.

Wawersik, W. R. & Fairhurst, C. 1970. A study of brittle rock fracture in laboratory compression tests. *International Journal of Rock Mechanics & Mining Sciences*, 7(5): 561-575.

West, G. 1988. *Innovation and the Rise of the Tunnelling Industry*, 355 p. Cambridge: Cambridge University Press.

Williams, P., Floyd, J., Chitombo, G. & Maton, T. 2010. Design implementation. In J. Read & P. Stacey (eds), *Guidelines for Open Pit Mine Design*, 265-326. Melbourne: CSIRO Publishing.

Windsor, C. R. 1993. Measuring stress and deformation in rock masses. In T. Szwedzicki (ed.), *Proceedings Australian Conference on Geotechnical Instrumentation and Monitoring in Open Pit and Underground Mining*, Kalgoorlie, 21-23 June, 33-52. Rotterdam: Balkema.

Windsor, C. R. 2004. A review of long, high capacity reinforcing systems used in rock engineering. In E. Villaescusa & Y. Potvin (eds), Ground Support in Mining & Underground Construction, *Proceedings 5th International Symposium on Ground Support*, Perth, 28-30 September, 17-41. Leiden: Balkema.

Windsor, C. R. & Thompson, A. G. 1993. Rock reinforcement – technology, testing, design and evaluation. In J. A. Hudson, E. T. Brown, C. Fairhurst & E. Hoek (eds), *Comprehensive Rock Engineering*, 4: 451-484. Oxford: Pergamon Press.

Witherspoon, P. A., Wang, J. S. Y., Iwai, K. & Gale, J. E. 1980. Validity of cubic law for fluid flow in a deformable rock fracture. *Water Resources Research*, 16(6): 1016-1024.

Wittke, W. 1977. Static analysis for underground openings in jointed rock. In C. S. Desai & J. T. Christian (eds), *Numerical Methods in Geotechnical Engineering*, 589-638. New York: McGraw-Hill.

Wittke, W. 1990. *Rock Mechanics: Theory and Applications with Case Histories*, 1075 p. Translated from German by R. Sykes in co-operation with S. Semprich & B. Plischke. Berlin: Springer.

You, T., Gatelier, N. & Laurent, S. 2006. Design methodology for hydrocarbon caverns, influence of in-situ stresses on large sections. In C. F. Leung & Y. X. Zhou (eds), Rock Mechanics in Underground Construction, *Proceedings ISRM International Symposium 2006 & 4th Asian Rock Mechanics Symposium*, Singapore, 8-10 November, Paper 63, 9 p (on CD-ROM). Singapore: World Scientific Publ. Co.

Zhang, L., Einstein, H. H. & Dershowitz, W. S. 2002. Stereological relationship between trace length and size distribution of elliptical discontinuities. *Géotechnique*, 52(6): 419-433.

Zhao, J. & Gong, Q. M. 2006. Rock mechanics and excavation by tunnel boring machine. In C. F. Leung & Y. X. Zhou (eds), *Rock Mechanics in Underground Construction, Proceedings ISRM International Symposium 2006 & 4th Asian Rock Mechanics Symposium*, Singapore, 8-10 November, 83-96. Singapore: World Scientific Publ. Co.

Zhou, W., Yang, R. & Zhou, L. 1986. An analysis of jointed rock using fracture mechanics for stability of arch dam abutment. *Proceedings International Symposium on Engineering in Complex Rock Formations*, Beijing, 3-7 November, 470-478. Beijing: Science Press.

Zienkiewicz, O. C. 1977. *The Finite Element Method*, 3rd edn, 787 p. London: McGraw-Hill.

Zienkiewicz, O. C. & Cheung, Y. K. 1964. Buttress dams on complex rock foundations. *Water Power,* 16(5): 193-217.

PROJECT NEWS

The Construction of Retaining Walls Alongside Auckland's Southern Motorway–
Mark Hedley, Downer NZ Ltd

THIS PAPER HIGHLIGHTS SOME OF THE PROBLEMS WHICH WERE RESOLVED IN THE CONSTRUCTION OF RETAINING WALLS FOR THE NEWMARKET – GREEN LANE AUXILIARY LANE PROJECT CONSTRUCTED FOR NZTA.

1. Introduction

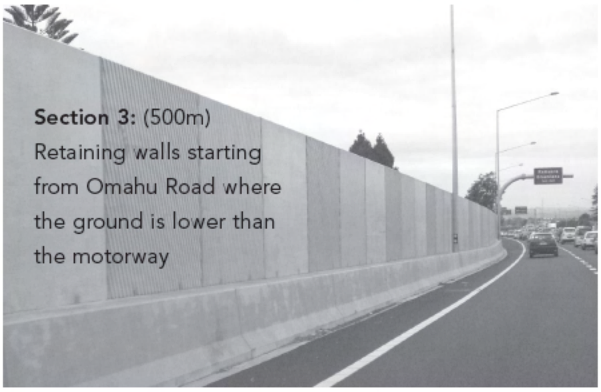
The Newmarket – Green Lane Auxiliary Lane Project involved the construction of a 4th lane from Market Road to the Green Lane interchange, a total length of 1500m. The $13.8m contract was designed by GHD Ltd, awarded to Downer in September 2009 and completed in April 2011.

The work included a re-construction of the existing shoulder to provide the 4th lane, along with drainage, ducting, lighting, signage, noise walls and landscaping.

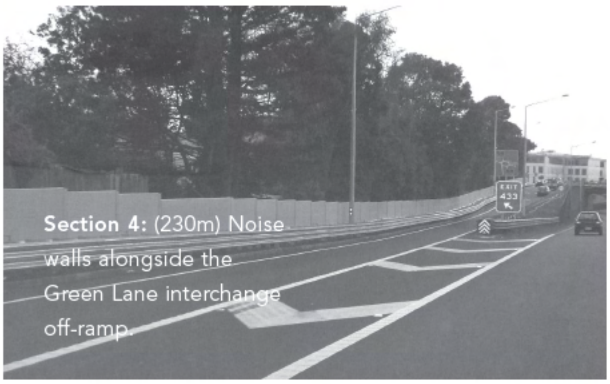
There were 4 distinctly different Sections along the site as illustrated on the right. This paper will focus on the retaining walls in Section 3.

Section 1: (300m) New barriers alongside the high concrete wall at the Market Road off-ramp.

Section 2: (470m) A soil nailed wall starting from Market Road where the ground is higher than the motorway.



Section 3: (500m) Retaining walls starting from Omahu Road where the ground is lower than the motorway



Section 4: (230m) Noise walls alongside the Green Lane interchange off-ramp.

2. Retaining Walls for Section 3

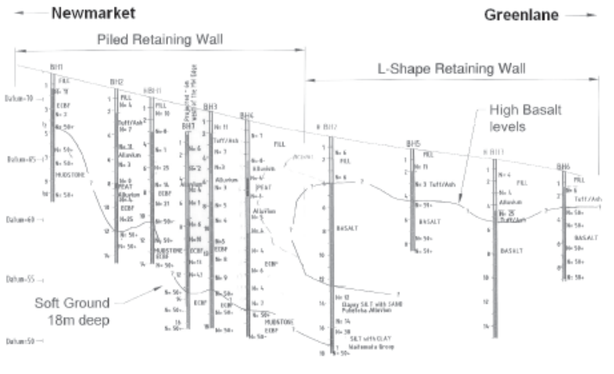
The retaining walls in Section 3 support the motorway which is generally about 3m higher than the adjacent properties and included a w barrier to resist traffic impact and a 3m high sound attenuation wall.

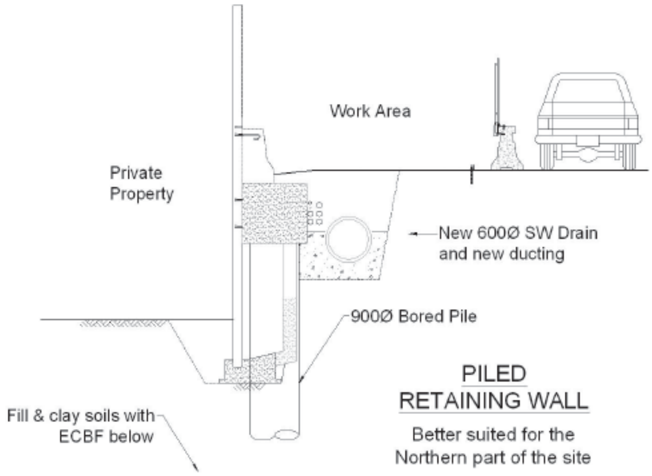
Some of the difficulties encountered and overcome on this section of the work included:

- Greatly varying ground conditions
- Buildings on or over the boundary
- A narrow site, 4m in places, restricting the size and turning of trucks and heavy plant
- Deep excavations beside heavily loaded motorway lanes
- Major services such as 11,000v cables intersecting the work
- Some 250 stakeholders with 68 residential properties adjacent to the work
- Traffic management and site access constraints
- The first re-use of the Harbour Bridge barriers for work site protection

In addition, there were some interesting results from concrete core testing which was carried out in the course of the project.

3. Ground Conditions Overcome by Hybrid Construction Method





Construction of the piled retaining wall

An unusual feature of the Contract was that two complete and fully designed options had been provided for the retaining walls in Section 3:

- a piled retaining wall.
- an L-shape retaining wall.

However, the existing ground profile presented a different challenge to each option.

The ground varied from ECBF mudstones to volcanic basalt rock, both overlain by soft material and fill as illustrated in the diagram to the left.

The Contractor opted to construct both wall types exploiting the advantages of each design:

- partly piled (at the Northern or "Newmarket" end of the site).
- partly L-shape (at the Southern or "Green Lane" end of the site).

Although this added complexity to the programming and procurement processes, it solved the following problems:

- Eliminated most of the drilling through the very hard basalt at the Southern end of the site.
- Eliminated the deepest excavations and major temporary shoring which would have been required if the L-shape had been constructed at the narrow Northern end of the site.

The decision by the Consultant and Client to provide the two designs allowed the Contractor to construct a hybrid structure that suited the variable ground conditions.

3. Contractor's Alternative Design

One of the problems to the Southern end of Section 3 was that some of the existing buildings were close to the boundary leaving little working room to construct a retaining wall. When site access was gained and a full survey carried out, it was revealed that some buildings in this area were on, or over the boundary.

The Contractor proposed a method to construct the walls in this area entirely from one side. This alternative design needed to meet the requirements of the both the Consultant and the Precast Sub-Contractor:

- Practical and constructible by the Precast Sub-Contractor.
- Robust enough to carry the loads that the structure would take - traffic impact being the dominant load.

The Contractor engaged the project designers, GHD Ltd to carry out the design work. Detailing and shop drawings were carried out by the precast sub-contractors; Stevensons Precast Systems Ltd and Stresscrete.

4. Success with Challenging Precast

Although the precast panel alternative overcame significant difficulties on site, there were challenges to be overcome in the precast factory.

The L-shape section of retaining wall was 295m long and made up of 59 'base' units, 118 'top' units and 118 noise wall panels.

Standardization of the moulds was difficult to achieve due to the following:

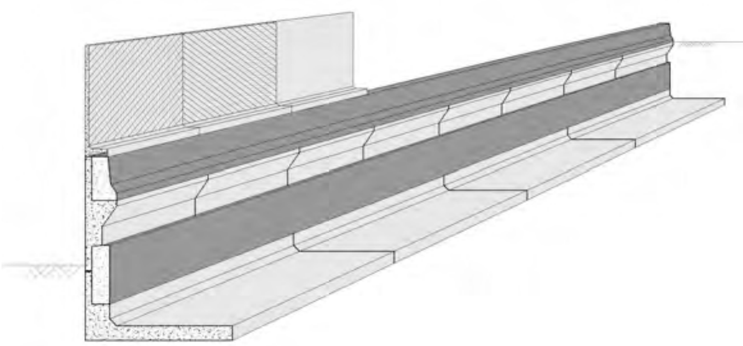
- The changing ground levels necessitated 8 different heights and 3 different widths of L-shape wall.
- Complex holes and slots in the moulds needed to accommodate different reinforcing steel sizes.
- Special units were required to accommodate Light Poles every 40 metres.
- Special units were also required for thickenings in the wall for the motorway sign gantries.

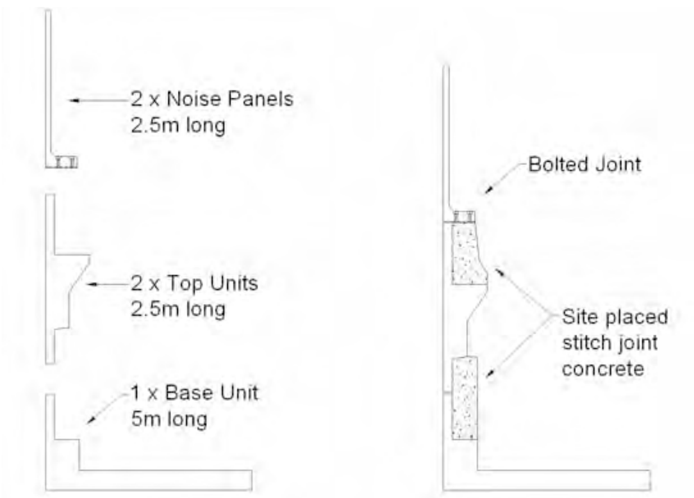
Although the top units were not particularly large, they were complex due to the need to satisfy design criteria. Success in producing these units without delays to site deliveries was achieved by:

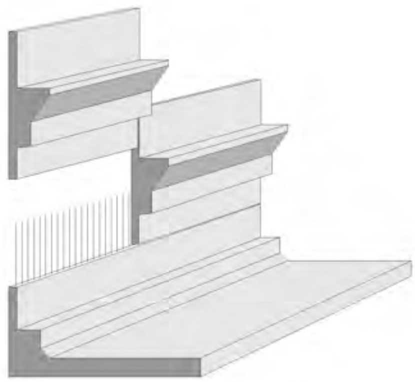
- Vigilance by the Precast Sub-Contractor in assembly of the reinforcing. It was necessary to fix the bars in precisely the same way every time.
- Quality Assurance by the main Contractor. Inspection attendance by the main contractor and Designer was increased above usual levels which helped eliminate errors and omissions.

Above: Top Unit precasting

Above: Base Unit precasting







Two Top Units containing Drossbach ducts are joined to one 5m long Base Unit. Starter bars in the Base Units are grouted into the ducts in theTop Units.

5. L-Shape Installation: Overcoming the Site Constraints

Although the precast L-shape design was an ideal solution for the Southern part of the site, avoiding the basalt and allowing construction from only one side, there were significant challenges to be overcome:

- Substantial excavation was required so that the wide precast 'base' units could be placed.
- The excavations, along with the narrow site prevented any through access.
- Trucks could not turn around and would thus need to enter & leave facing in the same direction. Loads would sometimes need to be double-handled
- Excavators had to be small and short-tailed otherwise they would not be able to turn around
- Access "Gates" from the motorway would continually require moving so as not to have a Gate where there was an excavation
- Motorway stormwater runoff needed to be managed
- Major services (11,000v cables) intersected with the L-shape structure requiring special work over a limited "shut-down" period.

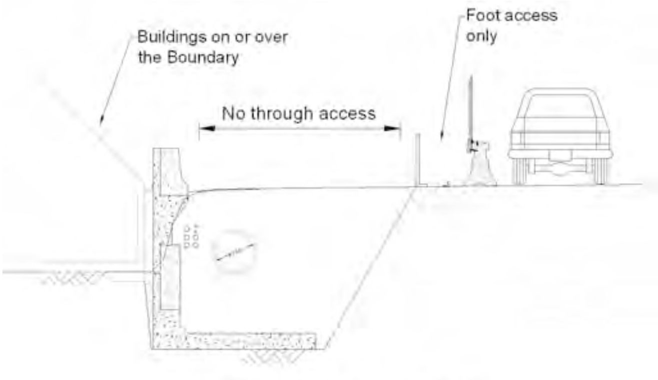
Of major importance in the construction of the L-shape was the integrity of the heavily trafficked and heavily loaded southern motorway while excavations were carried out alongside.

The motorway in this area consisted of asphalt, a stabilized 'concrete' layer and gravel and sandy soils overlying fill material. The cross sections were analysed for stability and it was found that relatively steep cut batters were possible.

Temporary support was required, however, in an area where the cut was around 4m and the site was particularly narrow. A system was devised using steel road plates clamped to the face of the batter. The plates were held by reidbars which in turn were attached to inclined screw anchors. In the remaining areas there was just enough width to safely batter the excavation back to the motorway.

The access restrictions of the narrow site were addressed by good planning and programming that was continually monitored and updated as work progressed.

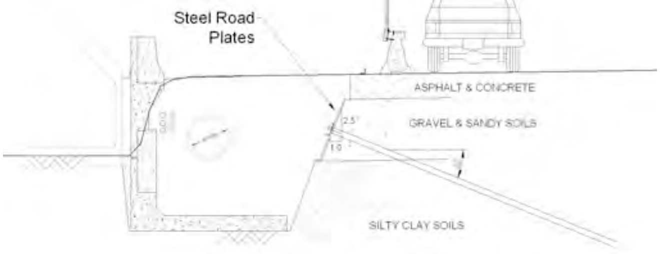
The L-shape wall proved to be quick to construct on site, the small crew achieving a dig and install rate of 20 lineal metres of wall per week.



L-SHAPE RETAINING WALL
Typical cross section

Above: L-shape wall installation on site

Above: 11,000v cable ducts passed under the house, through the L-shape wall and under the motorway



L-SHAPE RETAINING WALL
Temporary shoring for narrow section

6. Traffic Management and the use of the ex-AHB Moveable Lane Barriers (MLB's)

The work area was separated from the motorway traffic by a connected string of concrete barriers. There were four "Gates" in the barrier string to allow vehicles in and out of the site. This was the only access to the site for all vehicles, plant, materials and any emergency services.

Truck movements on and off the site from the motorway lanes could only be done between 9:30am and 3:30pm and only under attenuator escort. Some activities such as installing precast concrete units by crane required a lane closure. This could only be done at night, between 10:30pm and 4:30am and had to be pre-arranged in advance.

The ex Auckland Harbour Bridge moveable lane barrier units (MLB's) were offered as free hire to the Contractor by NZTA but required adaptation for use as work-site protection. As a barrier, they deflected too much and they did not fit locally available crash cushions. A method was developed using a steel angle bolted to the work-site side and a precast "transition" unit was designed and cast. These proved satisfactory following impacts from a number of traffic incidents.

Above: MLB's after removal from the Auckland Harbour Bridge

Above: Precast "transition" unit to connect the MLB's to locally available crash cushions

Above: Access "Gate" to and from the site via the southern motorway

Left: A 10-wheeler truck leaves the "Gate" escorted by 2 Attenuator Trucks

Above: Precast Units delivered and installed at night under lane closure

Above: Deflection of the barriers from impact on the Auckland Harbour Bridge

Left: Reduced deflection from typical impact with steel angle installed

7. Interesting Concrete Test Results

Testing was conducted on 8 samples of concrete which included:

- 28-day cylinder tests
- rebound hammer tests
- and concrete core tests

The testing was carried out as follows:

- 28-day cylinder testing was carried out at the batching plant in accordance with standard practice.
- Rebound hammer testing was done in three locations in accordance with the manual and the appropriate correction factors applied. The concrete surface at each location was ground smooth prior to testing.
- The precast unit was cored at each of the three locations. The cores were carefully removed, conditioned and crushed in an IANZ approved laboratory.

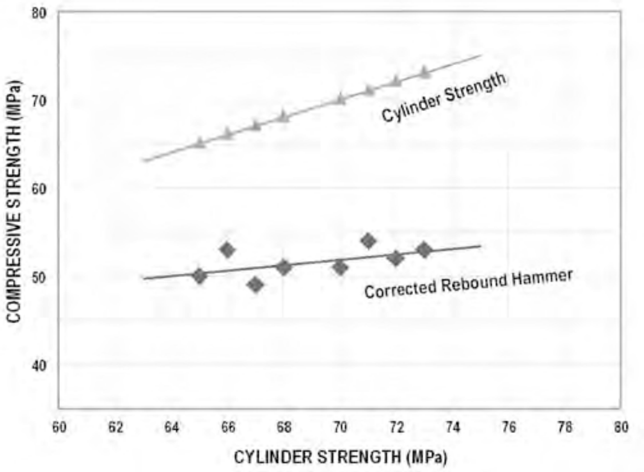
The concrete compression strengths inferred from the rebound hammer and the core tests were compared with the strength inferred by cylinders resulting in an interesting set of trend lines, which are shown opposite.

The X-axis records the cylinder strength of the 8 samples; the Y-axis records the compressive strength from two different tests. The results are a straight line for the cylinder vs cylinder plot and trend line for the plot of cylinder vs rebound or core tests. The results for both rebound hammer and cores fall below the cylinder results by about 77%. This is in keeping with the findings documented in other literature.

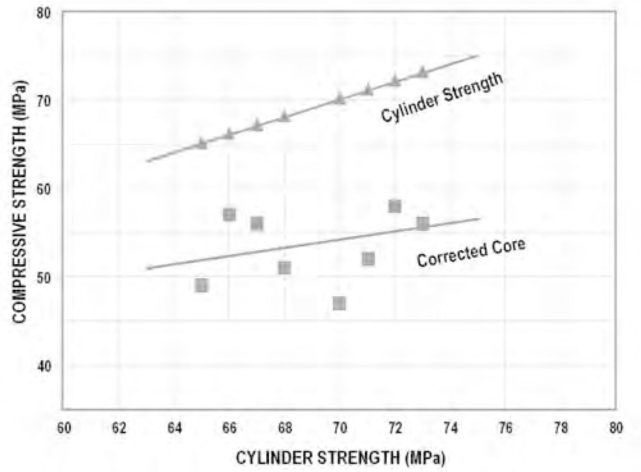
Unfortunately, the number of tests was small and the sample covered a narrow range of concrete strengths. Nevertheless, the results suggest that the rebound hammer indicated the cylinder strength as well as the concrete core tests. Rebound hammer testing is generally met with a degree of scepticism for a number of reasons. It is suggested that the construction industry could benefit from further study that gives designers and specifiers greater confidence in the use of non-destructive test methods.

Above: Rebound hammer for NDT of concrete

Above: Testing with the Rebound Hammer



Above: Comparison of average strength from 2 cylinders against average strength from 3x10 rebound hammer tests



Above: Comparison of average strength from 2 cylinders against average strength from 3 cores

8. Conclusions

The Newmarket – Green Lane Auxiliary Lane Project provided a 4th lane from Market Road to Green Lane involving the construction of concrete retaining walls.

The problems of variable ground conditions and buildings on the boundary were solved by a "hybrid" wall construction method and a precast concrete alternative that could be built from one side.

The difficulties of working on a very narrow site with the only access being from the Southern motorway were addressed and resolved.

The Contractor developed a method for the re-use of the redundant Auckland Harbour Bridge barriers for use as work-site protection.

The shared objectives of the Client, the Designer and the Contractor were formalized in a Partnering Charter which was signed at the commencement of the project.

The project is a good example of how ingenuity and the co-operation of all parties, Contractor, Sub-Contractors, Designer and the Engineer, can overcome difficulties and

contribute to success.

The 4th lane was opened in April 2011 and according to an article in the NZ Herald, Tuesday 3rd May 2011, was "tipped to save fuel, time and $1m a week".

9. Acknowledgements:

This paper was originally presented at the NZ Concrete Industry Conference, Rotorua, August 2011.

The author would like to thank NZTA and GHD Ltd for their co-operation in the preparation of this paper.

10. Further reading:

Gaimster, R., "The Cause for Cores or a Cause for Concern?", NZ Concrete Industry Conference, Wairakei, September 2007.

CCANZ Information Bulletin: IB 72, "Coring Concrete for Strength Assessment" Cement & Concrete Association of New Zealand, 2004.

Neville, A., "Core Tests: Easy to Perform, Not Easy to Interpret", Concrete International, November 2001, pp. 59-67.

Ali, M., & Moore, M., 1996, "Conversion of core strength to characteristic strength", Concrete in Australia, December 1996 – March 1997, pp 29.

NZ Geotechnical Society
2011 PHOTO COMPETITION
WINNER

Theme "...you don't see that every day!"

Morgan's Valley, March 1, 2011. Rockfall assessment following the Christchurch Earthquake, 22 February 2011. **Leon Gerraf.**

Clockwise from top left: *Luke Williams* Work at Ohakia; *Shamus Wallace*, Some of the team of geotechnical professionals that make up the EQC Land Damage Assessment Team (LDAT). The team is based on over 400 members of the geotechnical community sourced from more than 40 companies; *Luke Williams*, Indonesian jungle; *Bryan Wood*, Footing inspection; *John Aramowicz*, 22 Feb 2011 earthquake damage to a wall on the Port Hills; *Peter Bennett;* lonely beach.

TECHNICAL NOTES

Electronic Transfer of Geotechnical and Geoenvironmental Data

Overview

The AGS Data Transfer Format is not new, having been around since 1991. However, it has generally not been taken up in New Zealand, despite many organisations using data management software that is able to generate and read AGS data files. In 2007, the NZGS set up a Working Group to establish a version of the format tailored to New Zealand requirements. This was completed and the file format was published as Version 3.2 NZ v1.0. This has now been updated to reflect changes made to the base document by the AGS in the UK, where their Version 4 is about to be released.The updated version will remain closely aligned to the version published by the AGS UK in order to ensure that it is readily incorporated into the mainstream commercially available software. This approach will also maintain the ability to use New Zealand generated data elsewhere in the world, and vice versa.

It is anticipated that major client bodies will specify the provision of geotechnical data in AGS format in their procurement contracts. This, and the update to Version 4, will allow much greater access to geotechnical data with improved efficiencies and interpretation.

The background to the AGS data transfer format has been documented and made available in the NZGS website for some time. This is reproduced in part below.

The Problem

It is accepted that we generally have insufficient geotechnical data. In addition, the data that we do have is often difficult to access by all but the originator, either due to time constraints or the inability to read the data into an easily assimilated form.

All too often, geotechnical data for a project will come from multiple sources, possibly obtained over a wide period of time. Boreholes will be in different presentation formats, making them difficult to compare, laboratory test data will come in a mix of hard copy, computer spreadsheet and even computer text files, which renders collation impossible, except by manual transcription. This confusion of data presentation format is illustrated in Figure 1.

The Solution

It was established in the early 1990's that major benefits would accrue if geotechnical data were to be available in an electronic format. The challenge to develop such a format was taken up by the AGS in the UK in 1991. In 1992 the first version of the AGS format was published and rapidly became the accepted standard for the presentation of geotechnical data in electronic form.

The immediate effect of the AGS Format has been to eliminate the chaotic structure inherent in Figure 1 and replace it with an ordered structure typified by Figure 2.

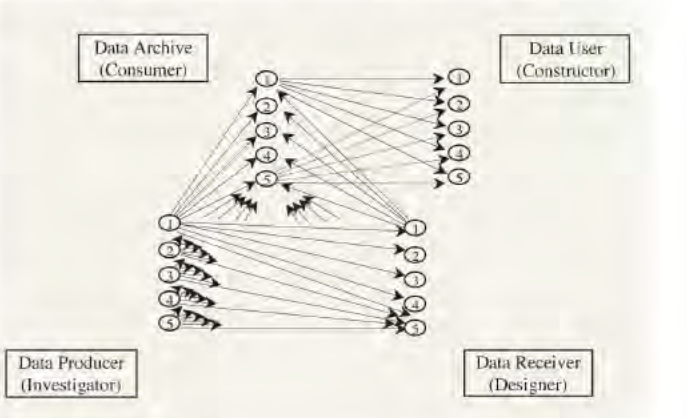


Figure 1: Before AGS

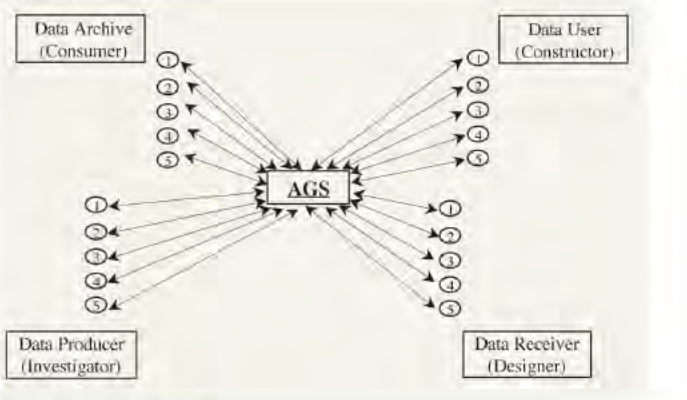


Figure 2: After AGS

In setting up the format, the AGS established a series of basic criteria to be met. These were that the format must:-

- Fbe independent of any software package, proprietary or otherwise.
- Fbe able to be incorporated into existing or future software either as an import filter or an export routine.
- Fbe a file format protocol. It is NOT a database.
- Fbe a simple ASCII text file.
- Fcontain fundamental data only. Interpolated or derived data is excluded in order to avoid cluttering of data files.

By adhering to the above base criteria, universal access to the data by all is maintained.

Advantages to data Access in Electronic Form

The overriding advantage of the use of the AGS format is that data can be transferred efficiently and accurately

AVALON
Professional
GEOTECHNICAL
products

AVALON
// ROPE ACCESS SERVICES
www.avalonltd.co.nz

// ROCKFALL PROTECTION SYSTEMS

Experience – Innovation – Performance

AVALON INDUSTRIAL SERVICES LTD
PH. +64 7 846 1686 // FX. +64 7 846 1016 // mail@avalonltd.co.nz // www.avalonltd.co.nz

between users with no transcription errors. It also ensures that data can be read and shared by the entire project team, therefore maximising its use. There is an old adage that one should enter computer data once and once only and that it must be done as early in the process as possible, preferably by somebody else!

Access to data in electronic form using appropriate software provides immediate access to the information. Data does not have to be manually collated, plotted or drawn. Data can also be obtained from multiple sources and combined into a single data set.

What can you do with AGS Data

Once the data is available in electronic form, it can be managed and output to a wide variety of applications including:-

- FBorehole logs
- FData plots
- FSite plans and sections
- F3-D modelling
- FArchiving

Flexibility and Adaptation to New Zealand Needs

The key to the widespread adoption of the Format has been its inherent simplicity and flexibility based on the use of the data dictionary concept. Within the international context, local requirements can be accommodated by the addition of new fields to existing groups and also the addition of new groups where required.

To adapt the format to New Zealand requirements, the NZGS established a working party tasked with identifying local requirements. This resulted in the publication of Version 3.2 NZ v1.0, available on the NZGS website.

Version 4 builds on feedback received from the current version and has been more closely aligned to the AGS UK format to ensure its incorporation into the mainstream commercially available software.

The Future

The major geotechnical database and data management software suppliers operating in NZ have indicated that they will incorporate AGS NZ Version 4 into their software. This will enable users to generate and receive data in the updated format.

It is acknowledged that the format has to be able to evolve with the changing needs of the industry. In order to achieve this, provision will be made for users to post queries and suggestions, together with responses and updates on the NZGS website. This will ensure the ongoing currency and effectiveness of the format.

Rodney Hutchison, Rhutchison@kga.co.nz
Geoffrey Farquhar, Geoffrey.farquhar@aecom.com

TECHNICAL REPORT REVIEW

Geotechnical Reconnaissance of the 2010, Darfield (New Zealand) Earthquake – Misko Cubrinovski and Russell Green (Editors)

THIS TECHNICAL REPORT BY the lead editors, Misko Cubrinovski (University of Canterbury, Christchurch, NZ) and Russell Green (Virginia Tech, Blacksburg, VA, USA), has thirteen contributing authors and eleven other contributors.

The authors are specialists from the fields of geotechnical engineering, structural/earthquake engineering and geology.

The book has 171 pages and is presented in an A4 spiral-bound format.

The table of contents covers:

- Introduction
- Geological Aspects
- Seismological Aspects
- Liquifaction and Lateral Spreading
- Impact on Building Structures
- Performance of Stopbanks and Oxidation Pond Embankments
- Effects on Lifelines

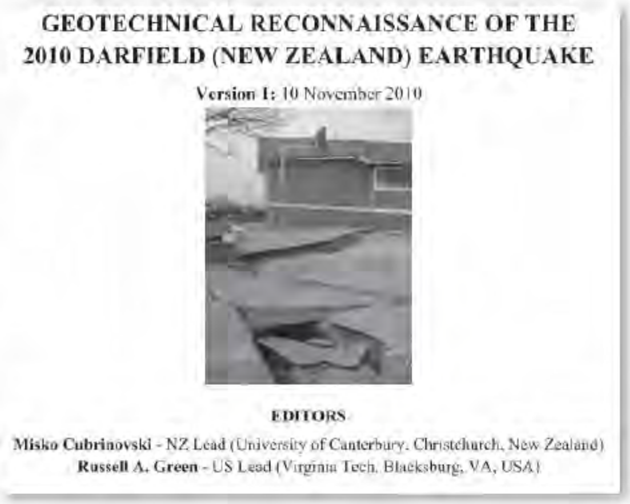
Each chapter provides technical references for the reader from the geological, seismological, geotechnical, structural and earthquake engineering sectors, etc…

Essentially, the book provides a reconnoitring survey of the magnitude M_w = 7.1 earthquake which struck the Canterbury region on 4 September 2010, with the epicentre focused in the Darfield area, 40km west of the city of Christchurch.

The rupture of a previously unrecognised strike-slip fault beneath the Canterbury Plains of New Zealand's South Island produced an earthquake that caused widespread damage throughout the region.

The authors, in their presentation, have taken full advantage of the fact that the Canterbury region is well instrumented with seismographs that can record strong ground motion. Further, in this instance, the glossary of photographs provided in many of the chapters reflects the fact that the low relief and well maintained agricultural landscape of the Canterbury Plains has provided an ideal environment to characterise even the most subtle of earthquake-related ground deformation at high resolution.

The chapter on geological aspects is both detailed and excellently presented. The chapter provides an absorbing overview of the epicentre of the 2010 Darfield earthquake and the mainshock features and aftershock distributions insofar as they relate to the Greendale fault. The chapter continues with sections on the characteristics of the surface fault rupture, history of the Greendale fault and


GEOTECHNICAL RECONNAISSANCE OF THE 2010 DARFIELD (NEW ZEALAND) EARTHQUAKE

Version 1: 10 November 2010

EDITORS

Misko Cubrinovski - NZ Lead (University of Canterbury, Christchurch, New Zealand)

Russell A. Green - US Lead (Virginia Tech, Blacksburg, VA, USA)

geomorphology of soil deposits in the Christchurch area.

Essentially, this early chapter describes the format and analytical tone of this publication. Namely, excellent details and description, well-presented and good colour definition on the graphs (particularly the log-normal plots), maps, plans and digital photographs.

The chapter entitled seismological aspects provides interesting information on regional seismicity and historical earthquakes. The manner in which the finite fault models for the Darfield earthquake are explained and the models are illustrated by clear coloured graphs.

The remainder of this chapter comments on the ground motion shaking and gives the attendant map of New Zealand showing the 'location of felt-it reports' and a map of the Canterbury region with plots of the peak ground accelerations as recorded by the strong seismometers.

Graphs which illustrate recorded acceleration time-histories and respective response spectra at three locations – Greendale, Christchurch Hospital and Kaiapoi are given at the conclusion of this chapter.

As might be expected, the two chapters on liquefaction and lateral spreading and impact on building structures are the main part of this publication.

The duality that liquefaction is a complex process and strong earthquakes provide the shear forces to trigger liquefaction is illustrated with considerable effect in these chapters.

Useful mention is also made that in the view of the extensiveness and severity of the liquefaction, lateral spreading and ground failures, that the most significant engineering aspects of the 2010 Darfield Earthquake were geotechnical in nature.

The many photographs which show the magnitude and effects of the liquefaction, sand boils, lateral spreading and structural damage to residential buildings and those in the business districts of Christchurch & Kaiapoi, are testament to the destructive forces of a large earthquake.

The chapters are enhanced by graphs giving post-event penetration resistance tests of the soils using a variety of test methods such as the Dynamic Cone Penetration Tests (DCPT), Swedish Weight Sounding (SWS) and Spectral Analysis of Surface Waves (SASW).

An interesting comment is made in the chapter on 'impact on building structures' insofar as concrete slab-on-grade foundations for residential structures are specified in the relevant code NZS3604: 1999 'Timber framed buildings'.

In this code, the application of NZS3604 is based upon the concept of 'good ground'. Site conditions that exclude the application of NZS3604 are specified as peat, soft clay and expansive clay but liquefiable soil is not mentioned!

The final two chapters of this publication relate to the seismic performance of stopbanks and embankments and the effects on lifelines – such as the transportation system (bridges, airports, ports, etc) and wastewater systems, electric power, waste management and landfill, etc…

In conclusion, I consider this publication to be a valuable reference on the extensive subject of earthquakes. The manner of its presentation – given the extremely broad range of the book's technical coverage – is excellent. I believe the book is a must on the bookshelf of all those involved in the multiple professional disciplines associated with earthquakes.

Reviewed by: Michael Wesseldine
Belgravia Building Consultants

Reference

Cubrinovski, M., Green, R., Allen, J., Ashford, S., Bowman, E., Bradley, B.A., Cox, B., Hutchinson, T., Kavazanjian, E., Orense, R., Pender, M., Quigley, M. and Wotherspoon, L. (2010) Geotechnical reconnaissance of the 2010 Darfield (New Zealand) earthquake. University of Canterbury. 173pp. (Technical Report):

Available for down from the UC Reserach Repository:
http://ir.canterbury.ac.nz/

COMPANY PROFILES

MWH Global – Building a Better World

Above: An image of Cambridge Terrace, Christchurch in the wake of the earthquake, captured by MWH's Senior Engineering Geologist Sigfrid Dupre.

Which organisation is:

- Designing and delivering road recovery works across the 177,582 sq km Fitzroy Region's network of roads, following the devastating flood and cyclone events of 2010-11.
- Providing support to the NZ Transport Agency in highway stabilisation and reconstruction work for the Manawatu Gorge.
- Managing geotechnical investigations, feasibility studies and geological surveys for new hydro and dams schemes across Fiji, Brunei, Romania and Malaysia.

It may surprise you to learn that those are just a few of the contracts MWH New Zealand's national team of geotechnical specialists are currently involved in. While MWH is primarily known for its transportation and water/wastewater engineering, its growing team of geotechnical experts are in demand for infrastructure development and maintenance projects both in New Zealand, and throughout the Asia Pacific Region.

Regional Opportunities

Currently MWH has a team of 22 staff in New Zealand providing geotechnical engineering, engineering geology and hydrogeology services, and the team is recruiting to meet increasing project opportunities. MWH works in the transportation, water, waste, energy and industrial sectors with geotechnical specialists usually part of multi-disciplinary project teams.

MWH's geotechnical team is part of AP DESIGN, a geographically spread design unit that links staff across New Zealand, Australia, Asia and India. The concept behind AP DESIGN is 'Right Person, Right Job' with projects being resourced on a regional basis to give clients the best specialist skill sets for their work, no matter where staff are physically located. For staff in AP DESIGN the regional focus provides genuine opportunities for working offshore in either short or long term assignments. AP DESIGN Geotechnical Discipline Leader, Grant Maxwell says this regional focus is particularly important in the geotechnical area. "Often local geotechnical engineers work only within a specific location meaning their skills are not easily transferable. Through AP DESIGN the skills transfer and knowledge sharing means our staff learn, see and undertake a wide range of projects in different locations building their skill sets." As well as the ability to undertake regional projects, AP DESIGN provides clear career pathways for technical specialist staff and the ability for training and career development as part of a global organisation.

Current major regional work includes the Transport Network Reconstruction Program (TNRP) for the Queensland Department of Transport and Main Roads. MWH has been appointed to plan, deliver and manage road restoration throughout the Fitzroy Region, which

Right: Manawatu Gorge. MWH's geotechnical team is currently working with the NZ Transport Agency on the latest SH3 Manawatu Gorge landslide.

was badly affected by flooding in 2010-11 and sustained significant erosion on road pavements and shoulders. The programme includes a large number of restoration projects almost all taking place on live roads with major stakeholders including 24-hour mining traffic, livestock and commodities carriers as well as tourist traffic. New Zealand geotechnical staff have been seconded on to this project with a particular focus on geotechnical slip site identification, site inspections and detailed assessment and design of remedial works.

Local Impact

While regional projects provide opportunities, MWH's geotechnical team is also in demand nationally with much focus on Canterbury earthquake recovery work. The team provided immediate voluntary services following the first earthquake in September 2010, and also undertook rapid response inspections for the Ministry of Education to report on damage to the city's primary schools including assessing the safety risks of each structure and providing data to support recommendations for remedial works. MWH geotechnical engineers are now involved as part of the MWH Mainzeal joint venture which is working on Vero and AA Insurance claims in Christchurch.

Reconstruction is also underway on SH3 in the Manawatu Gorge which was closed by a major progressive landslide following bad weather. MWH is providing specialist geotechnical advice to the NZ Transport Agency as it deals with landslips on this section of highway. MWH's geotechnical involvement in the Manawatu Gorge stretches back to 2004 and a range of emergency remedial measures, geotechnical investigations and highway stabiliation and reconstruction works have been completed. These have included MSE solutions and the design of new rock slope stabilition measures including scaling, catch fences, rock fall netting and rock bolting above the road.

Elsewhere in the country MWH is providing geotechnical support to strategically important transportation links including Rangiriri (Waikato) and the Matahorua Gorge (Hawkes Bay) and on wastewater treatment and pipeline projects for Tasman and Selwyn Councils.

Our Team

MWH's New Zealand based geotechnical team is led by Grant Maxwell and Charlie Price. Grant, AP DESIGN Geotechnical Discipline Leader, manages geotechnical staff across the region and is responsible for ensuring clients get the right skills and experience for every job. Grant is also responsible for the development of tools and templates to build consistency and enable efficiencies. Charlie Price is AP DESIGN Chief Geotechnical Engineer. Charlie has recently joined MWH and is responsible for ensuring the quality of all geotechnical work in the region. Charlie is also a Geotechnical Specialist Advisor to the NZ Transport Agency and a current member of the committee of the New Zealand Geotechnical Society. The geotechnical leadership team is also complemented by Senior Geologist Paul Wopereis who provides specialist engineering geology services to clients in the transportation, mining and hydro sectors.

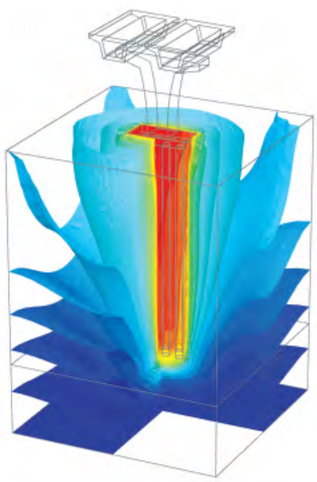
About MWH

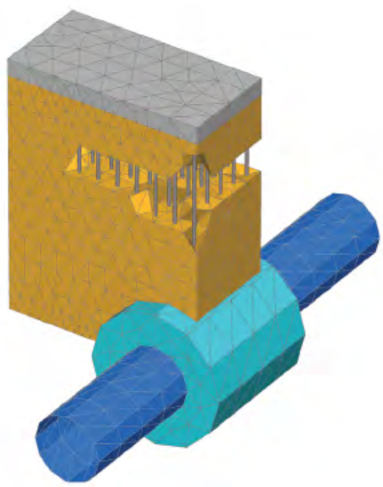
MWH operates in 35 countries and has over 6.500 employees. All around the world our purpose is to work with clients and communities in the interest of Building a Better World. In New Zealand we've been providing clients with infrastructure and environment expertise for over 100 years. Our team of 650 staff in 17 offices includes engineers, planners, scientists, project managers, technologies, surveyors and designers.

Contact Details

Grant Maxwell, 027 268 5021
grant.maxwell@mwhglobal.com
www.mwhglobal.com

MWH®
BUILDING A BETTER WORLD





Geoscience Consulting (NZ) Ltd

GEOSCIENCE IS ONE of the fastest growing, specialist geotechnical/environmental consulting firms in Christchurch. Founded by Matt Wiley and Greg Martin, the organisation has quickly developed a reputation for excellent work and responsive service.

The key to this success according to Geosciences' Matt Wiley is the team's refreshing approach to its work "Our team is empowered to take ownership of projects and foster client relationships. Our clients appreciate dealing with someone who can make decisions and our staff are proving to be more than capable of operating within their level of expertise and calling in the assistance of the broader group as required".

The team consists of 12 highly skilled geotechnical and environmental staff passionate about the industry and delivering smart, cost effective pragmatic solutions for our clients. With projects spread around New Zealand and Australia and with opportunities within the greater Pacific Region, Geoscience offers clients a breadth and depth of experience, and staff a variety of interesting project opportunities.

Our people enjoy working in this inclusive and collaborative environment. This philosophy was emphasised at a recent staff retreat to Noumea. The getaway not only provided staff with, the opportunity to catch their breath and get away from the stresses of post earthquake Christchurch, but also reaffirm their focus and approach for what is likely to be a very busy time for their profession over the next ten years.

Geosciences' unique structure and strategic business alliances provide the company with big business support and capacity whilst not compromising the small business service focus. Greg Martin, Director of Geoscience, explains that it is this focus that has resulted in much of the repeat business and strong client referrals the company thrives on. "Our small business feel and can-do approach is about fostering lasting relationships based on personal service, backed by big business support that provides clients with the level of service and certainty they appreciate and staff with a level of support that is not typically associated with organisations of our size. Our people are prepared to work above what is normally expected of their roles to ensure client expectations are met".

Whilst heavily involved in the geotechnical aspects of the Christchurch post Earthquake reconstruction effort, Geosciences' project office currently has a variety of other types of projects on its books. Rail and Port infrastructure along with various mining endeavours, both at home and overseas, are some of the bigger ticket items in the office at present. In addition the team has been delivering numerous

Left: Slope stabilisation of large failure, Stillwater

Below: Stabilisation work for daylighting Tunnel 19 on the Midland Line, Stillwater

detailed geological and geotechnical investigations, rockfall and liquefaction assessments and accompanying mitigation work.

Innovation

Thinking outside the box Geoscience have been developing a unique foundation solution better suited to deep liquefiable soils based on the use of a high strength no-fines concrete drainage blanket incorporated within a reinforced gravel raft. The idea is to greatly reduce the damaging effects of liquefaction under a floor slab during a significant earthquake and making any repair less costly. Geoscience has also been working with KiwiRail to develop smarter ways of using new technology to capture data in the field for current slope rating work being undertaken along the rail Network.

The Future

Looking forward Geoscience is expanding its environmental team, with their development of environmental management and monitoring services. This along with several planned new offices in New Zealand and abroad is expected to provide significant opportunities for the business and those in it.

But for Matt it is all about the now; "Our business has developed quickly. We have formed strong strategic relationships to ensure our business is sustainable longer term and staff have the opportunity to develop and broaden their horizons. We never lose sight of the fact that reputations are won and lost very quickly so our number one priority is to do a quality job every time".

Geoscience is proudly employee owned by nearly 50% of the staff. Share ownership is affordable thanks to the generous profit sharing scheme which rewards all staff for their efforts. Longer term the business is looking for opportunities to increase the share offering to similar liked minded individuals. "We always have opportunities for the right people" says Matt.

Contact Details

5 Norwich Quay, Lyttelton 8082
PO Box 110, Lyttelton 8841
ph +64 3 328 9012
fax +64 3 328 9013
www.nzgeoscience.co.nz

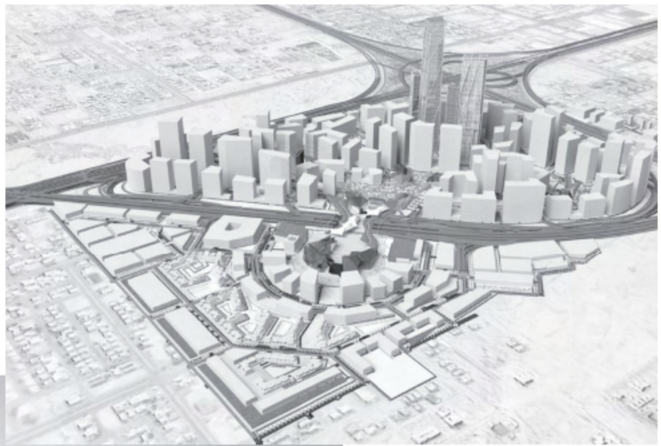
GEOSCIENCE consulting (NZ) LIMITED

Senior Geotechnical Engineer
Do you feel that it is time to take control of your career and shape your future?
Geoscience is looking for a senior Geotechnical Engineer to join its leadership team. For the right person an attractive package that includes competitive remuneration, profit share and ownership possibilities await.
To be successful in our business you will be someone who;
• Understands and fosters client relationships;
• Has a demonstrable can do attitude;
• Is passionate about the geotechnical profession;
• Will check your ego in at the door and utilise the strengths of our dynamic team to deliver superb results to our valued clients.
Your professional experience is likely to include;
• BE or ME and CPEng;
• Project management experience;
• Proven track record in the delivery of projects for your clients.
To confidentially discuss this Christchurch based opportunity please call Justin Davies on 021 435 069 or email your CV and covering letter to justin@nzgeoscience.co.nz. In doing so please ensure you are either a New Zealand resident or hold a valid New Zealand work permit.
GEOSCIENCE
consulting
(NZ) LIMITED

FOREIGN CORRESPONDENT

Ayoub Riman,

GIPENZ, LEED GA, SAV
Beirut, Lebanon
Geotechnical Engineer
Dar Al-Handasah (Shair and Partners)



Above: Site aerial perspective of King Abdullah Financial District (KSA).

Left: The King Abdullah Financial District during excavation works and construction

LEBANON'S LOCATION AT the triple junction of Asia, Africa and Europe has significantly contributed to its rich history, and shaped a cultural identity of religious and ethnic diversity. This diversity makes Lebanon a unique country, rich in culture with a history reflected in civilizations dating back to more than 7,000 years (predating recorded history). Living in Lebanon is quite interesting for someone who appreciates nature, history and cultural diversity.

Travelling to more than 18 countries across the continents in the last 10 years, I find Lebanon a safe place to work and live in, despite the conflicts and unrest that occurs from time to time. Despite all the hard times that the country has had to go through, from a civil war to several conflicts at the borders, nowadays Lebanon enjoys a peaceful atmosphere and a stable economy. People don't usually install security alarms and it is not common to get insurance against theft!

Working in Lebanon, or more precisely in the Geotechnical and Heavy Civil Engineering Department at DAR Al-Handasah (Shair and Partners), is a rich and valuable experience. Dar Al-Handasah is one of the leading consultancies worldwide, where it ranks 9th among ENR's top 200 International design firms, 5th among pure design firms and 1st in the Middle East. The international calibre of DAR Al-Handasah, with offices and projects all around the world has provided the opportunity to be involved in geotechnical design in several countries, with differing geology, engineering technologies and resources. This is definitely a challenging and rewarding experience that every engineering geologist and geotechnical engineer should have.

I have been involved on several geotechnical projects concurrently in the Middle East, Africa and Europe – so one time you're working in karstic limestone formations and worried about the behaviour of the rock masses and presence of cavities, another time you are working on soft clays where long-term deformations are the challenge... and then you find yourself working on sands susceptible to liquefaction, etc... It is a versatile experience that guarantees you will never be bored as a Geotech!

Above: Porto Arabia showing the reclaimed Marsa Arabia Island in the centre (The Pearl, Qatar).

One of the recent projects I was involved in was the "King Abdullah Financial District - KAFD" at Riyadh, Saudi Arabia. My company had two major tasks: the "design management" of thirty parcels and the design of three of those parcels. I was on the design team that worked on the three parcels delivering the foundation design and the necessary geotechnical recommendations for the construction of 3 towers. One of the most challenging and interesting aspects of this project was being onboard with several design firms where knowledge and lessons were shared and transferred among all of us to deliver an optimized state of the art result.

Another recent project is the "Four Seasons Resort" at Marsa Arabia which was planned over a reclaimed island located at the centre of Porto Arabia Marina (The Pearl, Qatar). The work included providing criteria for the foundation design of buildings and marine structures, dewatering activities during excavation works, temporary shoring system design, stability analysis of subgrades under high fills and the assessment of liquefaction hazards.

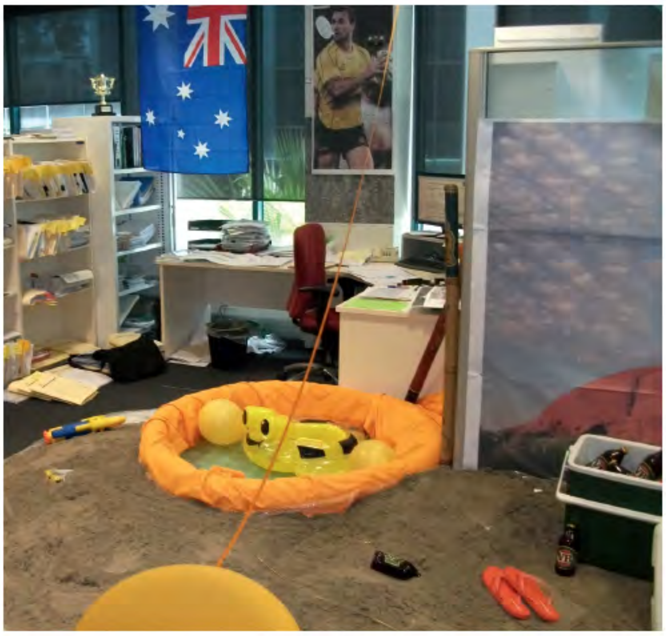
It is rare to have the opportunity to work in the geotechnical field in Lebanon at the high level of professionalism and expertise that Dar Al-Handasah provides, as there are few international companies in Lebanon that specialize in this area. For me, this is a great opportunity to work on projects worldwide, especially in the booming neighbouring countries, and at the same time live in Lebanon, which is considered a holiday destination in the region.

So if you value nature, cultural diversity and a long history (from the Phoenicians till nowadays), then Lebanon is the place to be in the Middle East, as well as the fact that it stands out with relatively high levels of freedom and democracy compared to elsewhere in the region.

NOTICE BOARDS

Around the Office

'Around the Office' is a collection of humorous snapshots spotted around the offices of NZGS members. Please send any suitable material to the Editors: Hamish Maclean at HMaclean@tonkin.co.nz or Paul Salter at paul.salter@urs.com



MEMBER PROFILES

Marc-André Brideau

Occupation
Lecturer in Engineering Geology
The University of Auckland

I GREW UP in a small town in New Brunswick on the east coast of Canada. After high school I travelled to the west coast to attend Simon Fraser University (SFU) in Vancouver. I started out studying physics but soon realized that I enjoyed spending time exploring the mountains around Vancouver a lot more than solving ordinary differential equations, so I transferred to the geology programme. My first summer job in geology was as a field assistant in a remote region of the Yukon (northern Canada). It was a great summer for me during which I discovered my love for fieldwork, research and the Yukon. I was introduced to engineering geology during my senior year, first as part of a soil and rock mechanics paper and then as a directed study with Prof. Doug Stead.

I found engineering geology so interesting that I decided to undertake an MSc at SFU under the supervision of Prof. Stead. My thesis investigated the influence of tectonic structures on the location and mechanism of large rock slope failures. This gave me the opportunity to work on the Hope Slide in British Columbia and two other large landslides in western Canada and the Yukon. During the later part of my MSc I also got the chance to be involved in a debris avalanche runout study on Vancouver Island. We worked on determining the attributes associated with the initiation of debris avalanches in logged terrain and their influence on the travel distance of these mass movements.

Following my MSc I worked for a year and a half in geotechnical consulting firms in Vancouver. My first summer was spent conducting geotechnical logging on-site for a helicopter supported diamond drilling rig in a remote area near the Canada-Alaska border. Afterward, I was primarily responsible for the engineering geological mapping of transmission line routes associated with small hydro-electric projects. I particularly enjoyed these assignments because they gave me the opportunity to consider all the large- and small-scale processes acting in the landscape and transfer that information into implications for engineering projects.

After a period of time I felt that I wanted to continue my formal training in engineering geology, so I embarked on my doctoral studies. I decided to continue my research at SFU under the supervision of Prof. Stead. My PhD delved into the three-dimensional controls of large rock slope failures. I approached this project by investigating conceptual slope profiles in a 3D distinct element code and compared the results with case studies. During my PhD I was lucky to be given the freedom to take on several side projects. I got to study a landslide at the northern end of town in Dawson City, Yukon. I also had the opportunity to characterize the stratigraphy and basic engineering geology properties of the glacio-lacustrine and loess deposits around the city of Whitehorse in the Yukon. I even got experience for my current position by teaching for one semester at a local college and for another at SFU. Toward the end of my PhD, I came across a job advertisement for an engineering geology position at the University of Auckland. Two days after submitting my thesis my partner and I were on a plane bound for the City of Sails.

I started in my new role as a lecturer in the School of Environment in May 2010. My integration at the University of Auckland was made all the more easy by a six month overlap with my predecessor Dr. Warwick Prebble and by his generosity in providing me with introductions to his industry contacts (many of which are his former students). I currently teach half of the Introduction to Engineering Geology course in the Department Civil Engineering, a third year paper in Engineering Geology and a graduate level paper in Analyses Techniques in Engineering Geology (both the latter in the School of Environment). My current research interests include applications of terrestrial photogrammetry to complement field rock masses characterization, numerical modeling of slope stability conditions, and engineering geology in periglacial environments. Each year I typically supervise 4-5 graduate students doing research on topics ranging from coastal cliff stability, volcanic edifice stability, landslide dammed-lake, debris flows, and deep seated gravitational deformations. All of these projects have field mapping, laboratory testing, and numerical modeling components. Since arriving in New Zealand I have become a member of the NZGS, NZ aggregate inventory group, and in 2012 I will become the NZ representative to the International Society for Rock Mechanics (ISRM). Looking forward, I hope to be involved in many more challenging projects investigating various aspects of the influence of the New Zealand's interesting geology on slope stability.

Erica Cammack

Occupation
Engineering Geologist
Beca Infrastructure Ltd, Auckland
NZGS YGP Representative

THE STORY OF my path to engineering geology probably starts back at high school in Wellington when I decided that geography sounded like a much easier subject than calculus even though I knew very little about either. Social geography didn't hold much interest for me, but the physical side of things was awesome! Mum and dad had to sit through many lectures on the landforms in Wellington after I had read Graeme Stevens' Rugged Landscape.

My other favourite subject at high school was biology, and having been a member of the Kiwi Conservation Club since I was 2 feet high I imagined that I would grow up to be an environmental saviour of some sort.

By my last year at school I still wasn't totally set in my life path, but luckily we had some bad weather on our skiing holiday that year and I decided I might as well head along to Canterbury University open day for something to do. The main thing I remember of that day was a lecture given by Professor Steve Weaver where he boasted of travelling to all seven continents in the world and he had amazing slides to prove it.

I enrolled at Canterbury University with an aim to integrate my interests in ecology and geology. This lead me down a path towards palaeontology, culminating in my honours research which involved geophysical surveying of swamps with the aim of identifying the presence of recent fossil deposits.

My supervisor, Dr David Nobes, was also involved with geophysics in Antarctica and he very generously offered to take me with his team as a field assistant over the summer season. The research involved GPR surveys of historic hydro-chemical spills in the Dry Valleys and at Scott Base, as well as surveying the pressure ridges in the Ross Ice Shelf to test whether GPR could be used as a tool to identify crevasse development on the ice runways at Ross Island.

When I graduated I decided that rather than working in an office or a lab 5 days a week, I wanted to get outdoors and get my hands dirty. I was also very passionate about helping preserve New Zealand's unique ecology and as a result I spent the next 4 years working for the Department of Conservation.

My time with DOC was kind of an OE, only it was spent relatively close to home. I spent 4 months in the weed control team on Raoul Island in the Kermadec Volcanic Archipelago, followed by 2 seasons working on the Travers-Sabine track in the Nelson Lakes. In between summer seasons I had shorter stints working on Mana and Matiu-Somes Islands in the Wellington Region. My last position with the department was as one of the resident rangers on Kapiti Island on the Kapiti Coast. I eventually decided that a secure career in the conservation field in NZ was not easy to come by and that perhaps it was time for a career re-think.

Above: Jared Pettersson and I doing GPR Surveys on Ross Island, Antarctica

Thanks to some nudging from a friend from university I applied for a job as engineering geologist at Beca in Auckland in 2005. I have been at Beca for 5 years now and haven't looked back. I find the work challenging and rewarding and the mix of office based and field based work is perfect.

So far at Beca I have gained experience over a wide spectrum, from geotechnical hazard assessment for local authorities, to hydrogeological modelling for large infrastructure projects including the Waterview Tunnel and the Christchurch Southern Motorway. I have been involved with foundation design for wind turbines, geothermal power stations and transmission lines which often involve some interesting site investigations, and I have recently taken on the management of the geotechnical component of the Transit New Zealand Network Management Contract, Region 2, Auckland North.

Beca has supported additional training; I recently completed the Geomechanics courses at Auckland University; as well as encouraging me to get involved with the NZGS. I recently started helping the Auckland Branch Organising Committee, and have taken up the role of Young Geotechnical Professional Representative in the NZGS. I am always looking for suggestions on how the society can help to support us young-un's in the industry, so if you would like to know more, or have any suggestions feel free to contact me either at one of the Auckland Branch meetings or via email.

GEOTECH TEASER

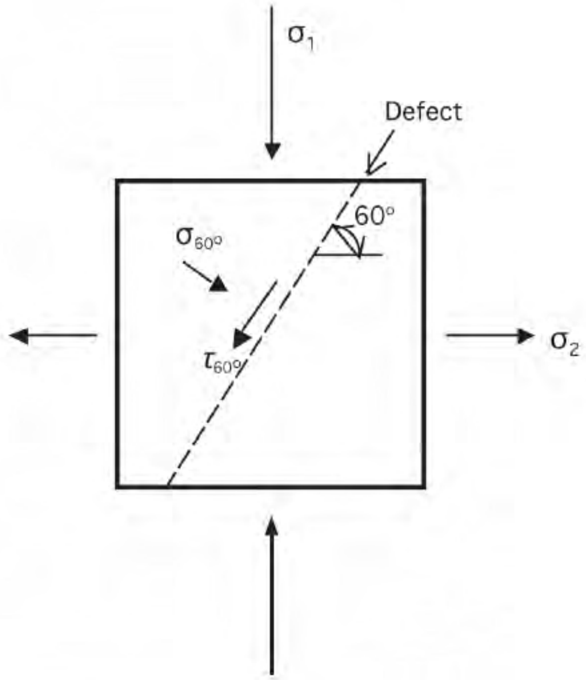
Stresses, Strains and Mohr circles

A 20mm thick piece of gneiss is cut into a 100mm square. Uniform compressive stress (σ_1) is applied along two opposite edges of the sample, and uniform tensile stress (σ_2) is applied along the other two edges (with σ_1 and σ_2 acting normally to the edges of the specimen).

A test is performed by increasing the magnitudes of σ_1 and σ_2 simultaneously, but keeping the magnitude of σ_1 always 4 times the magnitude of σ_2. Assuming failure of the gneiss occurs when the shear stress on any plane exceeds 1 MPa, and using the maximum shear stress formula $\tau_{\theta max} = ½(\sigma_1 - \sigma_2)$, what would be the values of σ_1 and σ_2 at the moment of failure?

Would the values of σ_1 and σ_2 at failure be changed if:

1) the rock had a tensile strength of 0.5MPa?
2) a defect runs through the sample as shown below, inclined at 60o to the direction of σ_2, which ruptures if the shear stress on it exceeds 0.8 MPa? (assuming the formula $\tau_{\theta max} = ½(\sigma_1 - \sigma_2)\sin 2\theta$ to consider applied forces)



Question by Dr CY Chin & Paul Salter, URS NZ Ltd, based on Parry (1995).

Answer: to June's Teaser

The 11 March 2011 Japan Earthquake released 11,220 times more energy than the 22 February 2011 Christchurch Earthquake.

SAVE THE DATE

9th ANZ Young Geotechnical Professionals Conference, Melbourne, Australia 11 July – 14 July 2012

The Australian Geomechanics Society and the New Zealand Geotechnical Society invite you to attend the 9th ANZ Young Geotechnical Professionals Conference (9YGPC). A call for abstracts will be announced shortly.

The 9YGPC is for geotechnical professionals from Australia and New Zealand 35 years old and younger with a maximum of ten years experience.

CONTACT: Erica Cammack / Erica.cammack@beca.com / NZGS Young Professionals Representative

NEW ZEALAND GEOTECHNICAL SOCIETY INC

Australian Geomechanics Society

EVENTS DIARY

Links are available from the NZ Geotechnical Society website – www.nzgs.org

2011

31 December, 2011
The nomination cut off for the 2013 Rocha Medal

2012

31 January -10 February 2012
The University of Auckland
GEOLOGY 701, Engineering Geological Mapping, Summer School
Engineering Geological Mapping – Summer School
http://web.env.auckland.ac.nz/course_pages/geology701/

15-18 February, 2012
Marriott New Orleans, New Orleans, Louisiana, USA
4th International Conference on Grouting and Deep Mixing
www.grout2012.org

3-4 March 2012
Kenchiku-Kaikan, Tamachi, Tokyo, Japan
Great East Japan Earthquake Symposium
http://www.jaee.gr.jp/event/seminar2012/eqsympo/Great_East_Japan_EQ_Symposium
One year after 2011 Great East Japan Earthquake – International Symposium on Engineering Lessons learned from the Giant Earthquake

30 May – 1 June, 2012
Brussels, Belgium
ISSMGE Technical Committee TC 211 Ground Improvement (TC 211)
Recent Research, Advances & Execution Aspects of GROUND IMPROVEMENT WORKS
www.bbri.be/go/IS-GI-2012

3-8 June, 2012
Banff, Canada
ISL/NASL 2012 – 11th International Symposium on Landslides (ISL) and the 2nd North American Symposium on Landslides (NASL)
www.isl-nasl2012.ca

17-23 June, 2012
Bulgaria
Intrenational Multidisciplinary Scientific GeoConference SGEM
http://www.sgem.org

18-21 June, 2012
Transamerica Expo Center; Sao Paulo, Brazil
SEFE7: 7th Seminar on Special Foundations Engineering and Geotechnics & 1st Foundation and Geotechnics Industry Show
http://www.dfi.org/conferences.asp

24-27 June, 2012
Westin Hotel, Michigan Avenue, Chicago, Illinois USA
46th US Rock Mechanics / Geomechanics Symposium
www.armasymposium.org

4-6 July 2012
Galway, Ireland
International Conference on Geotechnical Engineering Education
Organised under the auspices of the recently reformed TC306 Geo-engineering Education Technical Committee, ISSMGE

11-14 July, 2012
Melbourne, Australia
9th Australia – NZ Young Geotechnical Professionals Conference

July 15-18, 2012
Melbourne, Australia
11th Australia – New Zealand Conference on Geomechanics
www.anz2012.com.au

5-10 August 2012
Brisbane, Australia
34th International Geological Congress
www.34igc.org

3-5 September 2012
Lausanne, Switzerland
Advances in Multiphysical Testing of Soils and Shales
http://amtss.ep_.ch

3-5 September, 2012
Tallinn, Estonia
Baltic Piling Days 2012
www.balticpiling.com

18-21 September, 2012
Pernambuco, Brazil
ISC-4 – 4th International Conference on Site Characterization
www.isc-4.com

20-21 September, 2012
Tongji University, China
International Symposium on Coastal Engineering Geology (IS-Shanghai)
http://www.is-shanghai2012.org/ .

30 October – 2 November 2012
Wollongong, Australia
International Conference on Ground Improvement and Ground Control
http://www.icgiwollongong.com/

7-9 November 2012
Kiryu, Japan
International Symposium on Earthquake Induced Landslide
http://geotech.ce.gunma-u.ac.jp/~isel/

10-14 December 2012
Bangkok, Thailand
Geosynthetics Asia 2012 – 5th Asian Regional Conference on Geosynthetics
www.set.ait.ac.th/acsig/GA2012 / www.seags.ait.ac.th/conference.html

2013

19 November 2013
Queenstown, New Zealand
19th NZGS Symposium

2015

TBC
Christchurch, New Zealand
6th Intl, Conference on Earthquake Geotechnical Engineering

ANSWER

Answer to June 2011 Issue 81 Crossword

Across

3 STEREONET—Graph for plotting structural data
4 COBALT—trace element lacking in pumice soils that historically limited farming
6 SLAKING—rock cyclical wetting & drying
7 PLAXIS—commonly used finite element modelling software
9 IRONSAND—mineral source, used only by NZ, for industrial steel making
10 MULDOON—PM who sponsored "Think Big" infrastructure projects
12 LLOYDHOMER—Photographer of NZ geology & landscapes (5,5)
14 TOMO—Sinkhole in limestone landscape
15 SOFTROCK—Material in continuum between soil and rock (4,4)
16 PACKER—test to interpret dam foundation permeability
17 HOOVER—Famous concrete gravity-arch dam
19 PIEZOMETRIC—aquifer pressure head
23 LOG—Graphic summary of lithologic units
24 ALLOCHTHON—Miocene, geotechnically problematic, soils emplaced over Northland & East Coast
27 GRANITE—Predominant rock type exposed on Stewart Island
30 CERA—Established 2011 to work on rebuilding Christchurch
33 SCHIST—medium-grade metamorphic rock
34 STAPLEDON—Author of Engineering Site Investigation (1977)
35 SHEARBOX—lab test on undisturbed sample to determine residual strength (5,3)
36 HERETAUNGA—Coastal plain in southern Hawke's Bay used as groundwater resource
37 RUATANIWHA—Dam constructed from glacial outwash & colluvium from Benmore Range
38 YOUNGSMODULUS—soil stiffness derived from stress-strain curve (6,7)

Down

1 POINTLOAD—method of strength testing rock field specimens (5,4)
2 SEISMIC—Geophysical method using sledge hammer source
4 CHLORITE—often green phyllosilicate mineral with 4 endmembers
5 DSIR—Govt body disolved into Crown Research Institutes in 1992
8 ALLOPHANE—weathering product of volcanic glass
11 MOHRSCIRCLE—2-D graphical representation of state of stress
13 OVERCONSOLIDATION—Application of additional load on soil profile
18 PLINIAN—Eruption with columns of gas & ash
20 COARSE—soils with <35% fines
21 MASS—Term for non-homogeneous rock or soil
22 BISHOPS—hand calculation method for slope stability
25 THIRTYTHREE—Diameter (in mm) of large shear vane in Pilcon field kit (6,5)
26 GABRIELSGULLY—Location of gold find prompting Otago Rush (8, 5)
27 GEOMECHANICS—NZGS award for distinguished paper contributing to development of geotechnics in NZ
28 DUNSTAN—Major active fault near the Clyde Dam
29 BONDLENGTH—Portion of rock bolt fastened to borehole (4,6)
31 DILATANCY—soil tendancy to undergo volume change when deformed
32 DESKSTUDY—Typical 1st phase of investigation (4,5)

NEW ZEALAND GEOTECHNICAL SOCIETY INC.

Management Committee Address List 2011

NAME	POSITION	ADDRESS, EMAIL	PHONE, FAX
Burns, D (David) *	Chair (Elected Member)	AECOM Limited 47 George Street Newmarket 1023; or AECOM Ltd P O Box 4241 Shortland St Auckland 1140 David.Burns@aecom.com	09 336 5374 DDI 09 379 1201 Fax 021 999 019 Mob
Alexander, G (Gavin) *	Vice-Chair and Treasurer (Elected Member)	Beca Infrastructure Ltd 132 Vincent Street P O Box 6345 Auckland 1141 gavin.alexander@beca.com	09 300 9205 DDI 09 300 9300 Fax 0274 924 492 Mob
Blakey, A (Amanda) +	Management Secretary (Appointed Member)	P O Box 12 241 Wellington secretary@nzgs.org Hours: 10am – 2pm Mon, Wed, Thurs.	09 575 2744 Ph 021 025 11628 Mob
Cammack, E (Erica)	YGP Representative (Co-Opted Member)	Beca Infrastructure 132 Vincent Street P O Box 6345 Auckland 1141 Erica.Cammack@beca.com	09 300 9371 DDI
Chin, C Y •	Co-Opted Member	URS New Zealand Limited, URS Centre 13-15 College Hill Auckland 1011 cy.chin@urs.com	64 9 925 0686 DDI 64 9 355 1333 Fax
Fairclough, T (Tony) *	Committee Member (Elected Member)	Tonkin & Taylor Ltd 33 Parkhouse Road Sockburn TFairclough@tonkin.co.nz	03 363 2445 DDI 021 378 385 Mob
Maclean, H (Hamish)	Co-Editor Geomechanics News	Tonkin & Taylor Ltd PO Box 5271 Wellesley Street Auckland 1036 hmaclean@tonkin.co.nz	09 355 0777 DDI 021 469 215 Mob 09 307 0265 Fax
Price, C (Charlie) *	Committee Member (Elected Member)	MWH Global Hazeldean Business Park 6 Hazeldean Road P O Box 13249 Christchurch 8141 Charlie.H.Price@nz.mwhglobal.com	03 345 6637 DDI 021 240 9388 Mob
Robins, P (Philip)	Immediate Past Chair (Ex-officio Member)	Golder Associates Pty Ltd Level 2, 1 Havelock Street, West Perth, Western Australia 6005, Australia (PO Box 1914, West Perth WA 6872) probins@golder.co.nz	+61 8 9213 7600 Work +61 8 9213 7672 DDI +61 8 9213 7611 Fax +61 4 3751 9320
Salter, P (Paul) •	Co-Editor, Geomechanics News (Co-Opted Member)	URS New Zealand Limited, URS Centre 13-15 College Hill Auckland 1011 paul.salter@urs.com	09 355 1340 DDI 09 355 1333 Fax 029 355 1340 Mobile

Van Ballegooy, S (Sjoerd) ⋆	Committee Member (Elected Member)	Tonkin & Taylor Ltd PO Box 5271 Wellesley Street Auckland 1036 svanballegooy@tonkin.co.nz	09 355 0715 Ph 021 378 964 Mob 09 307 0265 Fax
Woodward, S (Simon) ⋆	Committee Member (Elected Member)	Geotek Services Ltd P O 39015 Howick Manuaku 2145 Auckland simonwoodward@geotek.co.nz	09 535 9814 Ph 09 535 7243 Fax 0274 735 712 Mob
Davies, M (Prof. Michael)	ISSMGE Australasian Vice President	Dean of Engineering Faculty of Engineering University of Auckland Private Bag 92019 Auckland Michael.Davies@auckland.ac.nz	09 373 7599 Ext 87924
Beck, D (Dr. David)	ISRM Australasian Vice President	Beck Engineering Pty Ltd 9 Reid Drive Chatswood West 2067 NSW Australia dbeck@beckengineering.com.au	+61 412 135 782 Cell
Brideau, M-A (Marc-André. Ph.D.)	NZ ISRM Representative	Lecturer in Engineering Geology School of Environment University of Auckland Private Bag 92019 Auckland, 1142 New Zealand m.brideau@auckland.ac.nz	09-373-7599 ext. 85195 Work 09-373-7435 Fax 027-244-7867 Mob
Williams, A (Ann)	IAEG Australasian Vice President	Beca Infrastructure 132 Vincent Street P O Box 6345 Auckland 1141 ann.williams@beca.com	09 300 9172 Ph 09 300-9300 Fax 021-809-162 Mob
Gitte Abildgaard	NZGS Web Manager	Contact Gitte: webmanager@nzgs.org	Website: www.nzgs.org

• Co-opted position + Appointed position ⋆ Elected members of committee

ADVERTISERS DIRECTORY

NEW ZEALAND GEOTECHNICAL SOCIETY INC.

Objects

a) To advance the education and application of soil mechanics, rock mechanics and engineering geology among engineers and scientists.
b) To advance the practice and application of these disciplines in engineering.
c) To implement the statutes of the respective international societies in so far as they are applicable in New Zealand.
d) To ensure that the learning achieved through the above objectives is passed on to the public as is appropriate.

Membership

Engineers, scientists, technicians, contractors, students and others who are interested in the practice and application of soil mechanics, rock mechanics and engineering geology.

Members are required to affiliate to at least one of the International Societies.
Students are encouraged to affiliate to at least one of the International Societies.

Annual Subscription

Subscriptions are paid on an annual basis with the start of the Society's financial year being 1st October. A 50% discount is offered to members joining the society for the first time. This offer excludes the IAEG bulletin option and student membership. No reduction of the first year's subscription is made for joining the Society part way through the financial year.

Basic membership subscriptions (inclusive of GST), which include the magazine, NZ Geomechanics News, are:

Members	$100
Students	Free
Annual IPENZ service centre fee applies to all NZGS members who are not members of IPENZ	$43.70

Affiliation fees for International Societies are in addition to the basic membership fee:

International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE)	$35.00
International Society for Rock Mechanics (ISRM)	$35.00
International Association of Engineering Geology & the Environment (IAEG)	$35.00
(with bulletin)	$80.00

All correspondence should be addressed to the Management Secretary. The postal address is:

NZ Geotechnical Society Inc, P O Box 12 241, WELLINGTON 6144

The Secretary
NZ Geotechnical Society Inc.
The Institution of Professional Engineers New Zealand (Inc)
P.O. Box 12-241, WELLINGTON 6144

NEW ZEALAND GEOTECHNICAL SOCIETY INC

NEW ZEALAND GEOTECHNICAL SOCIETY INC.
APPLICATION FOR MEMBERSHIP

(A Technical Group of the Institution of Professional Engineers New Zealand (Inc))

FULL NAME Dr/Mr/Mrs/Ms/Miss (Underline Family Name): ……………………………………………………………………………

HOME POSTAL ADDRESS: ……………………………………………………………………………………………………

Phone No: ( )……………………… Cell Ph: ( ) ………………………… Fax No: ( ) ………………………………

E-MAIL: Home…………………………………………………… E-MAIL: Work………………………………………………………

DATE OF BIRTH …………………………………

ACADEMIC QUALIFICATIONS: ……………………………………………………………………………………………

PROFESSIONAL MEMBERSHIPS: ……………………………………… Year Elected……………………………………………

PRESENT EMPLOYER: ………………………………………………………………………………………………………

WORK POSTAL ADDRESS: …………………………………………………………………………………………………

OCCUPATION: ……

EXPERIENCE IN GEOMECHANICS: …………………………………………………………………………………………

STUDENT MEMBERS: ………………………………………………………………………………………………………

TERTIARY INSTITUTION: …………………………………………………… SUPERVISOR: ………………………………………

SUPERVISORS SIGNATURE: ……………………………………………………

Preferred email (please circle): home/work Preferred address: home/work

Note that the Society's Rules require that in the case of student members "the application must also be countersigned by the student's Supervisor of Studies who thereby certifies that the applicant is indeed a bona-fide full time student of that Tertiary Institution". . . ; Applications will not be considered without this information.

Affiliation to International Societies: All full members are required to be affiliated to at least one society, and student members are encouraged to affiliate to at least one Society. Applicants are to indicate below the Society/ies to which they wish to affiliate.

I wish to affiliate to:

International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE)	Yes/No
International Society for Rock Mechanics (ISRM)	Yes/No
International Association of Engineering Geology (IAEG)	Yes/No
& the Environment (with Bulletin)	Yes/No

DECLARATION: If admitted to membership, I agree to abide by the rules of the New Zealand Geotechnical Society

Signed ……………………………………………………………………………… Date ……/……/…….

ANNUAL SUBSCRIPTION: Due on notification of acceptance for membership, thereafter on 1st of October. Please do not send subscriptions with this application form. You will be notified and invoiced on acceptance into the Society

PRIVACY CONDITIONS: Under the provisions of the Privacy Act 1993, an applicant's authorisation is required for use of their personal information for Society administrative purposes and membership lists. I agree to the above use of this information:

Signed ………………………………………………………… Date ……/……/…….

(for office use only)

Received by the Society …………………………………………………………………………………………

Recommended by the Management Committee of the Society ………………………………………………………

NEW ZEALAND GEOTECHNICAL SOCIETY INC. PUBLICATIONS 2011

Publication Name	List Price Members	List Price Non-Members
New Zealand Geomechanics Society Conferences:		
Proceedings of Technical Groups, Vol 22, Issue 1G **(1 left)** *Geotechnical Issues in Land Development* Hamilton 1996	$20	$35
Proceedings of the New Zealand Geotechnical Society Symposium – *Roading Geotechnics 98* Auckland 1998	$40	$70
Proceedings of the New Zealand Geotechnical Society Symposium – *Engineering and Development in Hazardous Terrain* Christchurch 2001	$50	$70
Proceedings of the New Zealand Geotechnical Society Symposium – *Geotechnics on the Volcanic Edge* Tauranga 2003	$50	$70
Proceedings of the New Zealand Geotechnical Society Symposium – *Earthquakes and Urban Development* Nelson 2006	$50	$70
Proceedings of the 18th New Zealand Geotechnical Society Symposium –	$50	$70
Soil-Structure Interaction, Auckland 2008. (CD)	$20	$25
Australia – New Zealand Conferences on Geomechanics:		
Proceedings of the 2nd Australia – NZ Young Geotechnical Professionals Conference, Auckland, December 1995	$25	$40
Proceedings of the 5th Australia – NZ Young Geotechnical Professionals Conference, Rotorua, March 2002 (spiral bound reprint)	$75	$85
Proceedings of the 6th Australia – NZ Conference on Geomechanics Christchurch, February 1992	$50	$100
Proceedings of the 9th Australia – NZ Conference February 2004 – 'To the enz of the Earth' **(Vol 2 only)**	$150	$200
Other Publications:		
NZ Geomechanics News Collection 1970–2010 Volumes 1–79 (CDRom)	$25	$40
2005 Soil & Rock Guideline	$25	$50
Shear Vane Guidelines	$15	$20
Back Issues of *NZ Geomechanics News* **(selected issues)**	$20	$20

Prices do not include GST or postage & handling

Orders to: Amanda Blakey, Management Secretary. Email: secretary@nzgs.org

ADVERTISING INFORMATION

NZ Geomechanics News is published twice a year and distributed to the Society's 800 plus members throughout New Zealand and overseas.

The magazine is issued to society members who comprise professional geotechnical and civil engineers and engineering geologists from a wide range of consulting, contracting and university organisations, as well as those involved in laboratory and instrumentation services.

BLACK AND WHITE	COST	SIZE
Full page	$310/issue	210mm x 297mm high
Half page	$240/issue	90mm wide x 265mm high
Quarter page	$210/issue	90mm wide x 130mm high
COLOUR		
Full page A4	$550/issue	210mm x 297mm high
A3 position	$1035/issue	420mm wide x 297mm high
Half page (vertical)	$275/issue	90mm wide x 265mm high
Half page (horizontal)	$275/issue	210mm wide x 148mm high
COVER PLACEMENTS		
Inside front & back and outside back cover	$830/issue	210mm x 297mm high
FLYERS/INSERTS		
Insert to be posted with magazine	$275/ for A4 single page flyer	

(For other size inserts the price is dependent on weight of insert. Price provided on request)

(advertiser to provide the insert at their own cost)

NOTE

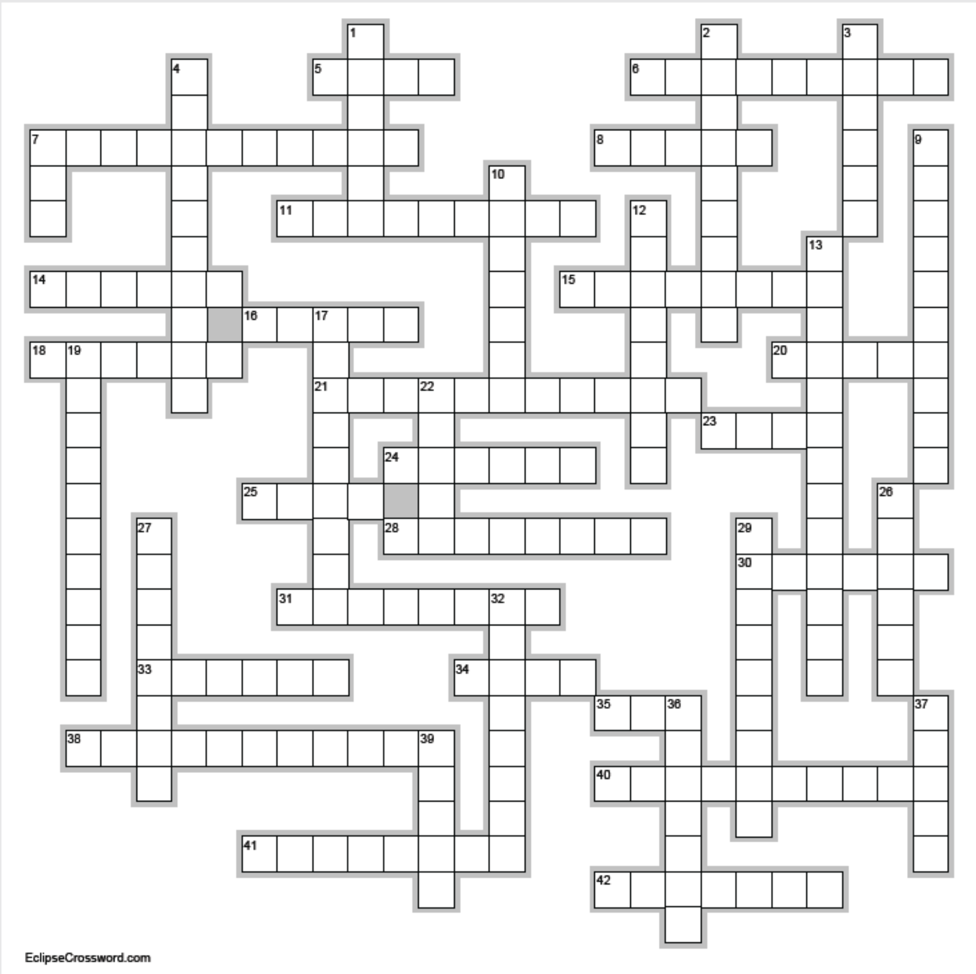
1. All rates exclude GST
2. Space is subject to availability
3. A 3mm bleed is required on all ads that bleed off the page.
4. Advertiser to provide all flyers

If you are interested in advertising in the next issue of NZ Geomechanics News please contact:

Management Secretary, Amanda Blakey

email: secretary@nzgs.org

GEOTECH CROSSWORD



Across

5 Excavated tunnel spoil
6 Active NZ fault resulting in raised beaches on northern parts of Cook Strait
7 Other main soil category (versus residual)
8 Jordanian system of ancient rock-cave dwellings
11 Renowned 20th century German geologist (4,5)
14 Manually controlled compactor
15 Wrote seminal paper on effective stress in 1936
16 Graded silt deposited by wind
18 Downthrown fault block
20 Common foundation footing
21 Factory-built concrete element with increased strength
23 Scale of rock hardness
24 Engineer who defined concept of stress in 1822
25 Italian tower subject to differential settlement
28 Dam drain point
30 Force per unit area
31 Seepage from landfill
33 Common surface expression for limestone
34 Glacial soil
35 Bedding inclination
38 Tunnelling method (3,3,5)
40 Developed the RMR system
41 Repository of buried refuse
42 Stress system acting in 2 directions

Down

1 Unit of measurement for packer test
2 Unique city-state built on Jurassic limestone rock
3 Geologic tool
4 Mega-city with line of aquifer injection wells to prevent sea-water intrusion (3,7)
7 Acronym for complex rift zone in central North Island, NZ
9 Plot of relationship between 2 stress parameters (6,4)
10 Largest grain-size category for coarse soils
12 Major 19th century NZ eruption
13 River or coastal process leading to island formation (8,5)
17 Trees growing near structures can cause foundation damage in these soils
19 Geophysical method using explosive, thumper, or sledge source
22 Upper extent of landslip
26 Unit of shear strength measurement
27 Developed theory of parabolic failure envelope in crack formation in 1920's
29 Rock mass with uniform material properties
32 Test holding cell pressure constant and increasing axial stress
36 Method to obviate differential settlement
37 Type of rock mass discontinuity
39 Manufacturer of large wrenches used by drillers

> The answers will be printed in the June 2012 issue of NZ Geomechanics News, and also posted on the website.

Crossword supplied by Paul Salter