

Barry.Sum@aecom.com (Chairman)





#### FINAL ANNOUNCEMENT

AGS (HK), HKIE Geotechnical Division (Working Group on Application of Innovative Technology in Geotechnical Engineering - Geotechnical Computer Program Users Group) & Department of Civil Engineering, HKU

#### 1-day Seminar on Geotechnical Computer Modelling

#### **Theme**

This 1-day seminar aims to provide a forum for sharing of knowledge, exchange of ideas and discussion on topics related to numerical modelling in geotechnical engineering involving both soft and hard ground. Local and overseas numerical experts from regulators, consultants, contractors and universities will give presentations at the seminar.

#### Date

20th April 2013, Saturday, 8:30 am to 5:00 pm.

#### Venue

Meng Wah Complex Lecture Theatre 1 (MWT1), Hong Kong University, see attached map.

#### **Program**

The program is shown on page 2.

#### **Registration Fee**

(Including tea and coffee for morning and afternoon breaks, lunch is NOT provided) HK\$ 700 for normal registration

HK\$ 500 for members of AGS (HK) (see enclosed list)

HK\$ 300 for full-time students (limited to 30 persons).

#### **Registration & Enquiries**

For registration and payment please refer to enclosed Registration Form.

For enquiries on registration please contact Doris Tse at tel: 2973 5777 or e-mail: chrislee@cmwal.com.

For general enquiries on seminar please contact S W Lee at tel: 2591 1713 or e-mail: swlee@golder.com.hk.

#### **Cancellation Policy**

Cancellation will only be accepted in writing via email or fax, not later than 2 weeks before the seminar, and only 50% of registration fee will be refunded.

#### **Attendance Certificate**

The seminar is designed for 1 CPD day. Attendance certificates will be provided at the end of the seminar.

#### **Book Prize**

Book prize is open to all young attendants under 35 years old for the submission of a good quality report (max. 500 words) on this event. Book Prize reward comprises a book "Geology of Site Investigation Boreholes in Hong Kong" by Chris Fletcher and book coupon HK\$300 from Page One. Please submit your report to <a href="mailto:swlee@golder.com.hk">swlee@golder.com.hk</a>, AGS (HK)'s Honorary Secretary. Please refer to AGS (HK)'s website for details of Book Prize.

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香港岩土及岩土環境工程專業協會
ASSOCIATION OF GEOTECHNICAL & GEOENVIRONMENTAL SPECIALISTS (HONG KONG)

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THE HONG KONG INSTITUTION OF ENGINEERS 看 港 工程 簡 學 會

Geotechnical Division
岩土分部



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1-day Seminar on Geotechnical Computer Modelling, 20 April 2013, HKU

Time	ar on Geotechnical Computer Modelling, 20 A Topics	Speakers		
8:30 – 9:00	Registration			
9:00 – 9:10	Welcome Address	Barry SUM (AECOM) Chairman AGS(HK)		
Session I - Chairmai	n (S W LEE – Golder)			
9:10 - 9:40 am	Applications & limitations of geotechnical computer programs commonly used in Hong Kong	Mark CHAN (GEO)		
9:40 - 10:10 am	Numerical modelling in geotechnical engineering – Concept and challenge	Axel NG (AECOM)		
10:10 - 10:40 am	Is my geotechnical modelling conservative or aggressive?	Gavin TOH (Gammon)		
10:40 - 11:00 am	Coffee Break			
11:00 - 11:30 am	Mohr Coulomb model and dilation angle - Do you really understand?	Ryan YAN (HKU)		
11:30 – 12:00 am	Recent experiences of numerical prediction & assessment – Excavation over a tunnel of unbolted segmental tunnel lining	Leslie SWANN (Jacobs)		
12:00 - 12:20 am	Discussion			
12:20 – 1:20 pm	Lunch (not included)			
Session II - Chairma	n (Ryan YAN - HKU)			
1:20 – 1:50 pm	Large cavern design in jointed rock using discrete fracture network and numerical modelling	Ardie PURWODIHARDJO & Les MCQUEEN (Golder)		
1:50 – 2:20 pm	Field considerations for computer analyses for underground space stability assessment	Sandy MACKAY (Nishimatsu)		
2:20 – 2:50 pm	Code based design: Examples in practice for retaining wall analysis	Nigel PICKERING (Benaim)		
2:50 – 3:10 pm	Coffee Break			
3:10 – 3:40 pm	Advanced 3D modelling for debris mobility and flexible barrier structures	Jack YIU (Arup)		
3:40 – 4:10 pm	Probabilistic slope stability analysis and seismic hazard assessment with Excel applications	Jui-pin WANG (HKUST)		
4:10 – 4:40 pm	Integrating geotechnical design prediction into the construction control process	Angus MAXWELL & William TAI (Maxwell Geosystems)		
4:40 – 5:00 pm	Discussion			
5:00 pm	Distribution of CPD Certificates			

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#### About the Speakers:

Barry.Sum@aecom.com (Chairman)

#### Mark CHAN (GEO)

Ir Dr Mark H. C. Chan has worked in the USA, UK, Canada and Hong Kong in geotechnical analysis, design and construction. Presently he works on vetting of geotechnical computer programs and other R&D projects at the GEO. He is the leader of the Geotechnical Computer Program Users Group, Working Group on Application of Innovative Technology in Geotechnical Engineering, HKIE GD.

#### Axel NG (AECOM)

Axel obtained his PhD in geotechnical engineering at the University of Sydney, specializing in finite element methods for complex time-dependent geotechnical problems. He has over 20 years of geotechnical experiences from projects in Hong Kong and other parts of Asia: China, Vietnam, and Korea. He is currently a Technical Director in the geotechnical business line of AECOM Asia Company Limited. Within the company, Axel serves as an in-house specialist to provide advice and training to project teams on numerical modelling for complex geotechnical problems, including deep excavation, tunnelling and debris flow. Axel was also a member of ISSMGE Technical Committee on Forensic Geotechnical Engineering.

#### Gavin TOH (Lambeth/Gammon)

Gavin obtained his BEng (Hons) in Civil Engineering from The University of Western Australia (UWA) in 1988. He then joined the Geomechanics Group of UWA. His research topic: "Numerical and Centrifugal Modelling of Soft Mine Tailing." He received his PhD in Civil Engineering in 1994. He came to Hong Kong in 1993 working in consultants involving in projects such as the Hong Kong Station, Kowloon Station and the Island West Transfer Station. He joined Gammon Construction in 1997. He is currently a Senior Engineering Manager of Lambeth Associates Ltd (in-house engineering consultancy of Gammon). He is responsible in managing the Foundation and Geotechnical Team to provide safe, economical, and innovative geotechnical engineering solutions for a variety of civil, railways, tunnels and buildings projects in Hong Kong. He is also an RGE.

#### Ryan YAN (HKU)

Dr Ryan Yan is an Assistant Professor at the University of Hong Kong. Prior to joining HKU in 2009, he has been a Postdoctoral Research Fellow at the Hong Kong University of Science and Technology, a Research Scholar at the Technical University of Hamburg-Harburg, Germany; and an Assistant Professor at the University of Macau. He is now serving as a committee member of a number of professional bodies, including HKIE (Geotechnical Division), ASCE (HK Section), and AGS(HK). Ryan's research interests include experimental testing and constitutive modelling of geomaterials, numerical modelling of soil-structure interaction problems, Bayesian-based reliability analysis and soil-plant interactions.

#### Leslie SWANN (Jacobs)

Leslie is a civil / geotechnical engineer with about 40 years of international experience including Hong Kong, UK, Middle East, Australia and throughout South East Asia. He has been based in Hong Kong since 1995 and has been involved in many of Hong Kong's major infrastructure projects. He has developed a geotechnical team locally with a significant capacity in numerical modeling.

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#### Ardie PURWODIHARDJO (Golder, Brisbane, Australia)

Ardie Purwodihardjo has more than 22 years of experience in civil and geotechnical engineering including project and design managements, business development, construction supervision and research. He has been involved with various types of projects: mining in United Kingdom and Indonesia, tunnels in France, United Kingdom, Middle East, Hong Kong and Australia, port facilities and marine engineering in Indonesia and Australia, buildings and other infrastructure projects in Indonesia and Australia.

Ardie's main areas of technical expertise are in design development, detailed design and design management, including soil/rock tunnelling design, soil/rock-structure interaction analyses, deep excavations in soil and rock, different types of retaining walls, deep and shallow foundation designs, slope stability assessment, embankment design, soft-soil engineering, ground improvement and geotechnical instrumentations.

Ardie started his career in Indonesia as a Civil Engineer and Structural Engineer, and then spent four and half years in France for his Masters and PhD in Geotechnical Engineering. Ardie worked in the United Kingdom as a Senior Tunnelling Engineer with W S Atkins, and moved to Australia in August 2005 to join Golder Associates. He is the author of several papers, mainly in numerical analysis and modelling in soil/rock structure interaction.

#### Leslie MCQUEEN (Golder, New South Wales, Australia)

Les is a Principal of Golder Associates with over 30 years' experience in geotechnical assessment and design for tunnelling infrastructure projects. His key skills are rock mass characterisation and classification, rock mechanics and tunnel support design, tunnelling machine performance assessment, risk assessment and financial due diligence. He is currently working on the tender bid for a 15km rail tunnel with 5 stations in Sydney. His recent experience includes investigation and temporary tunnel support design for a hydro tunnel in the Philippines and the CLEM7 Tunnel Project in Brisbane.

#### Sandy MACKAY (Nishimatsu)

Sandy is a Chartered Civil and Mining Engineer and Chartered Geologist with almost 28 years professional experience practicing in over 16 countries. He joined Nishimatsu Construction Company Limited as the Geotechnical Manager early 2012 and is presently responsible for tender coordination and advisory support (mainly design and construction) for their on-going Mass Transit Railway Corporation Ltd (MTRCL) contracts. Prior to this he was the Acting Regional Manager / Managing Director at Snowy Mountains Engineering Corporation (SMEC) Asia Ltd overseeing a team of 60 multi-disciplinary professional staff, based mainly in HKSAR and Mongolia, responsible for business development and maintaining profitability. Over the past five years, prior to joining Nishimatsu, he managed over 50 civil engineering projects, ranging from heavy haul railways, highways, site formations and subsurface excavations ranging in capital cost up to US\$ 2 Billion. Past project input includes being the Project Team Leader for the US\$ 23.5 Billion oil and gas pipeline installation across Sakhalin Island, East Russian Federation 2006 to 2007.

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#### Nigel PICKERING (Benaim)

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Nigel Pickering is currently Geotechnical Manager at URS Benaim, part of the URS Corporation a leading provider of engineering, construction and technical services for public agencies and private sector companies around the world. He is a Chartered Civil Engineer with more than 20 years geotechnical consultancy experience in civil, structural, marine and infrastructure projects. He has worked in UK, USA, Middle East before moving to Hong Kong.

#### Jack YIU (Arup)

www.aas-hk.ora

Jack is a senior geotechnical engineer in Arup Hong Kong. His genuine interest and strong technical background in civil / geotechnical engineering have led to his involvement in a wide variety of significant projects such as the 2012 London Olympics, Singapore MRT Downtown Line, and the Hong Kong Express Rail Link. His particular expertises are in deep excavation and numerical methods for geotechnical design. Jack is currently the lead geotechnical engineer for MTR South Island Line (East) C901 Consultancy, leading a design team on geotechnical / tunnelling works. He is also the project manager of the pilot numerical investigation in landslide debris - flexible barrier structure interaction for the Geotechnical Engineering Office in Hong Kong.

Jack obtains valuable overseas experience through his secondment to Singapore, London and San Francisco office. Since then he has developed his skill set in ground engineering works in markets such as the UK, Singapore, and the Gulf region.

Jack has been actively involved in the geotechnical computer programs development through his participation in the Geotechnical Software Committee in Arup. He is responsible for the development and statutory approval of geotechnical computer programs for Arup Hong Kong.

#### Jui-pin WANG (HKUST)

Dr. JP Wang received his B.S. and Ph.D. from National Taiwan University and Columbia University in 1999 and 2007, respectively. Before joining the HKUST in 2010, he was a practicing engineer in the U.S. mainly involved in probably-based earthquake projects. Also he worked for EPA Taiwan for another two years before starting his Ph.D study in 2004.

One of Dr. JP Wang's current research focuses is probabilistic analysis in geotechnical engineering and natural hazards. He has recently published a few technical articles about slope stability analysis and seismic hazard assessment, including those open-sourced user-friendly tools developed in-house for performing probabilistic analyses.

#### **Angus MAXWELL (Maxwell Geosystems)**

Dr Angus Maxwell is the founding Director of Maxwell Geosystems Ltd. providing instrumentation management systems and geotechnical consultancy services to the tunnelling and deep excavation industry. He is an Engineering Geologist with twenty two years of experience in underground excavation design and construction working on major projects in the UK, Europe, Australia and Asia. He retains an interest in geological and geotechnical data acquisition and processing as well as numerical analysis for design of tunnels, open excavations, slopes and foundations. He is an accomplished numerical analyst and software developer and has written code for non-linear numerical soil models in FLAC and for database

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information management systems on large projects including CTRL and the SSDS scheme. Between 2002 and 2006 he lectured on Tunnelling and Underground Space on the Hong Kong University MSc course on Applied Geosciences. He is immediate past Chairman of the Association of Geotechnical Specialists Hong Kong.

#### William TAI (Maxwell Geosystems)

William Tai is an Associate at Maxwell Geosystems and has 22 years of experience in the field of civil, structural, geotechnical engineering include project management, structural & geotechnical design and site supervision covering China (PRC) and Hong Kong. William is well versed in Hong Kong and Mainland design codes having designed or design checked several large infrastructure projects including KCRC and MTRC railways projects. He also has in depth experience of site supervision having been appointed as Engineering Representative and Resident Engineer. William is currently Project Manager for the Independent Monitoring Consultancy for the MTRC Regional Express Line.

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#### **REGISTRATION FORM**

	IVE	SISTINATION I CINIVI		
Event :		1-day Seminar on Geotechnical Computer Modelling		
Date :		Saturday, 20 <sup>th</sup> April 2013		
Time :		08:30 for registration; 09:00 –17:00 for seminar		
Venue :		Meng Wah Complex Lecture Theatre 1, HKU		
Registration Fee :		HK\$ 700 normal		
3		HK\$ 500 members of AGS (HK)		
		HK\$ 300 full-time students (limited to 30 persons)		
Note:		Registration is on a first-come, first-served basis		
		and seats are limited.		
A 4 '1	D	1 1 1 1		
Mail Registration :	-	ne details below and return together with your		
Registration.	-	ade payable to <u>The Association of Geotechnical</u> <u>ntal Specialists (Hong Kong) Limited</u> by mail to :		
	Ir Chris Lee (AGS HK)	tar specialists (nong kong) Elimited by mail to .		
	C M Wong & Associa	ates Limited		
	1104 Universal Trade			
	3-5A Arbuthnot Road	·		
		2973 5777 for Doris Tse)		
Fax / E-mail	Attn: Ir Chris Lee at fa	fax no. (852) 2521 9979 or chrislee@cmwal.com with expected at the seminar venue.		
Registration :				
Full Name :				
Contact e-mail :				
Contact Tel. No. :			Contact Fax No. :	
Company Name :			<u> </u>	
Registration Fee:		\$700 Normal (HI	\$500 AGS \$300 <) member Student	
Fax Registration ONLY		□ Vec	□ No	
I promise to pay on the day and		☐ Yes	No	
please reserve me a place.				
Mail Registration ONLY		Bank	Cheque	
My attached crossed cheque is			No.	
I would like to receive a CPD		Yes	☐ No	
attendance certificate :		<del></del>	1	
Signature :			Date:	

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List of AGS (HK)'s Member Organisations			
AECOM Asia Company Limited			
ALS Laboratory Group			
Atkins China Limited			
Au Posford Consultants Limited			
Aurecon Hong Kong Limited			
Bachy Soletanche Group Limited			
Benaim (China) Limited			
C M Wong & Associates Limited			
DrilTech Ground Engineering Limited			
EGS (Asia) Limited			
Fong On Construction Limited			
Fugro (Hong Kong) Limited			
Fugro Geotechnical Services Limited			
Gammon Construction Limited			
Golder Associates (HK) Limited			
Halcrow China Limited			
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Paul Tong & Associates Consulting Engineers Limited			
SMEC Asia Limited			
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Tenax International B.V.			
Tony Gee and Partners			
Tysan Foundation Limited			
Victor Li & Associates Ltd			
VSL – Intrafor (HK)			

Note: If your affiliated organisation is one of the above organisations, you are entitled to HK\$500 registration fee.

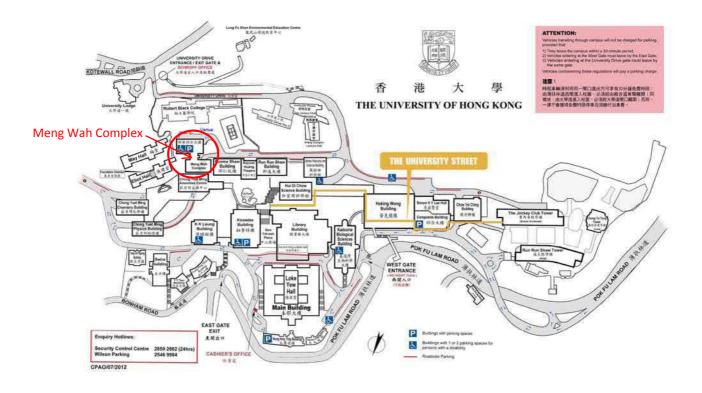
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#### Map for Meng Wah Compex, Hong Kong University



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# Applications and Limitations of Geotechnical Computer Programs Commonly Used in Hong Kong

Ir Dr Mark H. C. Chan

**Geotechnical Engineering Office Civil Engineering and Development Department** 

## Prior Acceptance

Private projects - BD (PNAP ADM-6)

Government projects - CGE/S&T, GEO (Project Administration Handbook for Civil Engineering Works)

The Standards and Testing Division of the GEO carries out the vetting/checking of geotechnical computer programs for the purpose of prior acceptance.

## Application for prior acceptance

- (i)the background and underlying theory of the program;
- (ii) Building Regulations, codes of practice or other requirements which the analysis or design produced by the program will comply with; (iii) areas of application and limitations; and validation examples.

Note: The limitations and precautions stated in the Appendix are not exhaustive.

"Validation of Geotechnical Computer Programs" by Mark H. C. Chan, *Proceedings of the International Workshop on Constitutive Modelling*, 2007:

- 1. Check whether the documentation is complete and clearly presented.
- 2. Review the underlying theory of the program.
- 3. Review the quality assurance procedures of the program (if any).
- 4. Review previous experience in the use of the program, in particular to solve local problems. Consult both in-house and external users, if possible.
- 5. Decide whether the test examples supplied by the program developer are adequate. If not, devise additional test problems, run the program using the additional problems and examine the test results.
- 6. Document the results of the validation process.

The prior acceptance of any geotechnical computer program will normally be valid for three years.

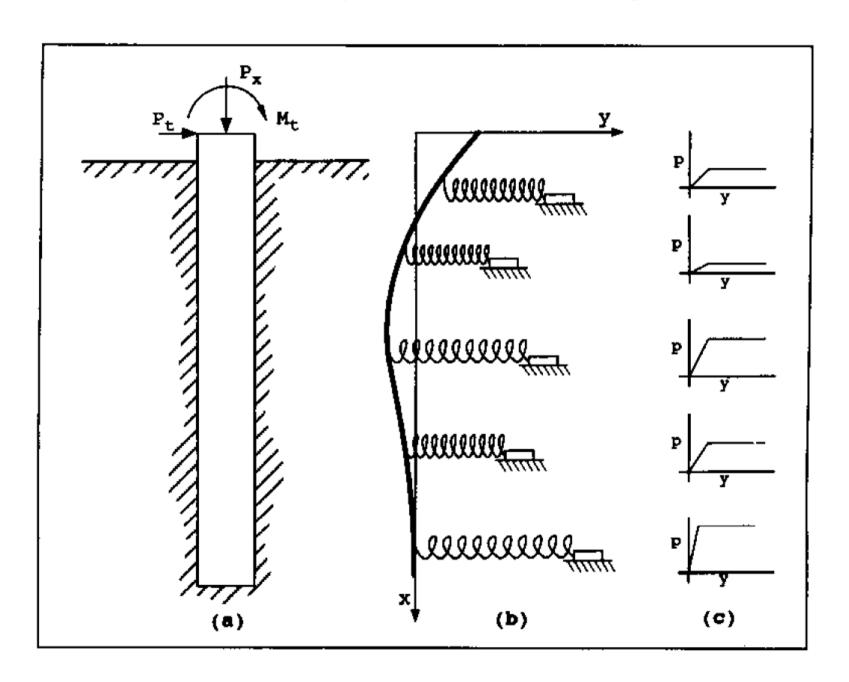
## Program Classes

- Excavation and Lateral Support
- Slope Stability Analysis
- Tunnel and Cavern Construction
- Foundation Analysis
- Seepage Analysis
- Rock Fall Analysis
- Debris Flow
- Retaining Wall Stability Analysis
- Rock Slope Stability Analysis.

## **Formulations**

- Finite Element
- Finite Difference
- Distinct Element
- Discrete Element
- Boundary Element
- Limiting Equilibrium Analysis
- Vibration Analysis
- Impact Analysis
- Hydrodynamic
- Particulate System
- Stereographic Projection
- Coupled/hybrid

LPILE Verification Notes by L.C. Reese and S.T. Wang, 2006:



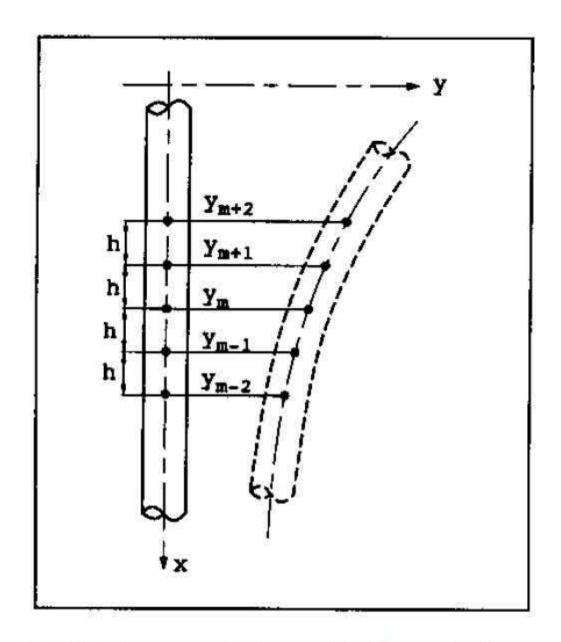


Fig. 3 Representation of deflected pile

$$\frac{d^{2}}{dx^{2}} \left( E_{p} I_{p} \frac{d^{2} y}{dx^{2}} \right) + P_{x} \left( \frac{d^{2} y}{dx^{2}} \right) - p - W = 0 .... (1)$$

where

 $P_x$  = axial load on the pile, F,

y = lateral deflection of the pile at point x along

the length of the pile, L,

p = soil resistance per unit length, F/L,

W = distributed load along the length of the pile, F/L, and

 $E_pI_p$  = flexural stiffness, FL<sup>2</sup>.

$$y_{m-2}R_{m-1} + y_{m-l}(-2R_{m-l} - 2R_m + Qh^2) + y_m(R_{m-l} + 4R_m + R_{m+l} - 2Qh^2 + k_mh^d) +$$
  
 $y_{m+l}(-2R_m - 2R_{m+l} + Qh^2) + y_{m+2}R_{m+l} - W_mh^d = 0$ ....(3)

where

$$R_m = E_m I_m, \dots (4)$$

$$k_{m} = E_{sm} \dots (5)$$

$$p_i = E_i y_i$$
.....(2)

where

 $E_i$  = a parameter with the units F/L<sup>2</sup>, relating pile deflection y and soil reaction p.

(Q is the same as  $P_x$ )

## Validation

## 7 types of error sources:

- (1) Modelling error,
- (2) Coding error,
- (3) Human error,
- (4) Discretization error,
- (5) Errors originating from inappropriate boundaries and boundary conditions (and initial conditions where applicable),
- (6) Errors originating from inaccurate input parameters, and
- (7) Computation error.

Chan, Mark H.C. (2012). "Sources of Errors in Numerical Modelling and Program Validation", Geotechnical Computer Program Users Group Meeting No.1, Working Group on Application of Innovative Technology in Geotechnical Engineering, HKIE Geotechnical Division.

Modelling Error (Error Type 1)

Query: The soil is assumed to act as a series of discrete resistances, not as a continuum.

Answer: Full-scale experiments show that p-y curves of a soil remain about the same when subjected to different pile loadings.

Reese, L.C., Wang, S.T., Isenhower, W.M. and Arrellaga, J.A. (2004). LPILE Plus Version 5.0 Technical Manual (Section 2.1.2.7), Ensoft, Inc.

Discretisation Error (Error Type 4)

Query: How many increments are needed?

Answer: From experience, perhaps 50 to 200, when using double-precision (i.e. 15 significant figures).

LPILE Verification Notes by L.C. Reese and S.T. Wang, 2006 (Page 6).

### Computation Error (Error Type 7)

Query: In performing a computation, the program utilizes the computed values of  $E_s$  and iterates until the differences in the deflections for the last two computations are less than a specified value. How can one ensure that the solution is sufficiently accurate?

Answer: If a tolerance of 0.00025 mm in pile deflections is selected, less than 20 iterations are sufficient.

LPILE Verification Notes by L.C. Reese and S.T. Wang, 2006 (Page 7).

Validation examples include a number of case studies in which the program outputs (bending moment and pile head deflection) are compared with experimental measurements.

Relative differences between experimentally measured maximum bending moments and program outputs are in the range of xx to xx%. For pile head deflections the relative differences are in the range of xx to xx%.

Consistency tests are also carried out on some of the program outputs.

## When using the programs, assure that

- 1.the programs are applicable to individual case;
- 2.all the program limitations are taken into account in the analysis;
- 3.the assumptions are valid;
- 4.the mathematical modeling is correct;
- 5.the calculations are accurate;
- 6.the theory of analysis and mathematical basis of the computational algorithm are correct; and
- 7.the results comply with the appropriate requirements of the Buildings Ordinance, Building Regulations and codes of practices.

## Quality Assurance of Engineering Simulation

System and competent personnel to carry out validation and simulation — do not rely too much on the program developer! (if you are not the program developer)

Maintenance of pre-accepted programs – check for updates from program developer; make notes of bugs found.

## **Excavation and Lateral Support**

OASYS FREW
PLAXIS 2D
WALLAP
FLAC (2D)
OASYS SAFE
DIANA
PAROI 2
RIDO

**OASYS STAWAL** 

## Slope Stability Analysis

SLOPE/W
OASYS SLOPE
GALENA
PCSTABL5M
SLOPE 2000
JANBU
SLOPE

## Tunnel and Cavern Construction

**PLAXIS 3D Tunnel** 

Phase 2

**UDEC** 

**OASYS XDISP** (or **TUNSET** previously)

## Foundation Analysis

PIGLET
PIES
OASYS VDISP
OASYS PILSET
OASYS ALP (a structural program)
PLATE (a structural program)
Lateral Pile (a structural program)

## Seepage Analysis

SEEP/W
OASYS SEEP
Phase 2
Processing Modflow (PMWIN)

## Rock Fall Analysis

RocFall CRSP

## Debris Flow

DAN-W 2d-DMM DEBRIFLO

## Retaining Wall Stability Analysis

GWALL OASYS GRETA

## Rock Slope Stability Analysis

DIPS
UNWEDGE
SWEDGE
Phase 2

## Who is a moonwalker?

Answer (a) Buzz Aldrin

## Technology Review

HOW TOMORROW'S STARTUPS WILL BE FUNDED

Business Report o75

TECH TRANSFORMS MUSIC, ART, **AND PROSE** 

Reviews p87

MITSNEW PRESIDENT: **EDUCATION AT** A CROSSROADS

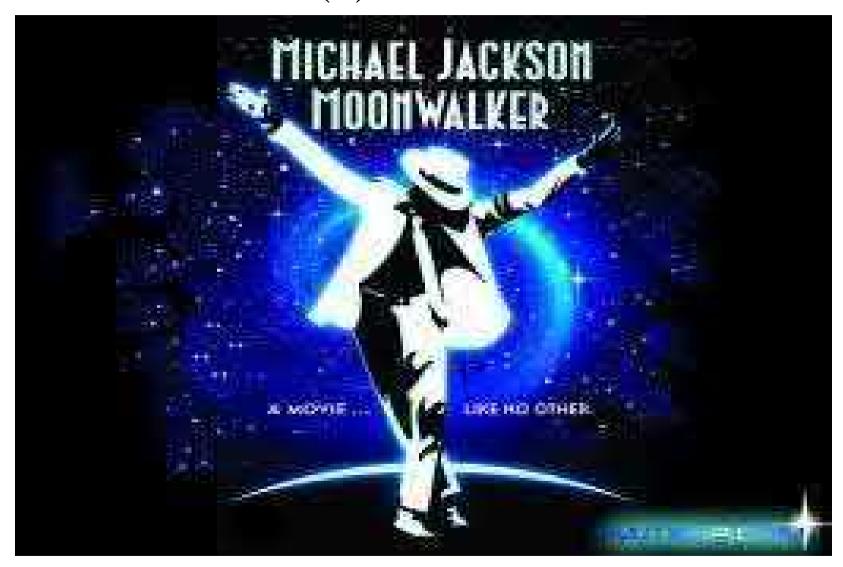
MIT Nows p17

would like a

You Promised Me Mars Colonies. Instead, I Got Facebook.

> We've stopped solving big problems Meet the technologists who refuse to give up ....

## Answer (b) Michael Jackson



(from Wikipedia, 16.4.2013)

# Simulation Animation

**Simulation** is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.

**Animation** is the rapid display of a sequence of images to create an illusion of movement. (Wikipedia, 15.3.2013)

"It is not only how <u>quickly</u> one can carry out an analysis; it is how accurately and quickly one can carry it out."



### Background

Geotechnical practitioners in Hong Kong have accumulated great amounts of knowledge and experience in using geotechnical computer programs in various projects. Discussion meetings between qualified and experienced users will help to advance the knowledge base of geotechnical practitioners in Hong Kong.

### **Purpose**

To promote knowledge of the underlying theory, applications, limitations, precautions, accuracy issues and user-friendliness of various geotechnical computer programs.

A model is a simplified abstract view of a physical phenomenon which can be very complex. In the model the physical phenomenon is characterized by a set of parameters/variables and geometric boundaries. Mathematical relationships are established between the parameters so that when some of the parameters are given (input parameters), some other parameters can be calculated (output parameters).

The relationships include basic relationships (e.g. strain-displacement), constitutive relationships (e.g. stressstrain relationships) and governing equations (e.g. stress equilibrium equations resulting from force and moment equilibria).

Numerical Modelling is a form of modeling in which numerical computation is used in calculating the output parameters. We will consider only cases in which the calculations are carried out using a computer program.

Numerical Modelling gives you an answer and a question:

Answer – settlement, structural force, etc

Question – how good is the answer?

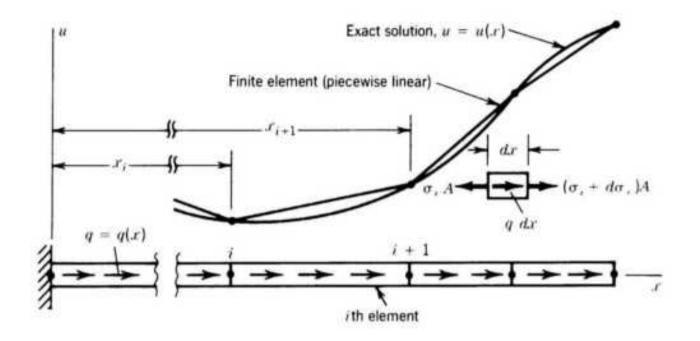
Errors in Numerical Modelling arise due to the following factors:

(1) Modelling error. Errors occur when the physical phenomenon is simplified. For example, a beam on elastic foundation is used to represent the interaction of a flexible retaining wall and ground. Errors also occur due to simplified constitutive relationships, mathematical approximations/errors in the formulations, etc.

- (2) Coding error. Examples include typos in coding a program.
- (3) Human error. It includes user error (e.g. misunderstanding of concepts, errors in inputting and in reading output), errors arising from misunderstanding of the program manuals (e.g. communication error), errors due to the user being misled by ill-written program manuals.

(4) Discretization error. Inaccuracies can arise from a coarse mesh.

(example below from Cook, Malkus and Plesha, 1989)



$$u_{int} = \frac{q}{AE} = 0$$
 (18.6-1)

$$\rho(x) = \rho(x) = o\left(1 - \frac{(x-y)}{h}\right) + o\left(\frac{x-y}{h}\right) + o\left(\frac{x-y}{h}\right). \quad (2000)$$

- (5) Errors originating from inappropriate boundaries and boundary conditions.
- (6) Errors originating from inaccurate input parameters (e.g. soil properties, structural properties).
- (7) Computation error (e.g. truncation error).

Due to the above errors, there are discrepancies between computed results (e.g. settlement) and field measurements (neglecting measurement errors).

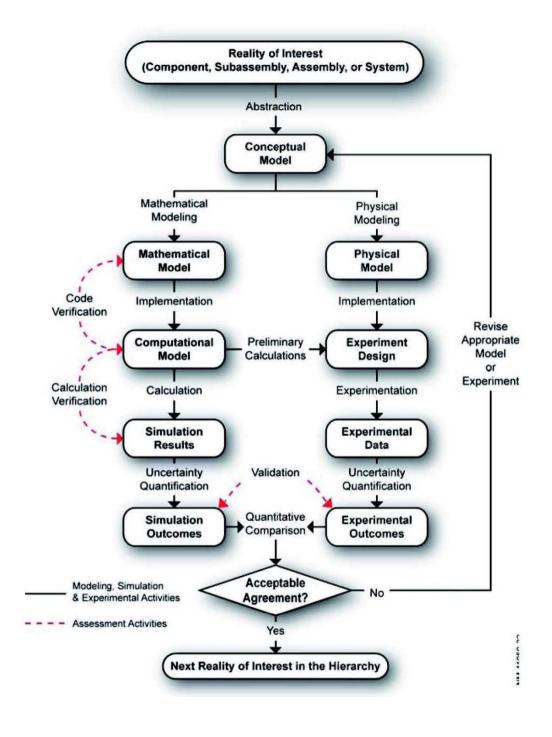
While program developers should use the best models available to develop their programs and prepare comprehensive documentation, program users should understand the capabilities of the programs and have awareness of possible inaccuracies. An experienced designer using the computer program should know the approximate error magnitudes in the calculations.

## "What is Verification and Validation?"

By

American Society of Mechanical Engineers &

National Agency for Finite Element Methods and Standards, UK



Who must ensure that a program works properly and produces correct results?

- -The program developer's responsibility?
- -The user's responsibility?

\*\*\*Life and economic consequences

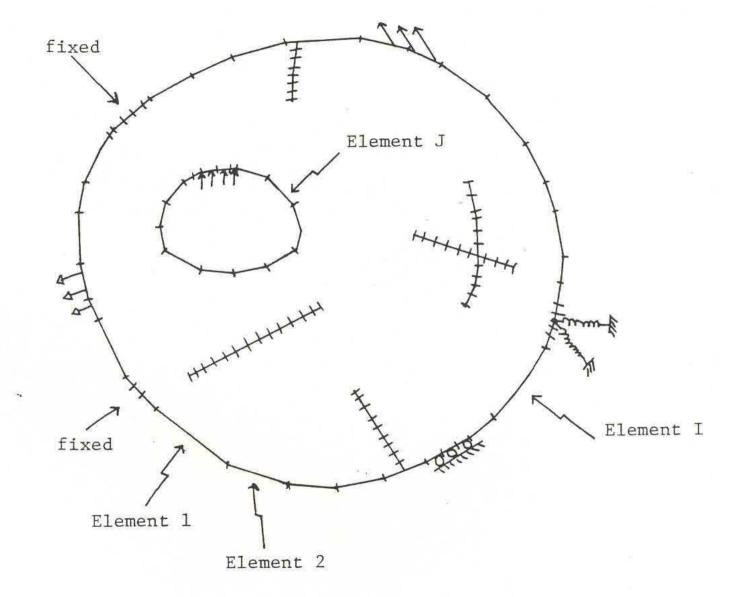
The program assessment (and later, the use of the program) must be carried out in a conscientious and professional manner, by personnel with suitable experience in geotechnical analysis and design.

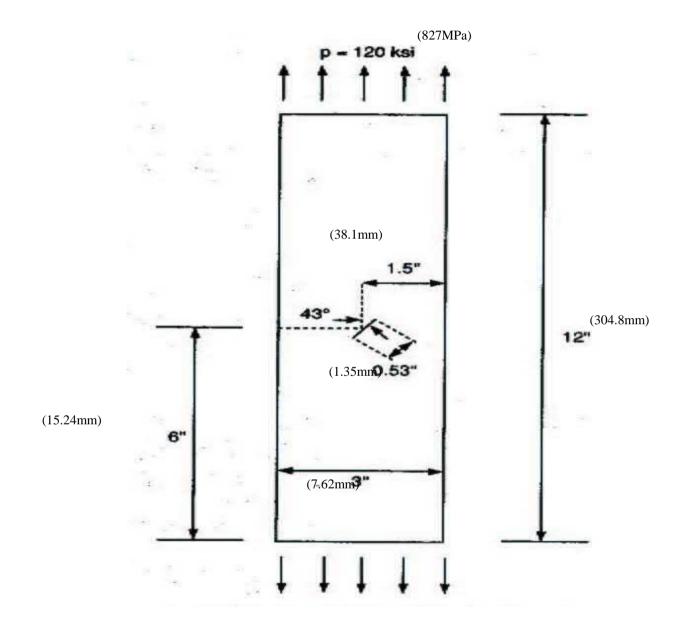
In Hong Kong, prior acceptance of geotechnical computer programs to be used to support engineering design of private projects should be obtained from the Buildings Department. Where requested by the BD, the Geotechnical Engineering Office checks that the technical assessments of the programs undertaken by the applicants for prior acceptance have been adequately carried out.

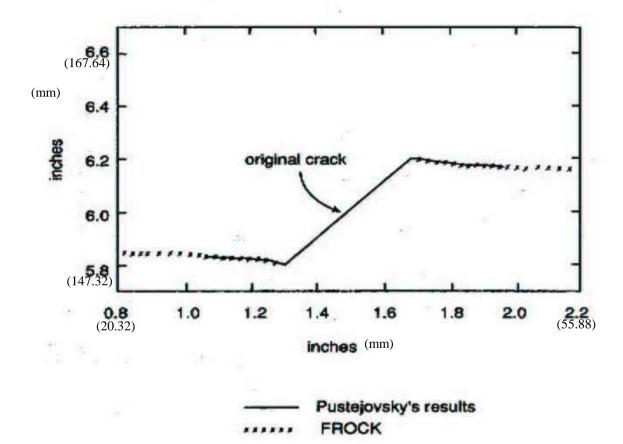
In Hong Kong, a useful source of information is the list of accepted geotechnical computer programs maintained by the Buildings Department, from which details of the areas of application covered by the assessment and the program limitations can be obtained.

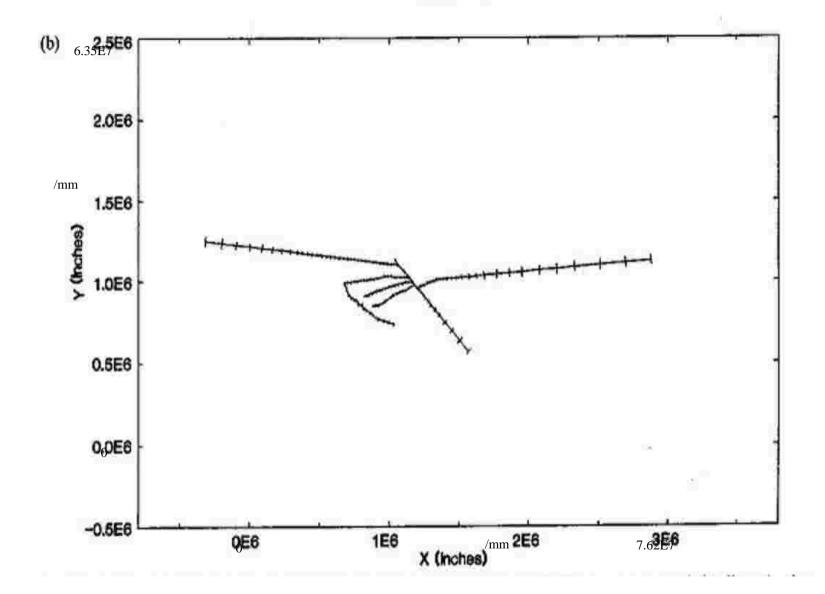
Quality Assurance Checks of a General-Purpose Boundary Element Program Named "FROCK" (Fractured ROCK)

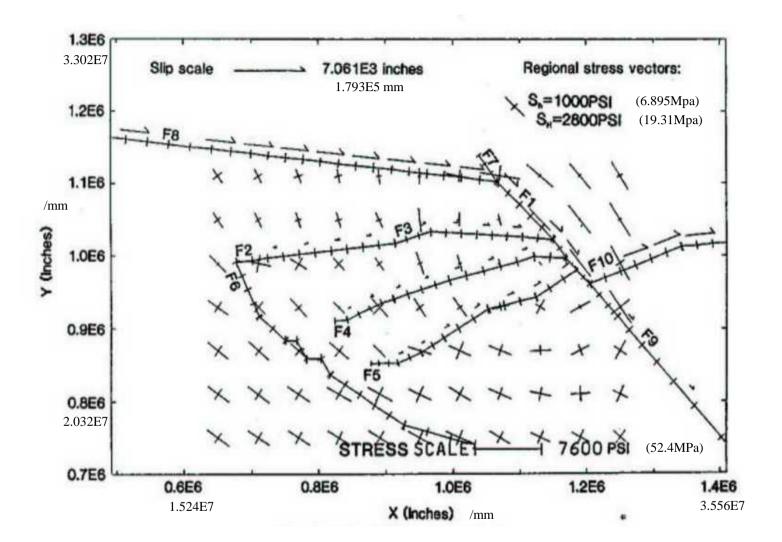
Chan et al (1990)











### **Applications and Limitations of Geotechnical Computer Programs Commonly Used in Hong Kong**

#### Mark H. C. Chan

Geotechnical	Engineering	Office, Civi	l Engineering	and Develo	pment De	partment

Nowadays the use of computer programs has become an integral part of geotechnical engineering analysis and design (for example, see Carter et al (2000)). The users of computer programs should carry out their own validation of the programs before use in actual projects which can have consequence to life or economic consequence implications.

PNAP ADM-6 advises that prior acceptance of geotechnical computer programs to be used to support engineering design of private projects should be obtained from the Buildings Department (BD), while the Project Administration Handbook for Civil Engineering Works advises that prior acceptance of geotechnical computer programs should be obtained from CGE/S&T, GEO, prior to their use in Government projects. GEO Circular No. 35 advises that geotechnical computer programs which have not been checked and accepted by GEO should not be used in designs or studies where errors could have significant safety or financial implications. The Standards and Testing Division of the GEO carries out the vetting/checking of geotechnical computer programs for the purpose of prior acceptance.

In applying for prior acceptance, the applicant should submit information on:

- (i) the background and underlying theory of the program;
- (ii) Building Regulations, codes of practice or other requirements which the analysis or design produced by the program will comply with;
- (iii) areas of application and limitations; and
- (iv) validation examples.

Based on records of vetting by the BD and GEO, Geotechnical Computer Programs can be categorized into different program classes according to their respective areas of application. These program classes include Excavation and Lateral Support, Slope Stability Analysis, Tunnel and Cavern Construction, Foundation Analysis, Seepage Analysis, Rock Fall Analysis, Debris Flow, Retaining Wall Stability Analysis and Rock Slope Stability Analysis. It is noted that a multiple-purpose program can fall into more than one program class (e.g. Excavation and Lateral Support and Seepage Analysis).

Regarding theoretical background, the programs utilize different formulations including Finite Element, Finite Difference, Distinct Element, Discrete Element, Boundary Element, Limiting Equilibrium Analysis, Vibration Analysis, Impact Analysis, Hydrodynamic, Particulate System, Stereographic Projection, and coupled/hybrid formulations.

In this paper, the relatively updated versions of most commonly used programs are reviewed. It is noted that the pre-accepted areas of application of the programs are based on the applications for prior acceptance submitted/forwarded to the GEO. Therefore a program could have other areas of application apart from the pre-accepted ones. Likewise, the limitations and precautionary statements of a pre-accepted program are based on the applications for prior acceptance. The limitations and precautions stated in the Appendix are not exhaustive. They are not based on a comprehensive review of the programs, nor a detailed assessment of performance of the programs and experience of their application.

The validation process of a geotechnical computer program, which should be carried out by the applicant for prior acceptance, normally includes the following steps (Chan, 2007; AGS, 1994):

- Check whether the documentation is complete and clearly presented.
- Review the underlying theory of the program.
- Review the quality assurance procedures of the program (if any).
- Review previous experience in the use of the program, in particular to solve local problems. Consult both in-house and external users as necessary.
- Decide whether the test examples supplied by the program developer are adequate. If not, devise additional test problems, run the program using the additional problems and examine the test results.
- Document the results of the validation process.

A summary of the pre-accepted programs and their respective areas of application, limitations and precautions are given in the Appendix. The prior acceptance of any geotechnical computer program will normally be valid for three years, after which a renewal of prior acceptance should be obtained by the users. This is to ensure regular updating of the program to incorporate recent advances in science and technology and revisions to relevant codes of practice. A list of the currently accepted geotechnical programs can be downloaded from BD's web page at http://www.bd.gov.hk/english/inform/index\_acp.html.

When using the programs to support calculations and designs submitted to the Building Authority, the user should thoroughly read the respective manuals and assure the following aspects (<a href="http://www.bd.gov.hk/english/inform/index">http://www.bd.gov.hk/english/inform/index</a> acp.html and PNAP APP-128): -

- i. the programs are applicable to individual case;
- ii. all the program limitations are taken into account in the analysis;
- iii. the assumptions are valid;
- iv. the mathematical modeling is correct;
- v. the calculations are accurate;
- vi. the theory of analysis and mathematical basis of the computational algorithm are correct; and

vii. the results comply with the appropriate requirements of the Buildings Ordinance, Building Regulations and codes of practices.

To assess and improve the accuracy of the calculations, more appropriate use of the program or even improvements in the program itself may be needed. Before doing so, it is important to understand the possible sources of errors in the numerical calculations (Chan, 2012; NAFEMS, 2009). Chan (2012) has proposed the following 7 types of error sources: (1) Modelling error, (2) Coding error, (3) Human error, (4) Discretization error, (5) Errors originating from inappropriate boundaries and boundary conditions (and initial conditions where applicable), (6) Errors originating from inaccurate input parameters, and (7) Computation error.

#### Acknowledgments

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#### References

Association of Geotechnical Specialists (AGS) (1994). Validation and use of geotechnical software. Version 1.0, June, AGS Guide.

Buildings Department (2005a). "Computer programs for use in structural and geotechnical design." *Practice Note for Authorized Persons and Registered Structural Engineers (PNAP) ADM-6.* 

Buildings Department (2005b). "Geotechnical Design Information." *Practice Note for Authorized Persons and Registered Structural Engineers (PNAP) APP-128.* 

Carter, J.P., Desai, C.S., Potts, D.M., Schweiger, H.F. and Sloan, S.W. (2000). "Computing and computer modeling in geotechnical engineering", Invited Paper, *Proceedings, GeoEng2000*, Melbourne, Australia.

Chan, Mark H.C. (2007). "Validation of Geotechnical Computer Programs", *Proceedings of the International Workshop on Constitutive Modelling*, The Hong Kong Polytechnic University, Hong Kong.

Chan, Mark H.C. (2012). "Sources of Errors in Numerical Modelling and Program Validation", Geotechnical Computer Program Users Group Meeting No.1, Working Group on Application of Innovative Technology in Geotechnical Engineering, HKIE Geotechnical Division. http://www.hkieged.org/geodiv/activity.aspx

GEO (2004). Prior Acceptance of Computer Programs for Use in Geotechnical Engineering (GEO Circular No. 35). Geotechnical Engineering Office, Hong Kong, 10p.

The Government of the Hong Kong Special Administrative Region (2012). Project Administration Handbook for Civil Engineering Works, Hong Kong.

NAFEMS (2009). Quality Management in Engineering Simulation - A Primer for NAFEMS QSS, 161p.

#### **Appendix**

### A summary of pre-accepted programs and their respective areas of application, limitations and precautions

#### **Excavation and Lateral Support**

#### **OASYS FREW**

Specific applications – FREW is a computer program used to analyse the behaviour of flexible retaining walls. It predicts the displacements, shear forces, bending moments and earth pressures on each side of the wall resulting from a series of actions. These actions include excavation, filling, dewatering, changing soil or wall properties and applying or removing struts, anchors or surcharges. Both Global Safety Factor and CIRIA C580 (Partial Safety Factors) Approaches are included.

Limitations – Regarding the soil model, only the SAFE model method should be used. Subgrade reaction model should not be used. Use only the linear elastic perfectly plastic soil model with Mohr-Coulomb failure criterion. The new stability check feature (V.19, for use under C580) is excluded.

#### Precautions -

- Ka and Kp values applied in FREW should be in the horizontal direction. When opting for the "Calculated" option, FREW will compute the earth pressure coefficients based on the method given in the User Manual.
- Numerical instability may occur if the ratio of separation distances between any two pairs of nodes is greater than 2.
- When the surcharge is expected to appear after the wall installation, the surcharge values should be applied in stage 1 instead of stage 0 of the FREW analysis. Users are reminded that the purpose of stage 0 is to model the existing ground condition prior to any construction works.
- Surcharge value applied in stage 0 corresponds to the situation where the loading is present at the existing ground condition, and FREW will reset the wall deformation to zero prior to the stage 1 analysis.
- Surcharge modeling: It is recommended to use UDL surcharge instead of strip load surcharge if the surcharge is widespread across the site. Users are reminded that application of strip load surcharge will only modify the active pressure limit of the underlying soil, whereas the application of UDL surcharge will modify both active and passive pressure limits of the underlying soil.

#### **PLAXIS 2D**

Specific applications – Both Global Factor and C580 Approaches are included. Hydrostatic or steady state seepage flow condition can be specified in the input. Ground deformations are also modeled in addition to wall deformations, shear forces and bending moments.

Limitations – Regarding the soil model, use only the linear elastic perfectly plastic soil model with Mohr-Coulomb failure criterion. The wall-soil interface friction ratio should not be assigned unrealistically low values to avoid non-convergence. Modelling of sound rock with individual joints which substantially affect the deformation-failure behavior of the rock formation is excluded. Transient seepage and consolidation analysis is excluded. When the Modified C580 Approach is used, specific procedures (e.g. checking the sensitivity of the wall behavior to the wall embedment depth) should be followed.

#### WALLAP

Specific applications – The program analyses a range of retaining wall problems including cantilevered walls, anchored walls and strutted excavations. It outputs the displacements, shear forces, bending moments and earth pressures on each side of the wall resulting from excavation. Both Global Factor and C580 Approaches are included.

Limitations – Some optional features are excluded - seismic loading, thermal stress of struts, wedge stability, yield moment of wall, FOS calculation, single pile analysis, etc. Linear elastic perfectly plastic soil model with Mohr-Coulomb failure criterion is assumed.

#### Precautions -

- Users are reminded that the active and passive earth pressure coefficients (Ka and Kp) values applied in WALLAP are the horizontal components. When opting for the manual input for Ka and Kp, users should use Figures 18 and 19 of Geoguide 1 to obtain the earth pressure coefficients. When opting for the WALLAP calculated values, WALLAP will compute the horizontal earth pressure coefficients based on the method given in the program manual.
- Users should note that the Finite Element (FE) Length parameter of the wall under "Wall / Pile" definition is pre-set by the Program automatically based on the actual length of wall, which however can be changed manually. It should be noted that a longer "FE length" may reduce the accuracy of analysis results, therefore it is recommended that the manually set length should not deviate from the "recommended length" by too much.
- In the case of computer analysis convergence failure, the user should check the problem geometry as well as other possible reasons. Convergence failure due to

geometry sometimes could be resolved by a minor adjustment of the "FE Length" parameter.

#### FLAC (2D)

Specific applications – The program predicts the displacements, shear forces, bending moments of the wall and earth pressures on each side of the wall resulting from a series of actions. These actions include excavation, filling, dewatering, changing soil or wall properties and applying or removing struts, anchors or surcharges.

Limitations – Only Global Factor Approach is included.

Precautions – Accuracy is limited by the quality of input coefficients. As a result, the program is normally calibrated to sites using observational data.

#### **OASYS SAFE**

Specific applications – The output of bending moment diagram, shear force diagram and deflection profile can be produced for the retaining structure.

Limitations - Only Global Factor Approach is included. Consolidation analysis is excluded.

#### **DIANA**

Specific applications – The program analyses propped and staged excavations with a vertical flexible retaining wall embedded in granular or cohesive soil layers. The soil model includes elasto-plastic stress-strain relations and strain softening laws.

Limitations – The modulus of the wall is constant.

#### PAROI 2

Specific applications – It outputs the displacements, shear forces, bending moments and earth pressures on each side of the wall resulting from excavation.

Limitations – Only Global Factor Approach is included. Elasto-plastic soil model is assumed.

#### **RIDO**

Specific applications – The program calculates the elastoplastic equilibrium of embedded retaining walls. It outputs the wall displacements, shear forces, bending moments, strut loadings and earth pressures on each side of the wall resulting from excavation and surcharges.

Limitations – Only 2 surcharge types are covered: CAQUOT and BOUSSINESQ.

#### **OASYS STAWAL**

Specific applications – The program analyzes a cantilever or propped 'non-gravity' retaining wall (e.g. sheet pile or diaphragm wall). It determines the penetration required to prevent instability and calculates the bending moments and shear forces occurring in the wall at this limiting condition. "Fixed earth" or "Free earth" condition with either active or passive soil pressures are assumed to act on the wall as appropriate.

Limitations – Mechanisms of failure other than "Fixed earth" or "Free earth" mechanisms are not considered.

#### Slope Stability Analysis

#### SLOPE/W

Specific applications – FOS of slope using limiting equilibrium method.

Limitations – Only Bishop Simplified, Janbu Simplified, Morgenstern & Price and Spencer methods with Mohr-Coulomb strength model. Some optional features are excluded:

- Use of partial factor for slope stability analysis
- Bearing capacity analyses
- Pseudo-static earthquake analyses
- Active and passive pressures
- Block failure
- Analyses allowing passive mode
- Probabilistic analyses
- Hoek-Brown failure criterion for modeling shear strength of soil or rock
- Unsaturated shear strength
- Analyses using SLOPE/W finite element stress method

- Auto-Locate (or Auto-Search) for critical slip surface will produce results for indication only
- SHANSEP model for soft soils
- geotextile reinforcement
- pile wall

Precautions – When excessively steep slip surfaces are used, or when a strong soil layer overlies a very weak one, iteration may not converge.

#### **OASYS SLOPE**

Specific applications – FOS of slope using limiting equilibrium method. The program uses the method of slices and variety of established methods for calculating interslice forces such as Fellenius or Swedish slip circle analysis, the Bishop horizontal or constant inclined inter-slice forces method and Janbu method.

Limitations - The Partial Factor Analysis function is excluded, and Fellenius Method should not be used.

#### **GALENA**

Specific applications – FOS of slope using Bishop Simplified Method and Spencer-Wright Method.

Limitations – Sarma Method not included. The following features are excluded: cohesion computed based on the function of the effective overburden pressure; overhanging slopes.

#### PCSTABL5M

Specific applications – The program analyses slope stability using Bishop and Janbu's simplified methods.

Limitations – Spencer's method is excluded.

Precautions – When using Janbu's simplified method, possible inaccuracies may occur in analyzing deep-seated slips, shallow slips or cases with tieback loads.

#### **SLOPE 2000**

Specific applications – The program analyses slope stability using Bishop and Janbu's simplified methods and Morgenstern-Price method. It can locate the critical slip surface (however, the user should cross check the output). Soil nail force calculation can be controlled by tensile strength of nail, bond length proportional to the effective zone or bond stress from vertical overburden stress. Bond stress from overburden stress can be determined using the Hong Kong practice.

#### Limitations -

- 1. Pile anchorage simulation is not allowed.
- 2. Sarma's, Wedge, Lowe Karafiath analysis and 3D analysis options are not allowed.
- 3. Davis method on bond load calculation for soil nail is not allowed.
- 4. Combined bond load from soil friction and rock bond for soil nail is not allowed.

#### **JANBU**

Specific applications – Circular or non-circular slip surfaces with different soil conditions, external loads and slope profile, using Janbu's Simplified Method.

Limitations – Minimum 3 slices and maximum 50 slices.

#### **SLOPE**

Specific applications – The program analyses slope stability with or without external forces using Bishop or Janbu's (simplified and rigorous) methods.

Limitations – The following are excluded: earth pressure and bearing capacity problems; wedge shaped failure analysis; landslip under earthquake force; reinforced soil analysis and design; Fellenius method; soil suction calculation.

#### **Tunnel and Cavern Construction**

#### **PLAXIS 3D Tunnel**

Specific applications –

(1) to determine the settlement of a building and the changes in load and bending moments in its piles caused by tunnelling beneath. The building is supported on

- friction piles where previous ground treatment by grouting to form a stiffened soil raft has been carried out. A similar previous case of tunneling under the building at the same site has been back-analysed for program calibration.
- (2) For 3D analysis of tunnel linings in soil. A tunnel dismantling process is being modelled. There is substantial soil cover (4 times tunnel diameter). Prior to the dismantling works, ground improvement works in the form of a 3 to 5 m thick annulus grout has been carried out to stabilise the ground. Compressed air is used before applying temporary shotcrete layers to support the exposed ground around the tunnel perimeter. The results are to be used to determine ground movements and to check localised tunnel stability and to assess the load on temporary (shotcrete) linings for advancement of a tunnel face beyond the zone supported by existing tunnel linings or the tunnel shield and the ground is supported by fluid or air pressure. The application is restricted to problems where 2D analyses are not appropriate.

#### Limitations/precautions-

- 1. The Lining Contraction method of modelling tunnel construction should be used with care, as in some circumstances the program can predict unrealistic and excessive ground heave. Sensitivity analyses using alternative methods of modelling ground volume loss caused by tunnelling are recommended.
- 2. The geometry of the 3D finite element model in the into-the-plane direction cannot be varied. For modelling of variable ground conditions into-the-plane, the variation may be modelled in a "stepped" changing manner. Circular piles may need to be modelled as equivalent square piles.
- 3. Interface elements can only be modelled in two directional planes, not in all three directional planes. Care should be exercised when high stress concentration is predicted, especially in the directional plane where interface elements cannot be modelled.
- 4. In a similar manner to other finite element programs, standard analyses are of small deformation type (i.e. typically used for Serviceability Limit State analyses). Analysis convergence problems may be encountered when substantial deformations/slips/yielding occurs. Where very large deformations are predicted which may be indicative of the development of incipient failure mechanisms, users should take particular care and consider other approaches to confirm the findings.
- 5. Relatively large deformations can occur in an "Updated mesh" analysis, the magnitude of which can exceed the typical limits of deformation associated

- with Ultimate Limit State (ULS) conditions of the structure. In such a situation, users should check the development of an incipient failure mechanism in the analysis.
- 6. When the "Updated mesh" function is used together with the "phi-c' reduction" function to calculate a factor of safety (FOS), the FOS calculated may be higher than when the "Update mesh" option is not used.
- 7. Only steady-state seepage flow analyses can be carried out. For cases involving transient flow, other approved seepage flow programs may be used to estimate the water pressure distribution at a particular time. This estimated water pressures can then be manually input into the Plaxis 3D Tunnel V2.4 program using the "User-defined pore pressure distribution" option to carry out the equivalent analysis with the transient water pressure distribution.
- 8. Acceptance is only given for the linear elastic, perfectly plastic Mohr Coulomb constitutive model. Where the analysis is to model relatively short term events where fine grained materials can be expected to behave in a predominantly undrained manner, the fine grained materials should be modelled as being undrained with undrained shear strength parameter (c<sub>u</sub>).

Further Precautions - where a good standard of ground investigation has been carried out and tunnelling methods are adequately controlled, the magnitudes of the variation between predictions using Plaxis 3D Tunnel and field measurements are typically as follows:

- (i) volume loss ratio ( $V_L$ ): -50% to +25%. For example, the analysis predicts a  $V_L$  of 1% for a given set of tunnelling parameters and the measurements give 0.5% to 1.25%.
- (ii) maximum greenfield ground surface settlements or building settlements: -50% to +20%. For example, the analysis predicts a maximum greenfield surface settlement of 10 mm and the measurements give 5 mm to 12 mm.
- (iii) soil pressure acting on tunnel linings: +/-25%. For example, the analysis predicts a total overburden pressure of 100 kPa acting on the tunnel crown level, and the measurements give 75 kPa to 125 kPa. This range is dependent on the magnitude of stress relief caused by the tunnel excavation and is affected by tunnelling workmanship.

- (iv) Maximum pile settlements/lateral displacements due to tunnelling: -50% to +20%. For example, the analysis predicts a maximum pile lateral displacement of 10 mm and the measurements give 5 to 12 mm. However, the overall pattern of the pile settlements/lateral displacements is usually reasonably predicted.
- (v) Pile axial forces/bending moments due to tunnelling: -50% to +20%. The pile axial force and bending moment are related to the pile settlement and lateral displacement respectively, hence they have the same percentage of discrepancy as Item (iv).

Please note the predictions of Items (i), (ii), (iii), (iv) and (v) associated with Serviceability Limit State (SLS) conditions normally have a safety factor against failure of at least 2 to 3.

In view of natural ground variabilities and variation of tunnelling workmanship, sensitivity/parametric analyses should be carried out for the upper and lower bounds of the input parameters of the analyses. The range of predictions given by the upper and lower bound analyses may approximately cover the typical variations between predicted and measured movements and stresses. The variations are primarily due to differences between assumed and actual input parameters.

#### Phase 2

Specific applications – circular hole in infinite elastic/Hoek-Brown medium with lining and structural support.

Limitations – Modelling of individual rock joints is excluded.

#### **UDEC**

Specific applications – Modelling of ground excavation and rock reinforcement in tunnel and cavern works using the Distinct Element Method.

### **OASYS XDISP** (or **TUNSET** previously)

Specific applications – The program calculates the ground movements induced by excavation of a circular tunnel, assuming a given volume loss and that along and parallel to the tunnel centre line settlement follows probability distribution curves. For the combined effect of multiple tunnels, the movements induced by each tunnel are simply added.

Limitations – Limited to the following calculation methods under the TUNNELLING problem type: O'Reilly and New (1982) with certain "k" derivation methods; Mair et al (1993) and New and Bowers (1994) with user-specified "k".

Precautions - Selection of an appropriate value of volume loss and "k" shall be based on engineering judgement and experience gained from prior projects in similar ground conditions and using similar tunnelling techniques. For the case of multiple tunnels, possible interaction between tunnels should be considered when determining the volume loss adopted in the analysis in order to obtain realistic settlement predictions. The user should assess the appropriateness of using the BUILDING DAMAGE ASSESSMENT function for the case in hand.

#### Foundation Analysis

### **PIGLET**

Specific applications – The program analyzes pile group behavior under axial, lateral and torsional loads. It estimates an overall stiffness of the pile group, together with the bending moments and lateral deflections for user-specified loads. The soil is assumed to deform elastically, with soil shear modulus being constant or varying linearly with depth.

Limitations/precautions – pile depth should be greater than the critical pile depth for lateral pile analysis, otherwise, lateral deflection will be underestimated and bending moment will be overestimated. Overall stability of the pile group is not checked.

#### **PIES**

Specific applications – The program computes the axial movement and load distribution within a single pile or a pile within a group, subjected to axial load and/or externally imposed soil movement.

Limitations – Only a pile within a group can be analyzed. Only vertical axial loading can be considered.

#### **OASYS VDISP**

Specific applications – The program calculates the settlement and stresses in the soil layers due to several foundation loads using the Boussinesq method and the Mindlin method. The modulus can be constant or vary linearly with depth in each soil layer. Non-linear stress-strain curves may also be specified.

Limitations – The soil zones and loaded areas must be orientated parallel to the Cartesian co-ordinate system.

#### **OASYS PILSET**

Specific applications – The program calculates the settlement and stresses of a single pile and settlement of the surrounding soil using the integral method by Mattes and Poulos (1969). Effects of pile-soil slip, soil heave and settlement are modelled.

Limitations/precautions — An approximate treatment is employed to allow for two different soil stiffnesses above and below the pile toe. It automatically assigns a Young's Modulus to the soil around the pile shaft even when the soil has literally zero stiffness, leading to an underestimation of pile settlement.

### OASYS ALP (a structural program)\*

Specific applications – The program predicts the pressures, horizontal movements, shear forces and bending moments induced in a pile when subjected to lateral loads, bending moments and imposed soil displacements.

Limitations/precautions – Only Elastic-Plastic or Specified P-Y curves soil models can be used. Loadings are applied at nodes only. Water pressure can be specified and may be either hydrostatic or piezometric, but may not be applicable to the specified P-Y curves. Surcharges may be specified at any level, but may not be applicable to the specified P-Y curves.

\* Note: The program is classified by BD as a "structural program", however, it still has substantial geotechnical contents.

### **PLATE** (a structural program)

Specific applications – Analysis and Design of Plate Structure to Code of Practice for Structural Use of Concrete 2004. For a piled foundation, the ring shear theory (Randolph and Wroth, 1978) is used to model the pile-soil-pile interaction. For a raft foundation, to model the foundation soil, a Finite Element program is used as a subroutine to PLATE.

Limitations/precautions – Lateral and moment loads are applied on the pile cap but not directly on the piles. In modeling pile-soil-pile interaction, the case with multi-layered soil is excluded.

### Lateral Pile (a structural program)

Specific applications – analysis of a vertical pile under lateral load in Winkler media.

Limitations/precautions – The analysis is basically for a single pile, however, a pile group may be simulated by equivalent pile or each pile can be analysed according to its share of load. No consideration of the shadow effect or interaction between adjacent piles; reduction factor may be applied to subgrade coefficient for closely spaced piles.

### Seepage Analysis

#### SEEP/W

Specific applications – Analyses 2-D steady state/transient and saturated/unsaturated seepage flows.

Limitations – Vaporization from ground surface is not modeled.

#### **OASYS SEEP**

Specific applications – Analyses 2-D steady state saturated seepage flows using FEM. Plan flow or radial flow conditions may also be analyzed. It can also analyze flow normal to a row of wells.

#### Phase 2

Specific applications – steady state seepage flow analysis in saturated-unsaturated soils.

Limitations/precautions — The saturated coefficient of permeability, the water phase coefficient of permeability and any other assumptions related to the matric suction of the ground to be input should be verified using proven experimental techniques. Modeling of siphon effect in steady-state seepage analysis through saturated-unsaturated soils has not been validated in the application for prior acceptance.

### **Processing Modflow (PMWIN)**

Specific applications – To model 2D seepage in homogeneous and isotropic soil using the Finite Difference Method.

Limitations – Modeling of wells, recharge, transient flow and solute transport is excluded.

#### Rock Fall Analysis

#### RocFall

Specific applications – Energy, velocity and "bounce height" envelopes of the falling rock over the entire slope are determined by the program, as is the location of rock endpoints. Distributions of energy, velocity and bounce-height are also calculated along the slope profile. The distributions can be graphed and comprehensive statistics are automatically calculated.

Limitations – The rock is assumed to be spherical.

#### **CRSP**

Specific applications – The program simulates rocks tumbling down a slope and predicts the statistical distribution of speed, kinetic energy, and bounce height based on slope profile, re-bound and friction characteristics of the slope, and the shape and rotational energy of the rocks. The constants used in the friction function and the scaling factor in the program's algorithm were determined by experiment.

Limitations – Rock shapes are limited to spherical, discoid or cylindrical.

Precautions – Accuracy is limited by the quality of input coefficients. As a result, the program is normally calibrated to sites using observational data. It is helpful to choose a

range of input parameters and vary only one input parameter at a time to know what effect each input parameter has on the results. The accuracy of the Program is limited by the number of boulder fall simulation runs. Sensitivity runs should be carried out using different simulation numbers to see the effects on the output results. In any case, the user should justify that the number of simulations used is adequate for the problem being analyzed.

#### Debris Flow

### **DAN-W**

Specific applications – Dynamic analysis of landslides assuming shallow flow.

Limitations – Voellmy and frictional rheological models only.

Precautions – Solution may be unstable in certain cases where the flow is deep or abrupt changes of slope occur. If the walls of the boundary blocks are drawn normal to the slope profile, a highly curved slope will cause the top surface to loop on itself if it is too steep, creating an incorrect geometry. On the other hand, vertical slices do not have this problem, however, they are not recommended for steep slopes because their shape can become very stretched. Large time steps are more prone to instability caused by numerical divergence of the solver.

#### 2d-DMM

Specific applications – Dynamic analysis of landslides assuming shallow flow, using Voellmy, plastic and frictional rheological models. The landslide debris can consist of trapezoidal cross-sections. A functionality module for simulating motion of landslide debris using the sliding-consolidation model is available. The initial debris velocity can be specified by the user. Volume changes of debris due to entrainment/deposition are also simulated.

Limitations – It cannot simulate sharp changes in the flow path profile such as man-made steps and bends on plan. It cannot simulate lateral spreading of debris.

#### **DEBRIFLO**

Specific applications – Modelling of debris flow fronts where the debris is composed of soil, rock and water flow along an inclined channel.

Limitations – estimates of runout are conservative when no deposition is assumed as the debris front is decelerating.

#### Retaining Wall Stability Analysis

#### **GWALL**

Specific applications – The program calculates factors of safety of gravity retaining walls and cantilever walls with a base. Bending moments and shear forces in the stem and base of the wall are also calculated.

Limitations/precautions – No checking on bearing failure. The active pressure due to compaction is used as a lower limit on the active pressure in the calculation of bending moments and shear forces, but not in the stability calculation.

#### **OASYS GRETA**

Specific applications – The program analyzes the overall stability of a gravity retaining wall. Bending moments and shear forces in the stem and base of the wall are also calculated.

#### Rock Slope Stability Analysis

#### **DIPS**

Specific applications – rock slope stability (kinematic) analysis using stereographic projections.

Limitations - The following features / functions are excluded - Flexural toppling, fold analysis, oriented core and rock mass classification.

#### **UNWEDGE**

Specific applications – Stability analysis of a 3D underground rock wedge formed by 3 intercepting discontinuities and excavated surface.

Limitations – Initial in-situ rock stress is neglected. Excluded features – modeling of zero water pressure condition at tunnel face; use of Swellex and Split-Set bolts; use of Barton-Bandis strength criterion.

#### **SWEDGE**

Specific applications – Evaluation of geometry and stability of surface rock wedge.

Limitations – Areas in seismic and probabilistic analysis are excluded. The program (Version 4.0) cannot identify some potential wedges (e.g. wedge formed where the intersection of the two joints being considered intersects a tension crack).

#### Phase 2

Specific applications – shear stress distribution in a thin annulus of grout around a grouted rock bolt subjected to a pull out force.

#### References

Mair, R.J., Taylor, R.N. and Bracegirdle A. (1993). "Subsurface settlement profiles above clay in tunnels", *Geotechnique*, Vol. 43, No. 2, pp315-320.

Mattes, H.S. and Poulos, H.G. (1969). "Settlement of single compressible pile", *Journal of the Soil Mechanics and Foundation Division*, Proc. of ASCE, Vol. 95, No. SM1, Jan. 1969: 189-206.

New, B.M. and Bowers, K.H. (1994). "Ground movement model validation at the Heathrow Express trial tunnel", *Proc., Tunnelling 1994*, IMM, London, pp 301-327.

O'Reilly, M.P. and New, B.M. (1982). "Settlements above tunnels in the United Kingdom – Their magnitude and prediction", *Proc.*, *Tunnelling* '82, IMM, London, pp 137-181.

Randolph, M.F. and Wroth, C.P. (1978). "Analysis of deformation of vertically loaded piles", *Journal of the Geotechnical Engineering Division*, American Society of Civil Engineers, vol. 104, pp 1465-1488.

Association of Geotechnical & Geoenvironmental Specialists (Hong Kong)

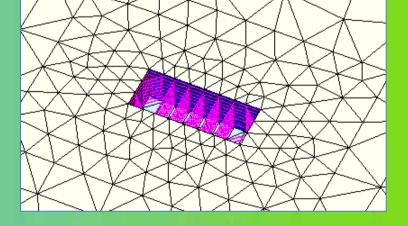
1-day Seminar on Geotechnical Computer Modelling 20 April 2013

Numerical Modelling in Geotechnical Engineering –

Concept and Challenge

Axel K L Ng

AECOM Asia Company Limited





- Concept
  - Why do we need them
  - How it works
  - Powerful tool how about limitations?
- Challenge in numerical modelling
  - Non-linear problems
  - Iteration process
  - Mesh
- Level of skill required in numerical modelling
- Discussions



- Common numerical methods for continuum
  - Finite Element Method Finite Strip Method
  - Finite Difference
  - Boundary Element Method
- Common types of geotechnical problems
  - Equilibrium force displacement
  - Seepage
  - Consolidation



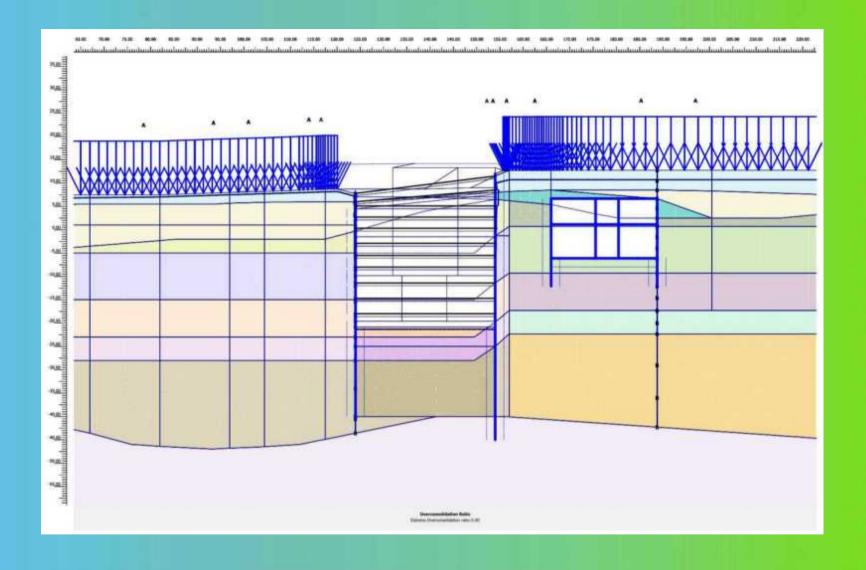




### Geotechnical problems

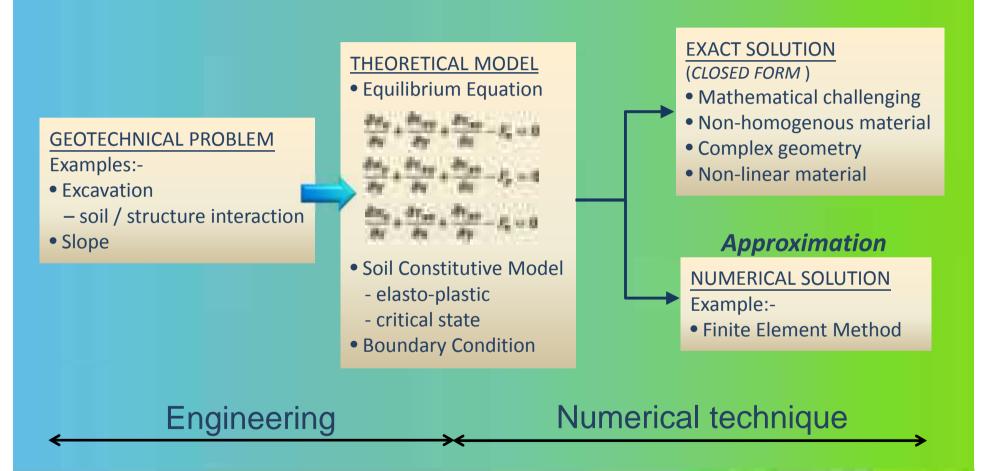
- Failure classical method where we postulate failure mechanism (upper bound solution), e.g. method of slices for slope, wedge analysis for retaining wall
- Deformation, soil-structure interaction classical method available but usually for very simple case, theoretical or empirical





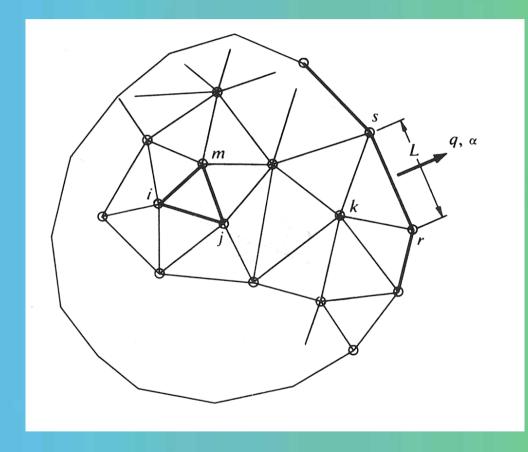


### Solution to continuum problem





### Finite Element Method – division the domain into element



- We cannot solve the theoretical model for the whole domain easily
- But we can solve it for the finite element (as least numerically)
- Then we assemble them back



Concept of FEM – division the domain into elements (issues)

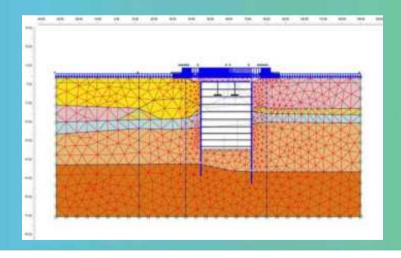
- Performance of the elements (order of element)
- Fineness of the mesh
- Compatibility of elements (gaps between elements as they deform)
- Degenerated element, extremely thin element, etc.



# FEM Formulation in force-displacement problem

$$\mathbf{k} = \int_{\mathbf{v}} \mathbf{B}^{\mathsf{T}} \mathbf{D} \mathbf{B} \ d\mathbf{v}$$

$$f = \mathbf{K} \mathbf{u}$$



k: Element Stiffness Matrix

D: Stress-strain Matrix

**B**: Strain-displacement Matrix

f: Force Vector

K: Global Stiffness Matrix

u : Displacement Vector

No. of element: 1978

No. of degree of freedom: 33926

K is a 33926 x 33926 matrix



FEM Formulation in force-displacement problem

*f* = K u

f: Force Vector

K: Global Stiffness Matrix

u : Displacement Vector

- If K is constant, then it is just a set of simultaneous equations
- Solve it with computer
- But K may not be constant...i.e. Non-linear problem







# So why we have non-linear problems

The governing equation is not linear

Poisson's Equation	$\nabla^2 f = f(x,y)$	Heat Transfer
Diffusion Equation	$\nabla^2 f = \left(\frac{1}{h^2}\right) \frac{\partial f}{\partial t}$	Transient Problems, Consolidation (time-dependant)
Wave Equation	$\nabla^2 f = \left(\frac{1}{c^2}\right) \frac{\partial^2 f}{\partial t^2}$	Wave propagation, Vibrations
Bi-harmonic Equation	$\nabla^4 f = f(x,y)$	Deformation of Plates



## Non-linear problems

- Material non-linearity, non-elastic constitutive model, e.g.
  - Non-linear elastic
  - Bi-linear (elasto-plastic)
  - Strain softening and hardening (Cam clay)

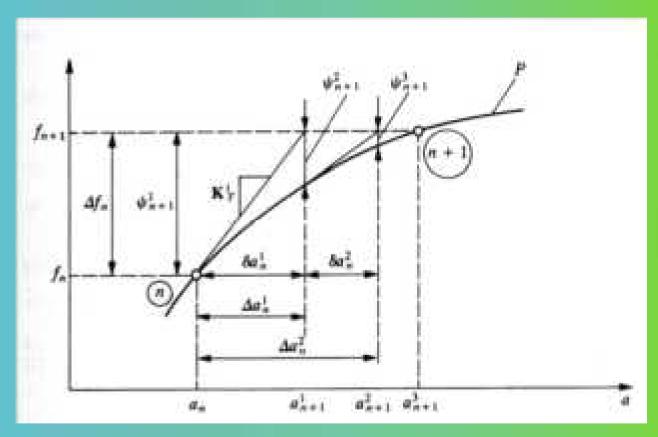


We need iteration process to find the solution

- To account for non-linearity
- Linear problem direct solving of the FEM equations is difficult/costly, use iteration process



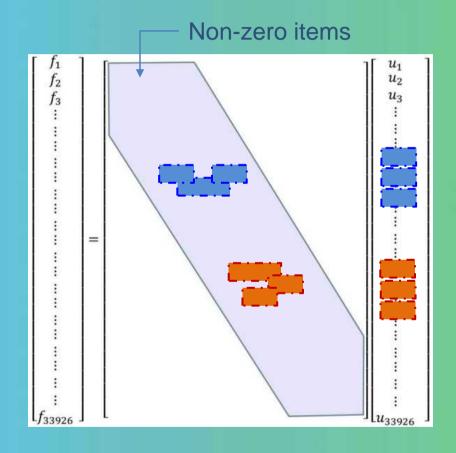
Typical iteration process – prediction – correction approach



The Newton – Raphson method



# Iteration process for changing K



$$f = K u$$

f: Force Vector

K: Global Stiffness Matrix

u : Displacement Vector

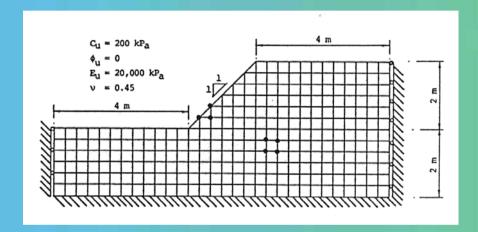


### Iteration process – converge or not

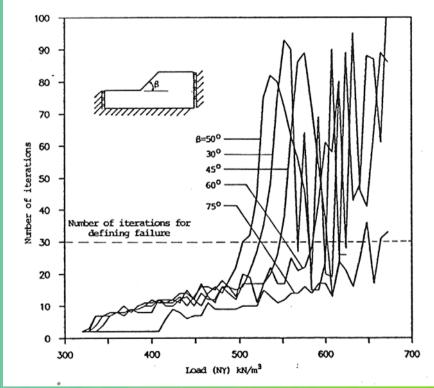
- A numerical process
- How good is the solver of the equation (predictor and corrector)
- How close from the next solution
- Convergence criteria
- Whether there is a true solution (failure)
- Machine accuracy (byte/floating-point variable)



## Iteration process – oscillation in number of iteration



Lee, P. K. K. & Ng, K. L. (1988)



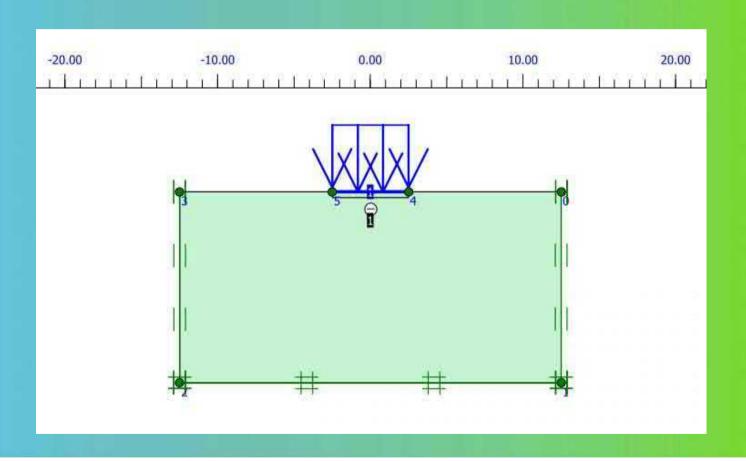


## Iteration process

 Fail to converge in the iteration process is not necessary equal to failure of the whole domain

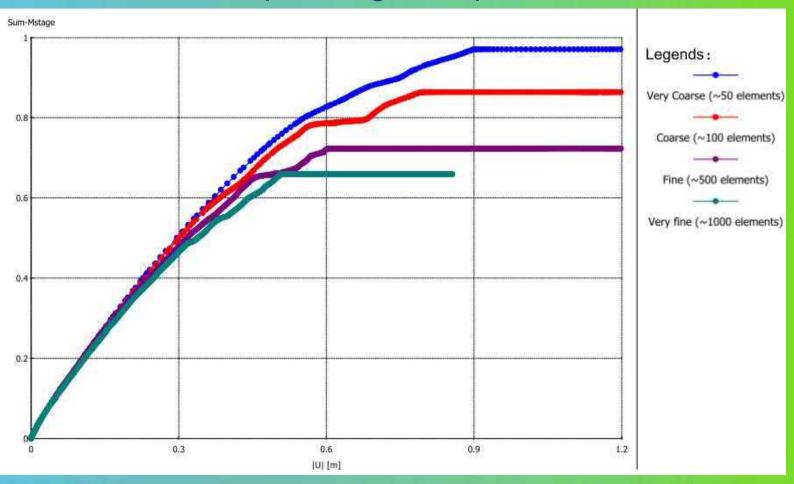


Mesh Fineness – Strip footing example, elasto-plastic, cohesless soil





# Mesh Fineness – Strip footing example



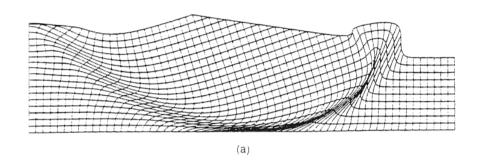


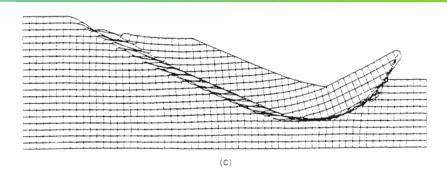
## Mesh Fineness – Strip footing example

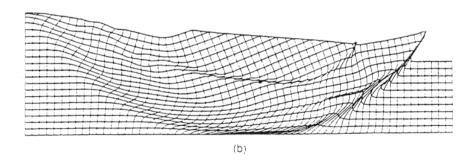
- In this example finer mesh gives lower ultimate load
- This is to expect, as failure will mean a lot of yielding and therefore rapid change in stress across the soil mass
- In the elastic range different mesh finenesses give similar results



# Slope example







Griffiths, D.V. and Lane, P.A. (1999)

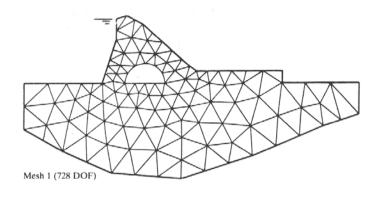


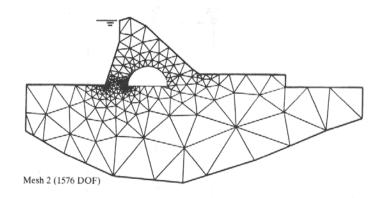
## Adaptive finite element mesh

- Algorithm to refine the mesh to reduce the 'error'
- Operate on two simple rules and do it automatically
  - Introduce new element or the same type
  - Use the same-element definition but introduce higher order of element

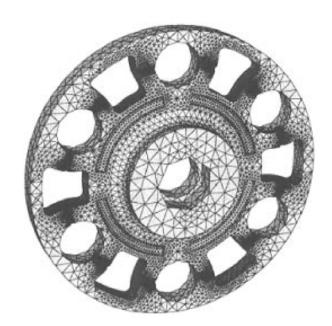


# Adaptive Finite Element Mesh







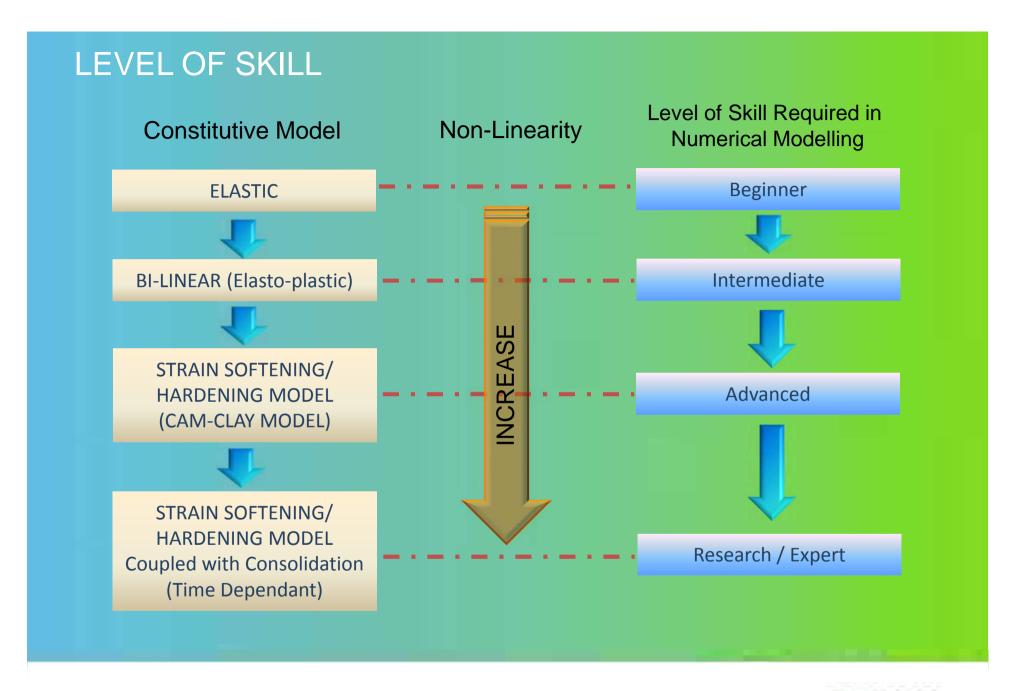


Lo, S. H. (2002)















#### **DISCUSSIONS**

- Numerical Method is an approximation method in nature
- Quality of the model depends on not just the engineering but the understanding of the numerical techniques involved
- Material non-linearity in geotechnical problem play an important role in our modelling
- Facing even bigger challenges in numerical modelling as we move on to more sophisticated soil constitutive models











## Is My Geotechnical Modeling Conservative or Aggressive?



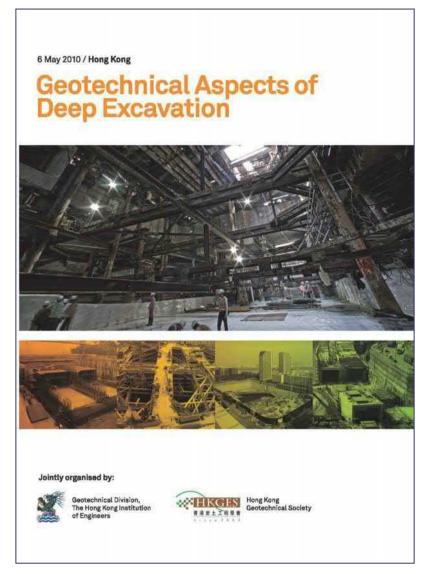
**Gavin Toh** 

20 April 2013

#### Reference:

"Constructability and Safety
Perspective in Design of a Deep
Basement Excavation in the Urban
District of Tsim Sha Tsui."

The HKIE Geotechnical Division
Annual Seminar 2010

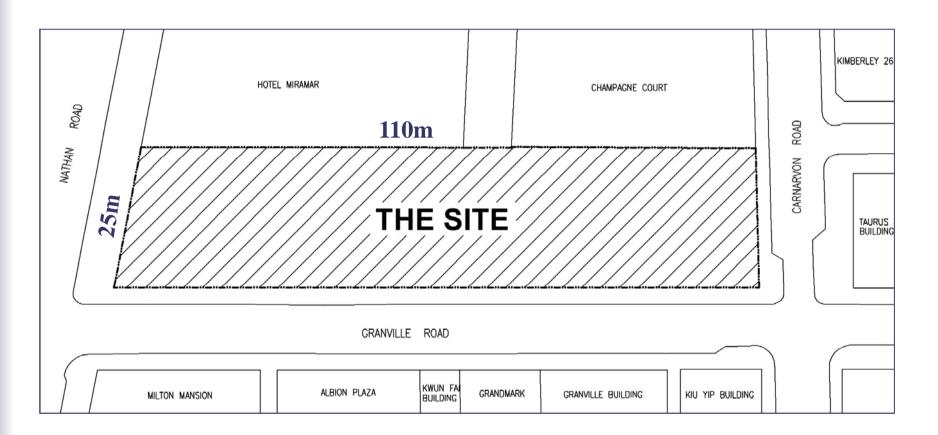


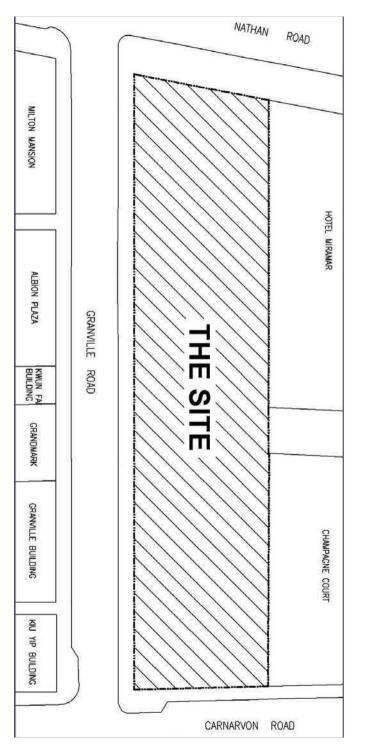
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#### **Site Location**



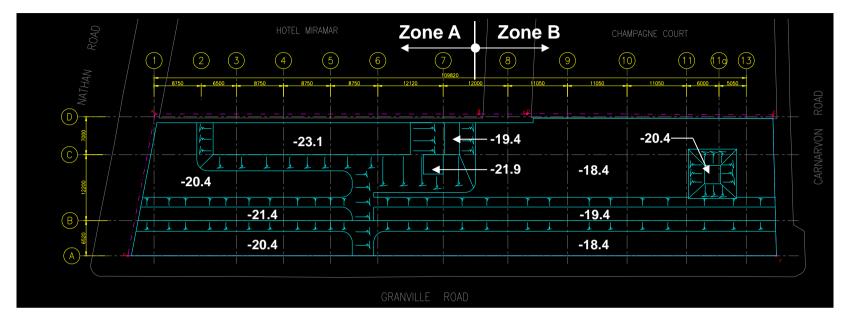
#### **Site Layout**

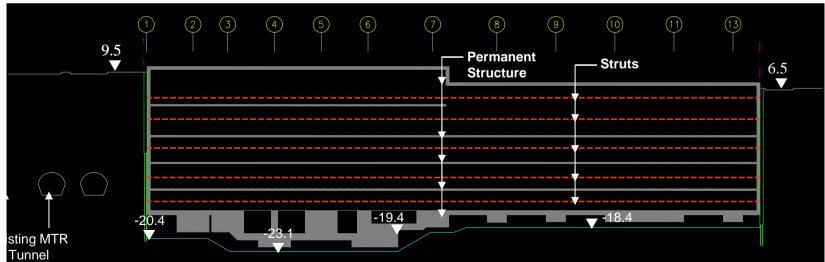




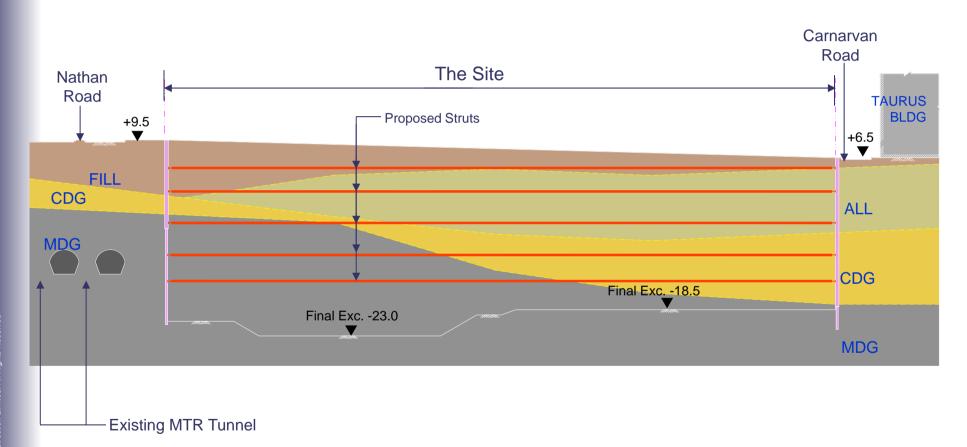


#### **ELS Works**

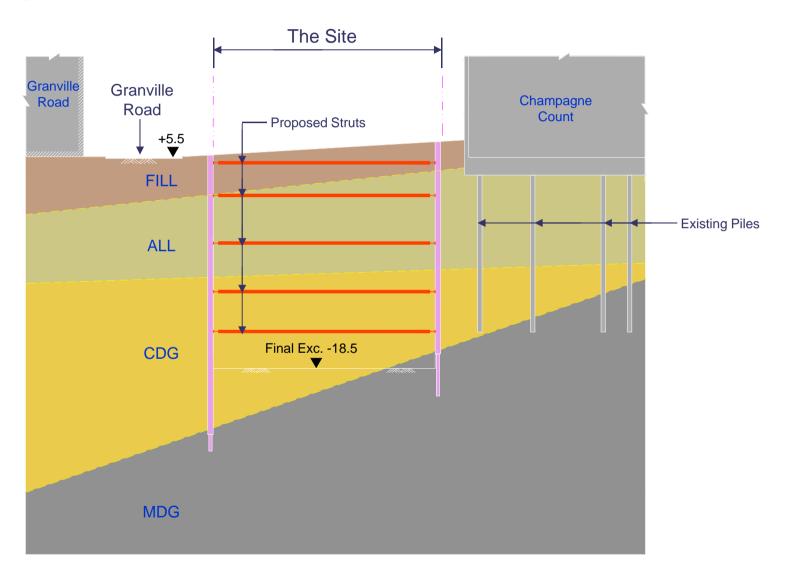




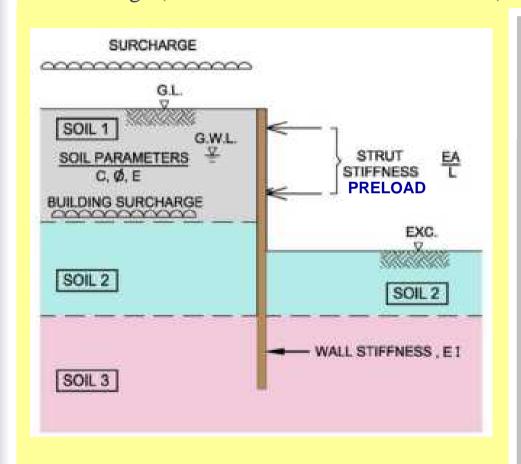
#### **Geological Condition**



#### **Geological Condition**



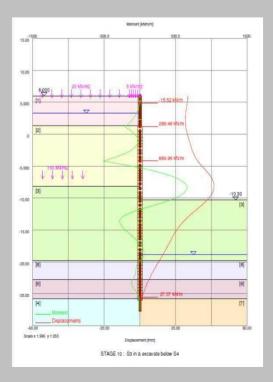
- Geological profile (from GI logs)
- GWL (measured with reasonably accuracy)
- Wall/strut stiffness & preloading (specified structure)
- Surcharge (estimated with some conservatism)





#### Monitoring:

- Deflection/Settlement
- GWL
- Strut forces

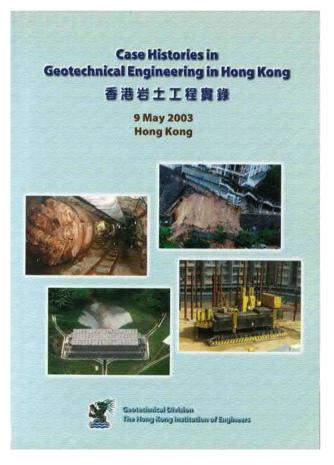


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#### **Soil Parameters – Published Literature**

Chan (2003) "Observations from Excavation – A Reflection" HKIE Geotechnical Seminar 2003

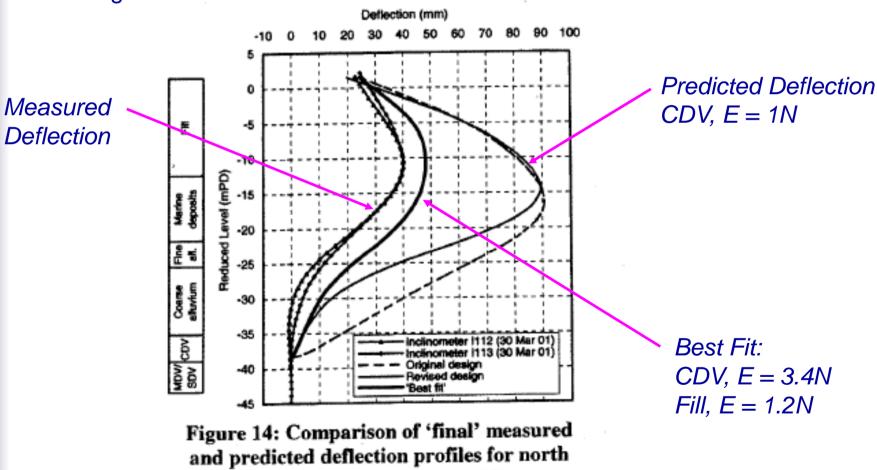
Project	Material	E = factor x N
	Fill & Marine Deposit	E = 1.5N
Chater Station, Central	CDG	E = 2.0N
	CDG / HDG	E = 4.0N
HSBC Headquarter, Central	Fill & Alluvium	E = 1.5N
	CDG	E = 2.0N
Evergreen Hotel, Wan Chai	Fill & Alluvial Deposit	E = 1.5N
	CDG	E = 3.0N
Dragon Centre, Sham Shui Po	Fill & Alluvium	E = 1.0N
	CDG	E = 1.5 – 2.0N
Festival Walk, Kowloon Tong	CDG	E = 2.0N
Hong Kong Station, Central	Fill / Alluvium / CDG	E = 4.0N



#### **Lesson from Published Literature**

Pan, et al (2001) "An application of the observational method at Tsueng Kwan O Station and Tunnels" HKIE Geotechnical Division Seminar 2001

#### Tseung Kwan O Station and Tunnels



wall at Section D of Area 57b

#### **Lesson from Published Literature**

Sze & Young (2003) "Design and construction of a deep basement through an existing basement at Central" HKIE Geotechnical Division Seminar 2003

Chater House, Central

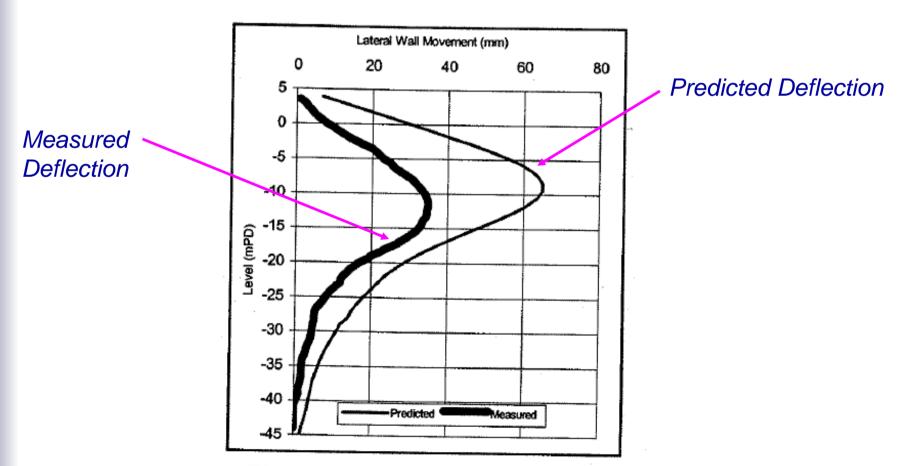


Figure 4: Diaphragm Wall Movement

#### **Lesson from Published Literature**

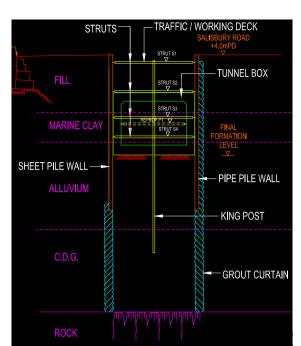
Askew, I, Sein, D, Frame A (2006) "Improving Design Efficiency and Construction in Substructure Building Works in Hong Kong Through Observational Method Design"

## KCRC Contract HCC301 - Hung Hom to TST Tunnels

Strut Layer	Max Predicted Strut Force (kN/m)	Max Measured Strut Force (kN/m)	% of Predicted Strut Force
S1	155	65	42%
S2	927	550	59%
S3	700	470	67%

<sup>\*</sup> S2 preload 37%; S3 preload 47% of max. Load

Max Predicted Deflection (mm)	Max Measured Deflection (mm)	% of Predicted Deflection
95	70	74%





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#### **Lesson from Published Literature**

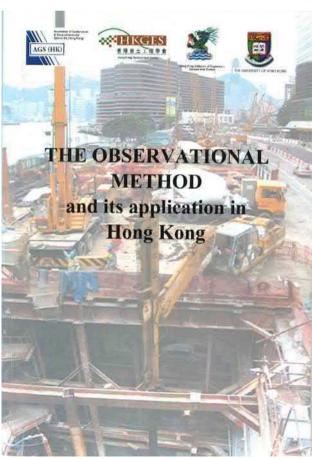
Askew, I, Sein, D, Frame A (2006) "Improving Design Efficiency and Construction in Substructure Building Works in Hong Kong Through Observational Method Design"

#### ASD Youth Centre - Chai Wan

Strain Gauge	Max Design Strut Force (kN)	Max Measured Strut Force (kN)	% of Design Strut Force
L3G1	435	200	46%
L3G2	725	250	35%
L3G3	350	200	57%
L3G4	3300	950	29%
L3G5	2970	900	30%
L3G6	990	600	60%
L3G7	2310	600	26%

<sup>\*</sup> No preloading applied





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#### ... are we being conservative?



high consequence

dense population

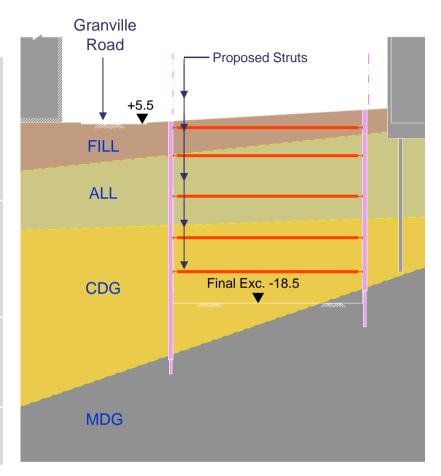
close proximity



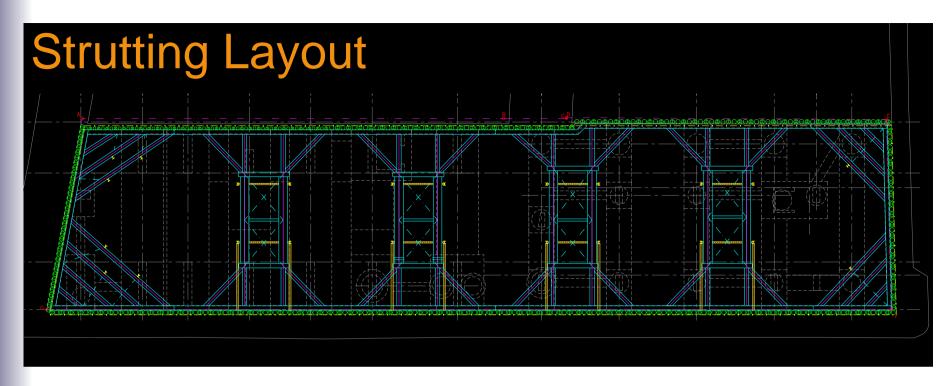


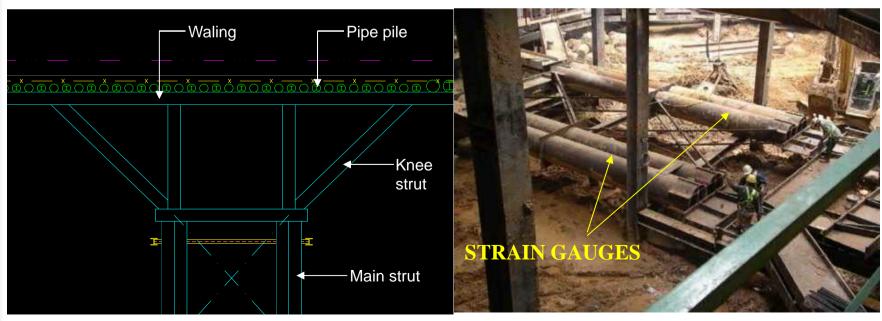
## Design Model

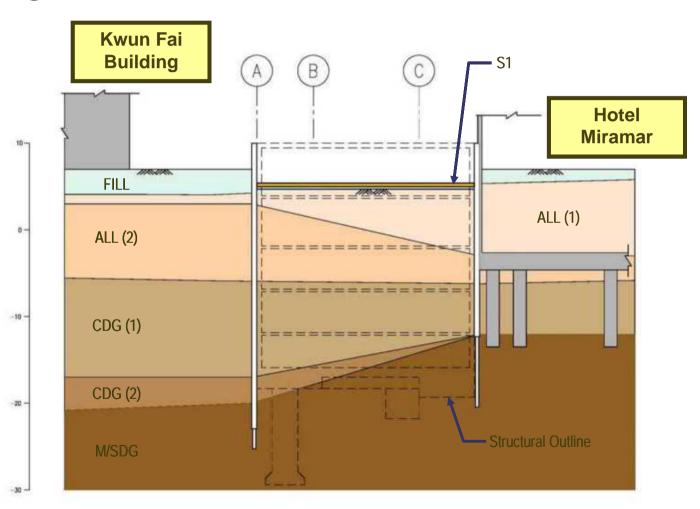
1.	Soil Shear Strength Fill Alluvium CDG (N<200) CDG (N>200)	φ' = 33° φ' = 35°, c' = 2kPa φ' = 36°, c' = 5kPa φ' = 38°, c' = 10kPa
2.	Soil Stiffness Fill Alluvium CDG	E = 1.0 x N E = 1.0 x N E = 2.0 x N
3.	Groundwater Movement Design Structural Design	Measured Level Measured + 2m
4.	Modelling of rock socket**	Socket modelled as a strut (zero rotational stiffness)

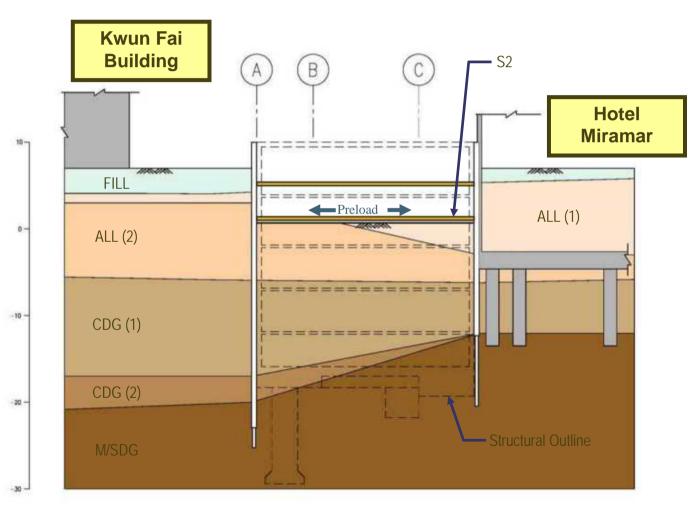


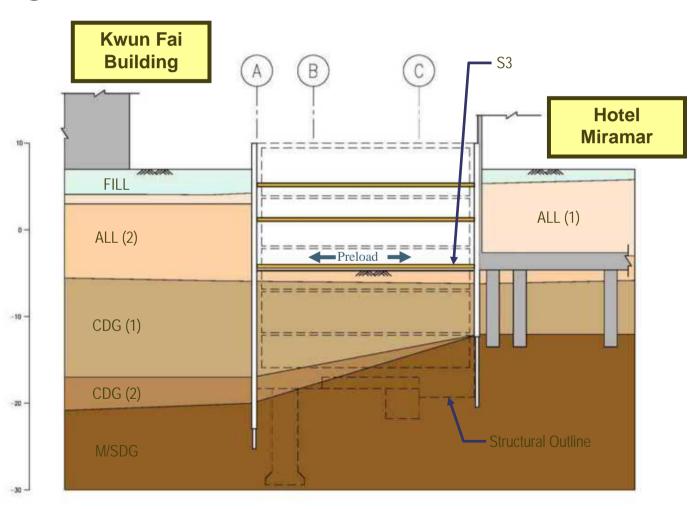
\*\* 610 pipe toe at rock + UC section into rock

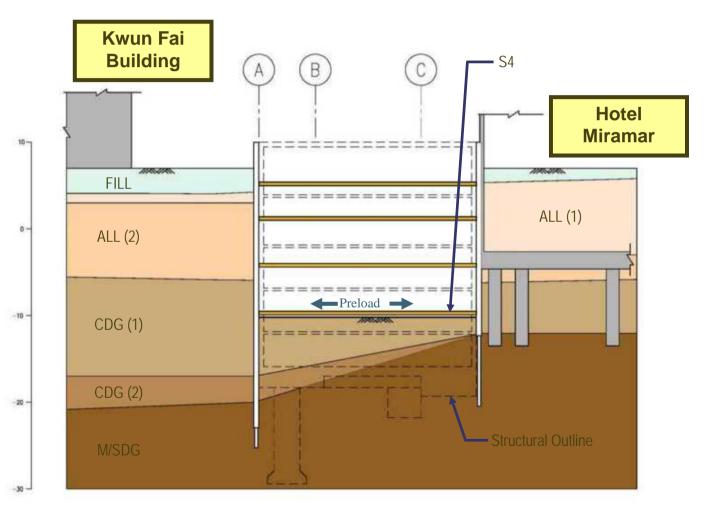


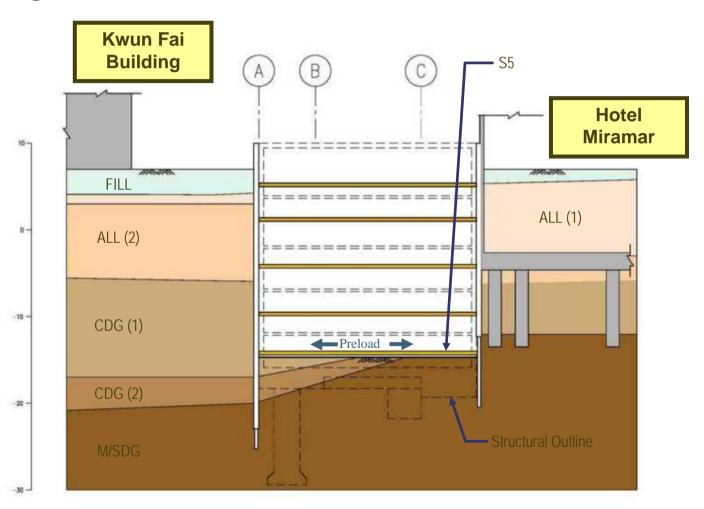


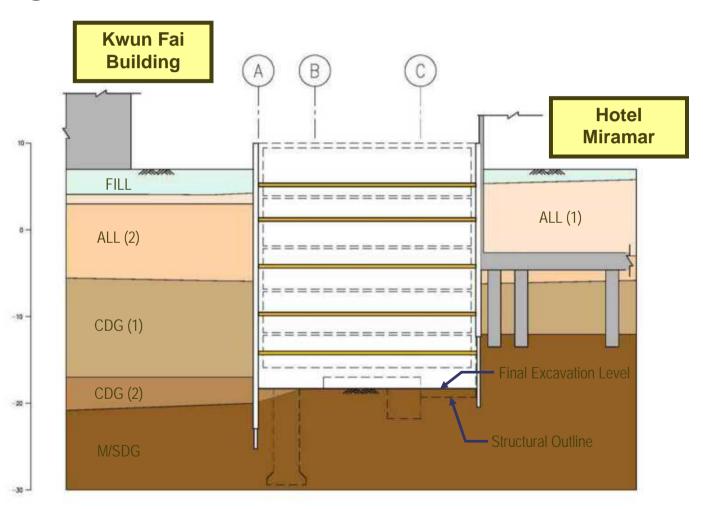


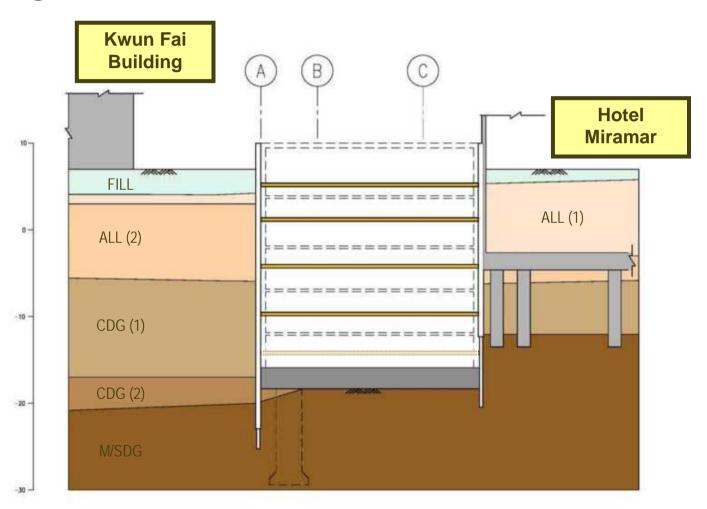


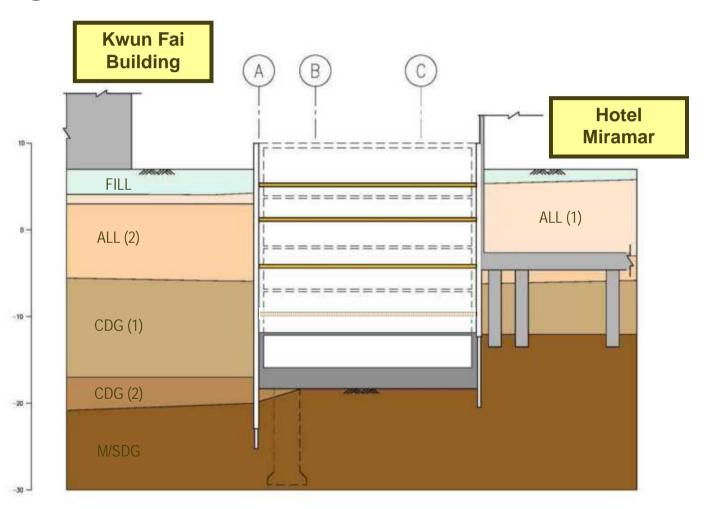


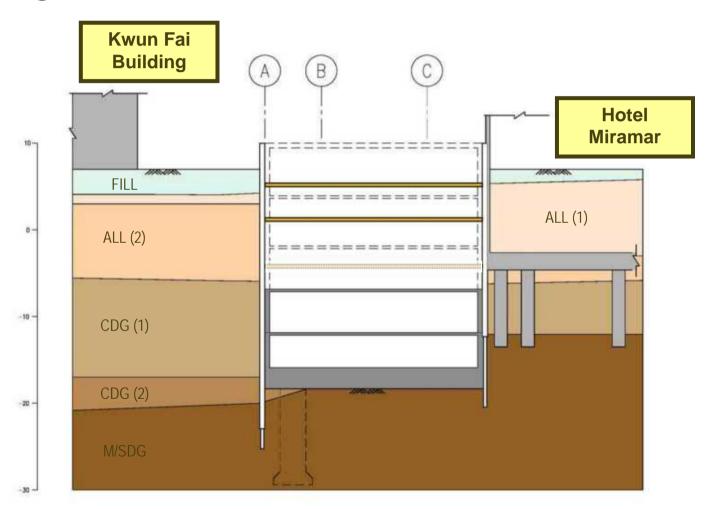


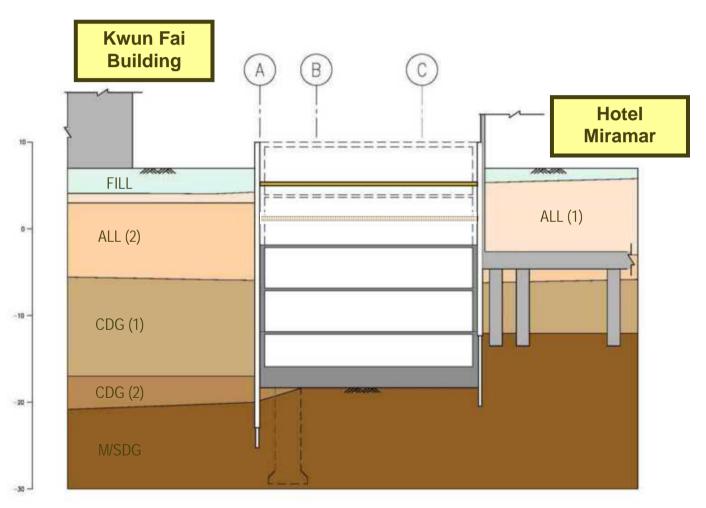


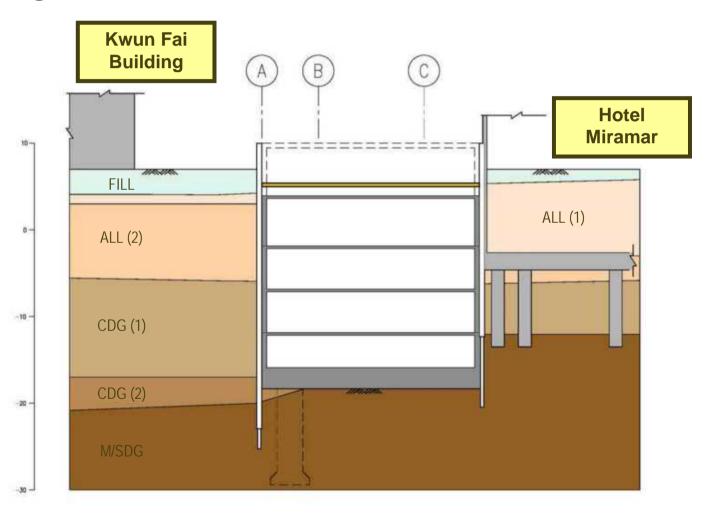


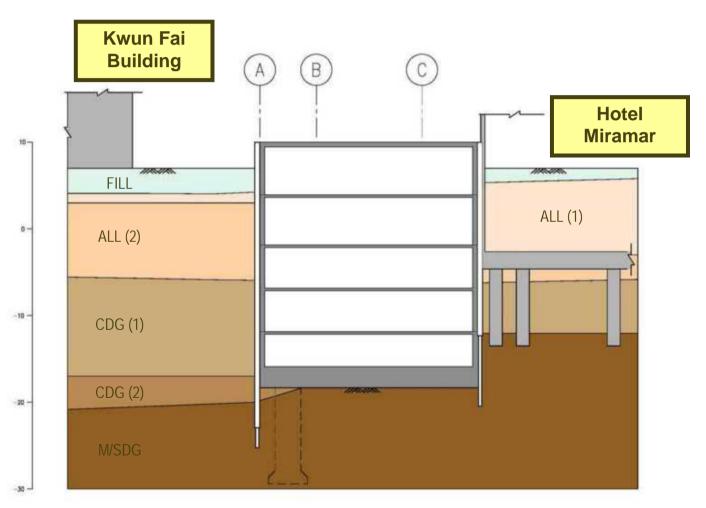


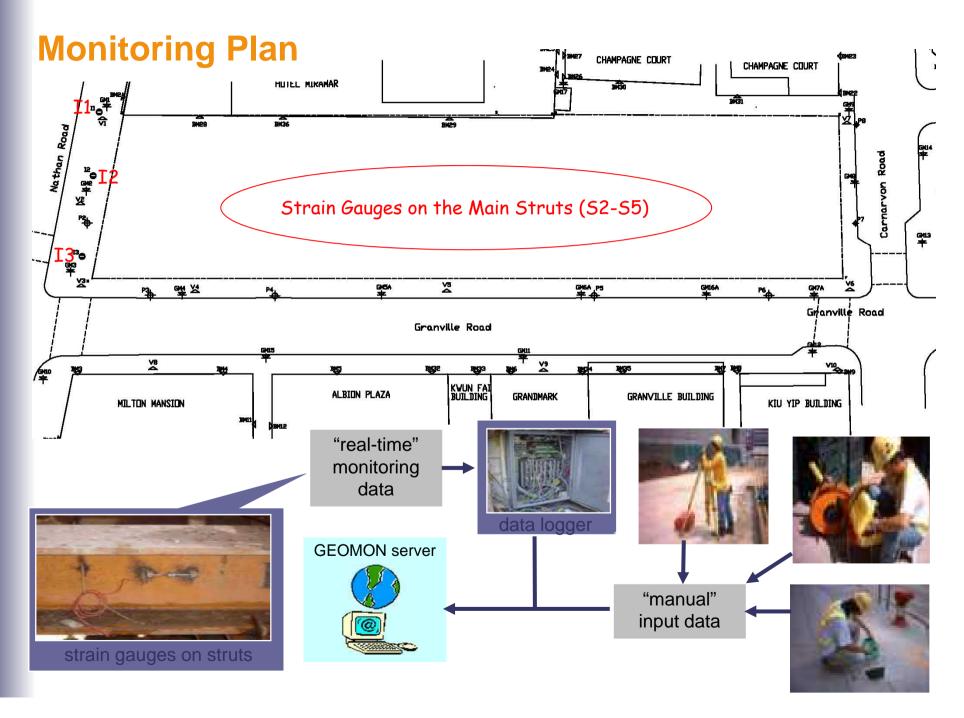


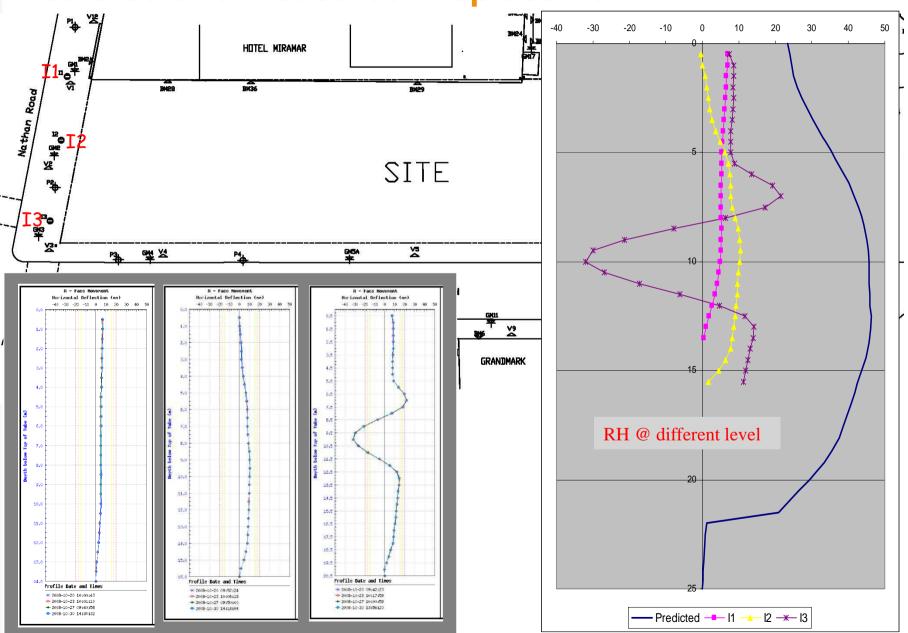






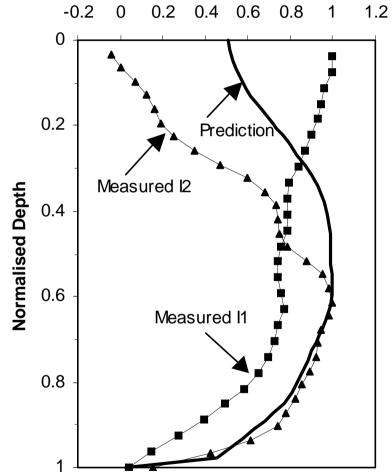






#### **Predicted and Measured Displacement**

#### **Normalised Deflection**

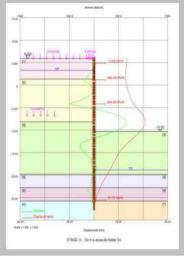


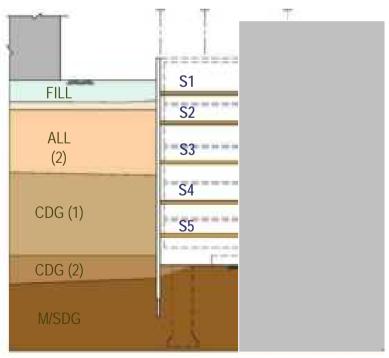
Prediction	Measured	Location of Inclinometer Along Nathan Road
<b>46mm</b> (RH @ 22m)	10mm	I2 – at middle portion of the cofferdam (RH @16.5m)
<b>36mm</b> (RH @16.5m)	7mm	I1 – at the corner of the cofferdam wall (RH @ 12.5m)

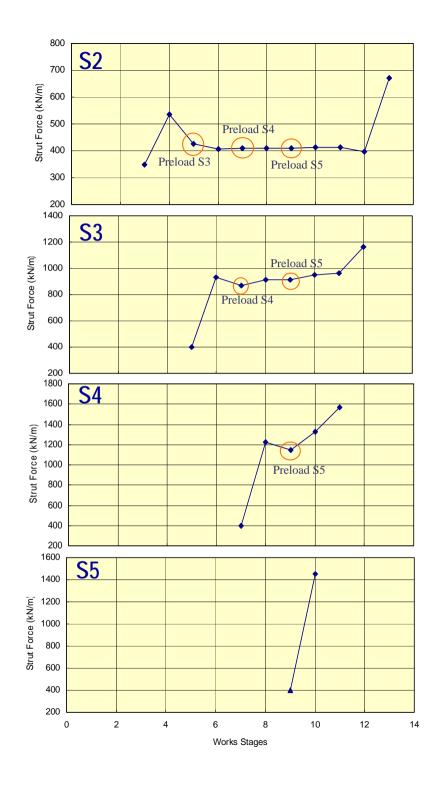
Max Predicted Settlement (mm)	Max Measured Settlement (mm)	% of Predicted Settlement
19	10	52%

#### **Predicted Strut Forces**

FREW Model

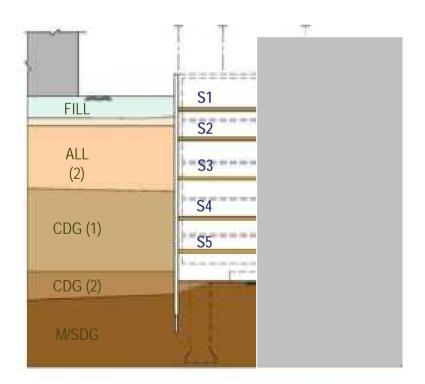


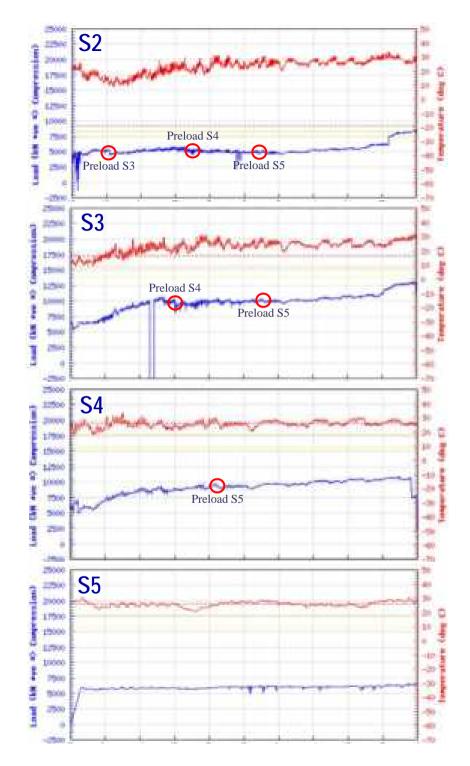




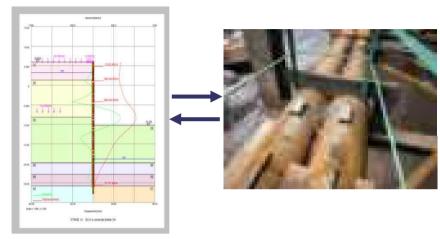
Strain Gauges SG3

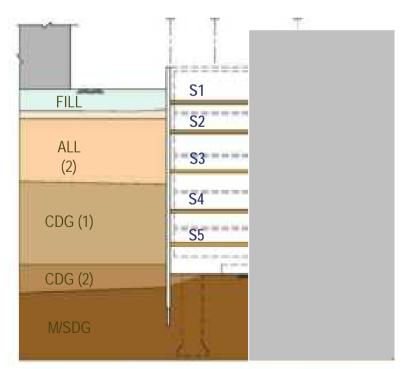


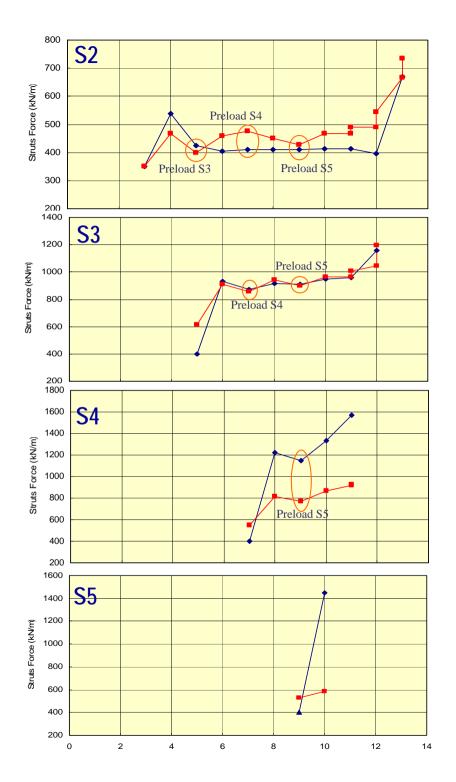


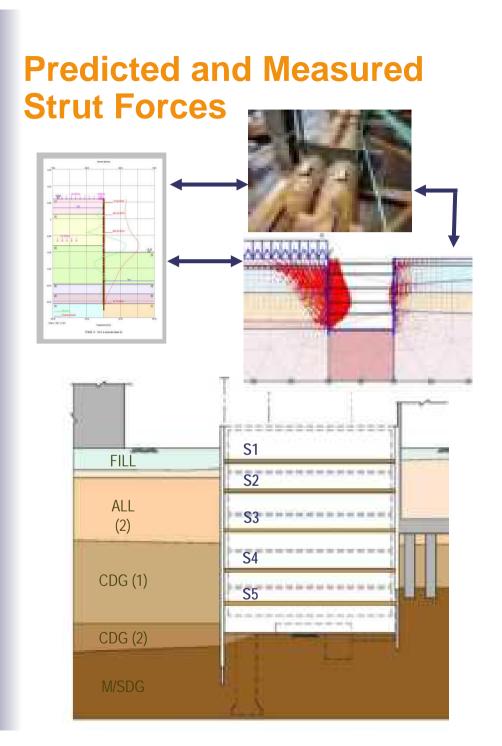


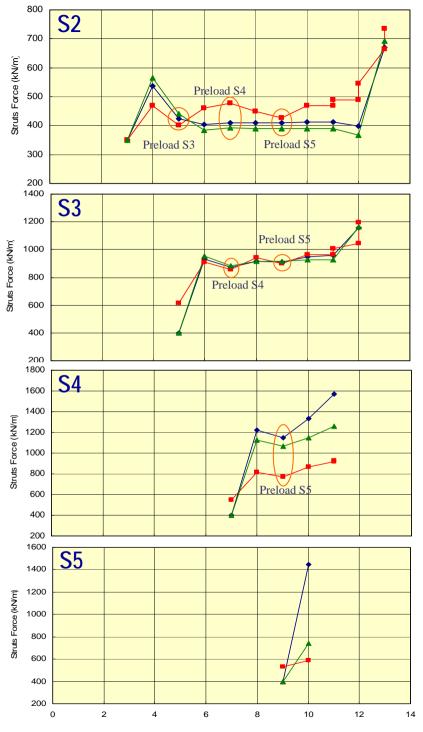
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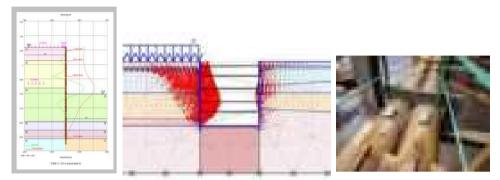








Max Predicted Settlement (mm)	Max Measured Settlement (mm)	% of Predicted Settlement
21	15	70%



Strut Layer	% Difference Measured / FREW	% Preload / Max. Load** (FREW)
S2	± 15%	65%
S3	± 5%	41%
S4	64%	30%
S5	40%	28%

Strut Layer	% Difference Measured / PLAXIS	% Preload / Max. Load** (PLAXIS)
S2	± <b>20</b> %	62%
S3	± 4%	42%
<b>S4</b>	73%	35%
S5	79%	54%

<sup>\*\*</sup> Max. Strut Load of Excavation Stages Only

## .... Is my geotechnical modeling conservative or aggressive?



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#### ... does success means ...?



#### ... or this ...?

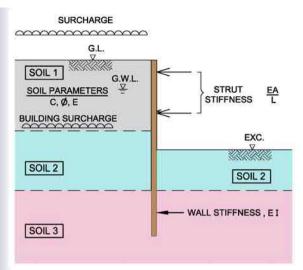


#### ... or this ...?



#### ... or this ...?





one piece of puzzle in geotechnical modeling – specified & verified during works





## Mohr Coulomb Model and Dilation Angle – Do you really understand?

Ryan Yan
Dept. of Civil Engineering
The University of Hong Kong

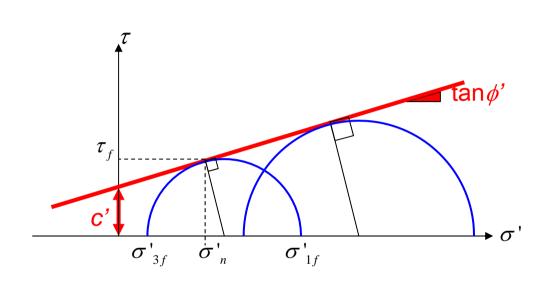


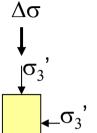
#### **Agenda**

- Mohr Coulomb "Model"
- Dilation Angle
- What's Wrong !?
- Concluding Remarks



#### **Mohr Coulomb Model**





What did we learn in BEng



$$\tau_f = c' + \sigma' \tan \phi'$$

The so-called "model" only gives us the shear strength (yield criteria) of the material!!

i.e., 
$$\tau < \tau_f(OK)$$
;  $\tau = \tau_f(FAIL!!)$ 

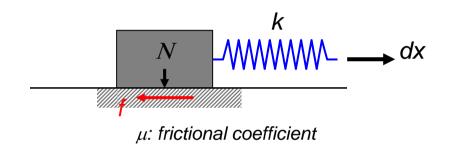
**Pre-yield behaviour?** 

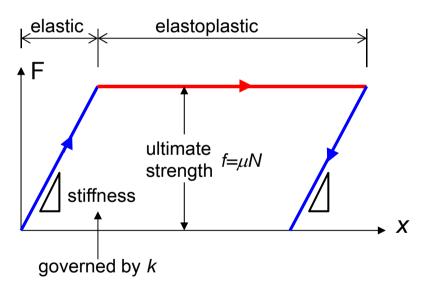




#### **Elasto-plastic Model**

- Elastic region
- Failure (yield) criteria





Stress-strain-strength response is completed only if both elastic and plastic behaviour are fully described !!



#### **Elastic Part**

Isotropic linear elastic

$$[\delta \mathbf{\sigma}] = [\mathbf{C}][\delta \mathbf{\varepsilon}]$$

$$\mathbf{C} = \mathbf{C}(E, v)$$

where E and v are constants

Isotropic nonlinear elastic

$$[\delta \sigma] = [C][\delta \varepsilon]$$

$$\mathbf{C} = \mathbf{C}(E, v)$$

where E and v vary with material state

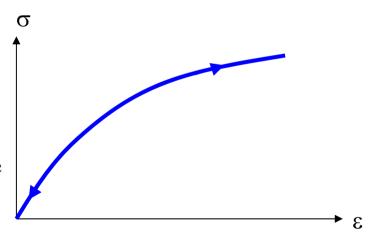
e.g., 
$$E=E(\sigma,\Lambda)$$

Anisotropic linear elastic

$$[\delta \mathbf{\sigma}] = [\mathbf{C}][\delta \mathbf{\varepsilon}]$$

$$\mathbf{C} = \mathbf{C}(E_{11}, E_{22}, v_{11}, v_{12}, etc)$$

i.e., E and v depend on the orientation



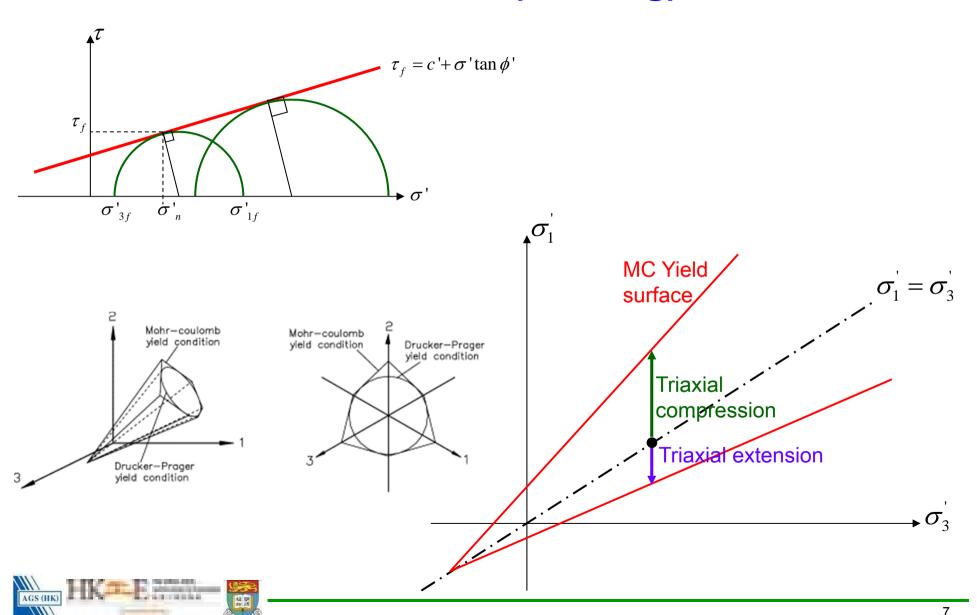
#### **Poisson's Ratio**

Poisson's ratio – could it be negative?

Auxetic material

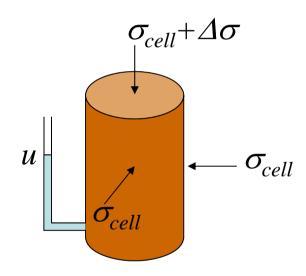


#### **Plastic Part (Yielding)**



#### **Mohr Coulomb Material upon Yielding**

- Simple test helps to understand the model response
- Triaxial test





#### **Quick Review on Triaxial Compression**

Stress tensor 
$$\boldsymbol{\sigma} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix}$$

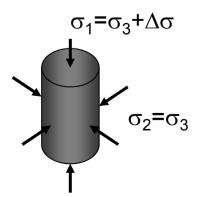
Often omitted for simplicity

$$p' = \frac{tr(\sigma')}{3} = \frac{\sum_{i} \sigma_{ii}}{3} = \frac{\sigma_{ii}}{3} = \frac{1}{3} (\sigma'_{1} + 2\sigma'_{3})$$

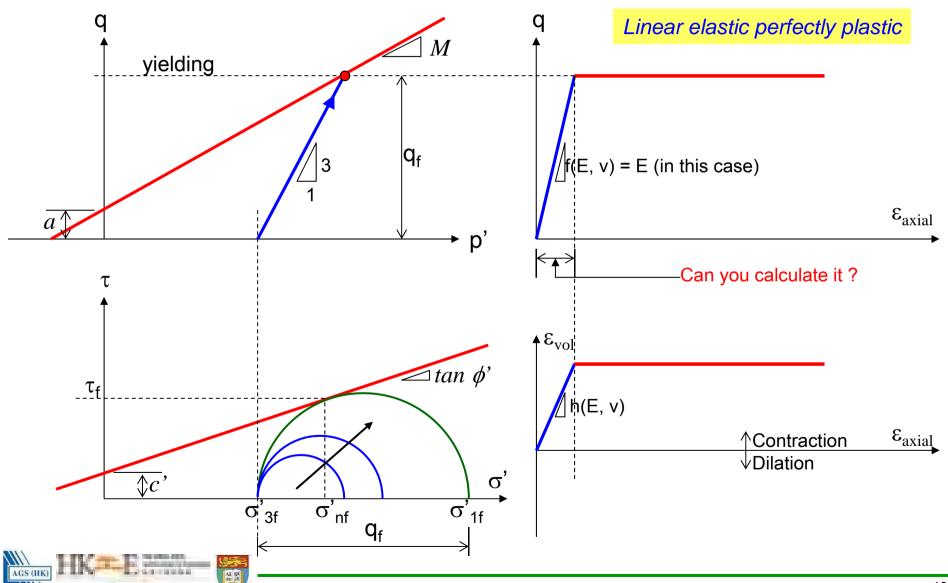
$$q = \sqrt{\frac{3}{2}\mathbf{s} : \mathbf{s}} = \sqrt{\frac{3}{2}s_{ij}s_{ij}} = \boxed{\sigma'_1 - \sigma'_3}$$
 Triaxial condition where  $\sigma_2 = \sigma_3$ 

$$\mathbf{s} = \mathbf{\sigma}' - \frac{tr(\mathbf{\sigma}')}{3}\mathbf{I}$$

Physical meanings of p and q!!



#### **Drained Triaxial Compression - MC**



#### **Drained Triaxial Compression – Elastic Part**

 For simplicity, let's assume that the material follows an isotropic linear elastic model prior to failure (plastic). Under the triaxial condition, we have

Fully drained condition implies "a constant difference between  $\sigma$  and  $\sigma$ '", i.e.,  $\Delta u=0$ 

$$\begin{bmatrix} \Delta \varepsilon_{a} \\ \Delta \varepsilon_{r} \\ \Delta \varepsilon_{r} \end{bmatrix} = \frac{1}{E} \begin{bmatrix} 1 & -v & -v \\ -v & 1 & -v \\ -v & -v & 1 \end{bmatrix} \begin{bmatrix} \Delta \sigma_{a} \\ \Delta \sigma_{r} \\ \Delta \sigma_{r} \end{bmatrix}$$
 with initial stress:  $\sigma_{a} = \sigma_{r} = \sigma_{cell}$ 

$$\Rightarrow \begin{bmatrix} \Delta \varepsilon_{a} \\ \Delta \varepsilon_{r} \\ \Delta \varepsilon_{r} \end{bmatrix} = \frac{1}{E} \begin{bmatrix} 1 & -v & -v \\ -v & 1 & -v \\ -v & -v & 1 \end{bmatrix} \begin{bmatrix} q_{f} \\ 0 \\ 0 \end{bmatrix} \Rightarrow \Delta \varepsilon_{a} = \frac{1}{E} q_{f}; \quad \Delta \varepsilon_{r} = \frac{-v}{E} q_{f}$$
Known (see previous page)

$$\Delta \varepsilon_{vol} = \Delta \varepsilon_a + 2\Delta \varepsilon_r = \frac{\left(1 - 2v\right)}{E} q_f$$

What happens if

v=0.2 ?

v=0.5 ?

In a triaxial drained compression test:

Change in the radial stress is zero

Change in the radial effective stress is also zero



#### **Undrained Triaxial Compression – Elastic Part (1)**

 Under an undrained condition, volume change is zero and we expect to see the generation of pwp.

We are looking at the effective stress!!

Initial stress: 
$$\sigma_a = \sigma_r = \sigma_{cell}$$

$$\begin{bmatrix} \Delta \varepsilon_{a} \\ \Delta \varepsilon_{r} \\ \Delta \varepsilon_{r} \end{bmatrix} = \frac{1}{E} \begin{bmatrix} 1 & -v & -v \\ -v & 1 & -v \\ -v & -v & 1 \end{bmatrix} \begin{bmatrix} \Delta \sigma_{a} \\ \Delta \sigma_{r} \end{bmatrix}$$
 Unknown

$$\Rightarrow \Delta \varepsilon_{a} = \frac{1}{E} \left( \Delta \sigma_{a}^{'} - 2v \Delta \sigma_{r}^{'} \right); \quad \Delta \varepsilon_{r} = \frac{1}{E} \left( -v \Delta \sigma_{a}^{'} + (1-v) \Delta \sigma_{r}^{'} \right)$$

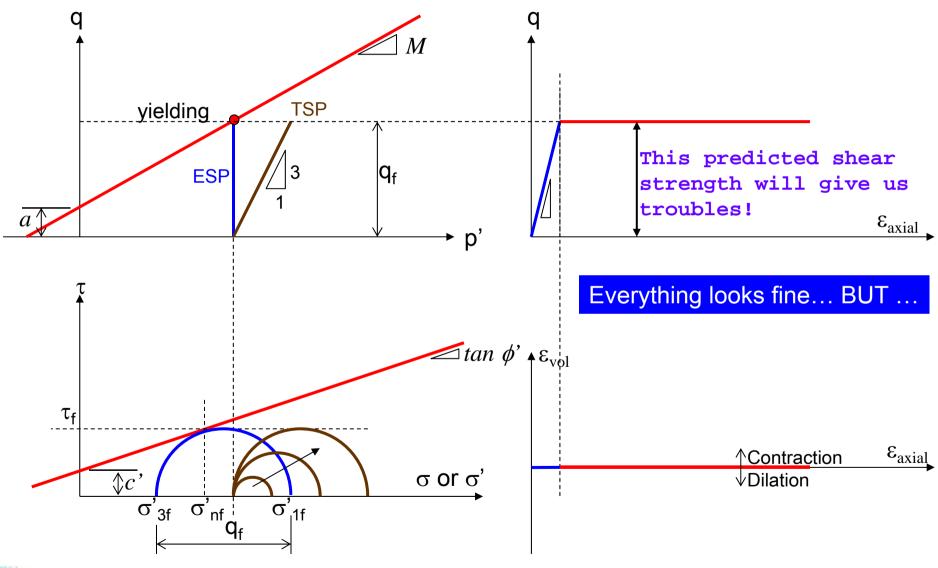
$$\Delta \varepsilon_{vol} = \Delta \varepsilon_a + 2\Delta \varepsilon_r = \frac{3(1-2v)(\Delta \sigma_a + 2\Delta \sigma_r)}{E} = \frac{1}{K} \Delta p'$$

To give zero volume change for a finite value of  $K(K \text{ in this case should be calculated by say v=0.2-0.3 but not 0.5)}, <math>\Delta p$ ' must be 0.

In other words, the no-volume-change condition imposes a constraint to the mean effective stress increment.



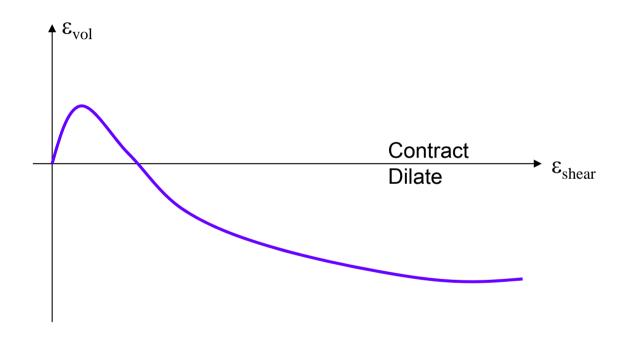
#### **Undrained Triaxial Compression – Elastic Part (2)**





#### **Angle of Dilation**

Dense sand / OC clays dilate upon shearing !!

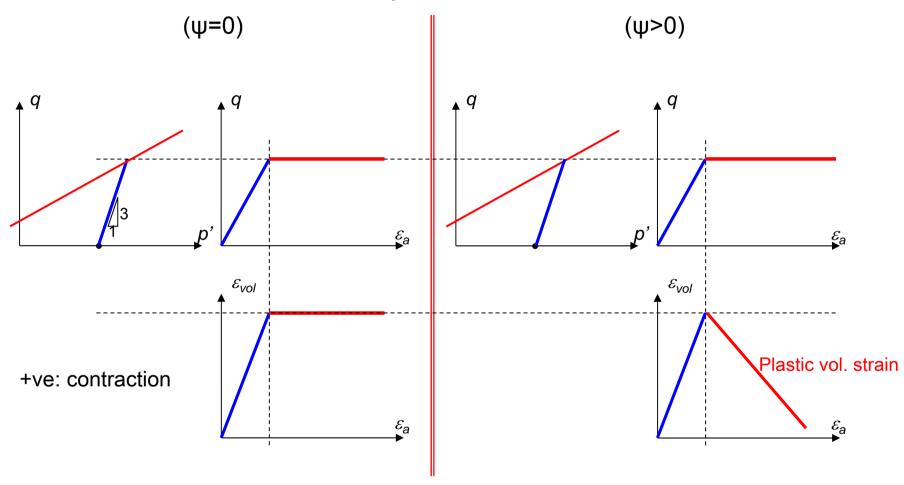


Could we capture the behaviour by slightly modifying the simple elasto-plastic model ?!



#### **Angle of Dilation + Mohr-Coulomb (1)**

Dry material

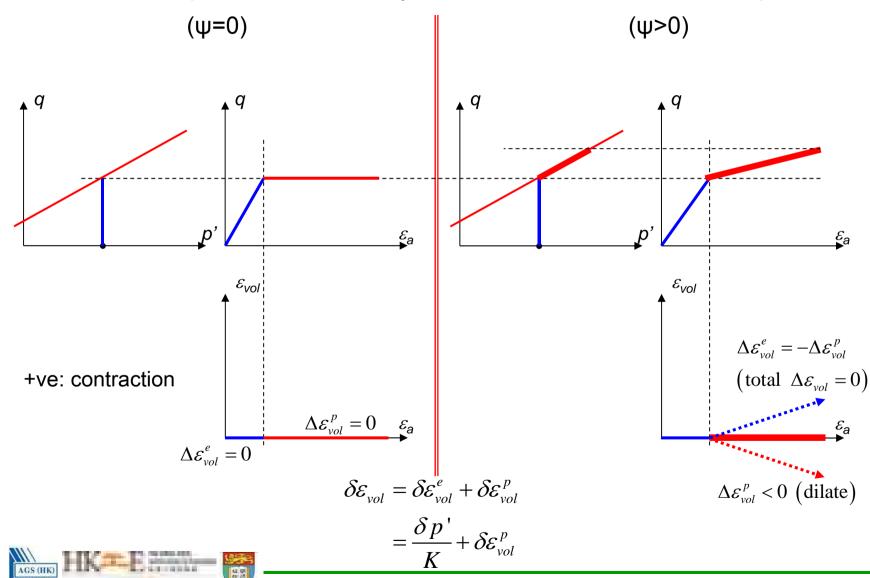


How about saturated material under a fully drained condition?



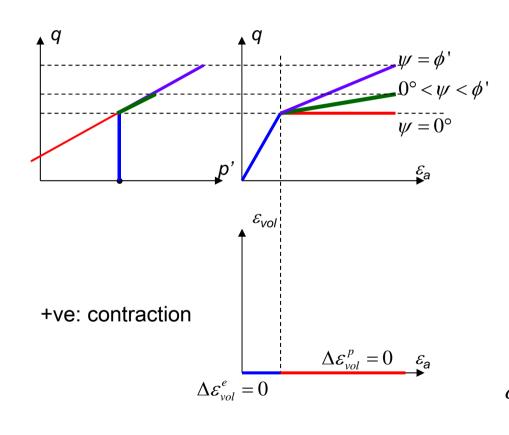
#### **Angle of Dilation + Mohr-Coulomb (2)**

Fluid-coupled undrained analysis. PWP is allowed to be developed.



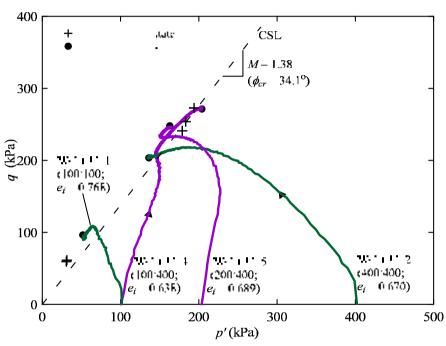
#### **Angle of Dilation + Mohr-Coulomb (3)**

#### Magnitude of dilation angle

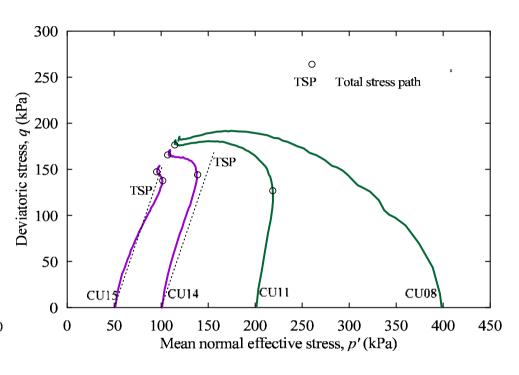




#### **Soil Response**



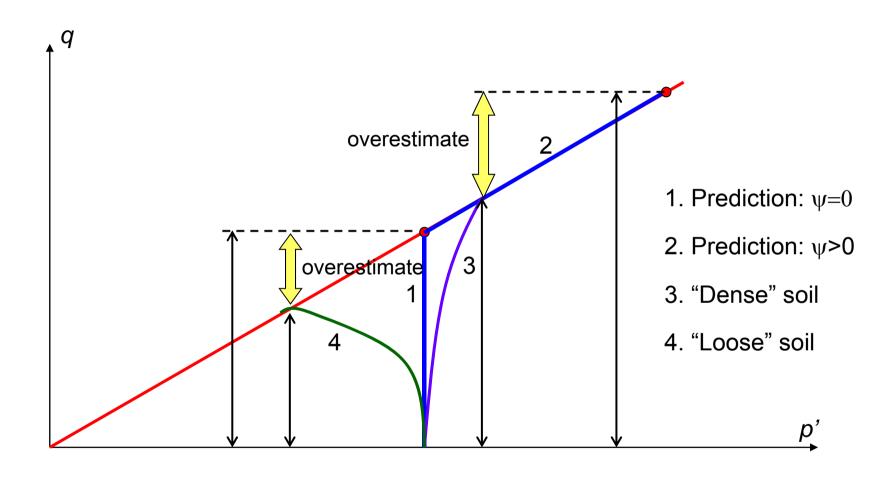
Wang, YH and Yan, WM. (2006). Laboratory studies of two common saprolitic soils in Hong Kong. J. Geotech. Geoenviron. Eng ASCE 132(7), 923-930.



Yan, WM and Li XS. (2012). Mechanical response of a medium-fine-grained decomposed granite in Hong Kong. Eng. Geol. 129-130, 1-8.

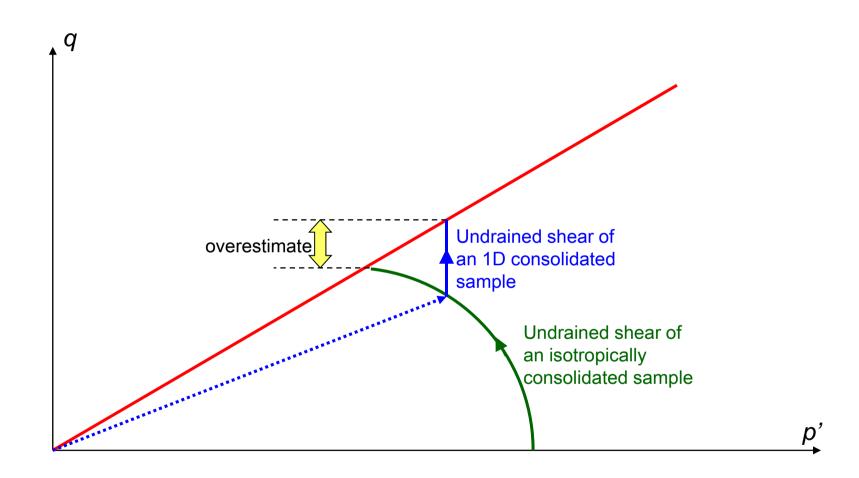


#### **Implications (1)**





#### **Implications (2)**





#### **Way Forward**





#### **Some thoughts**

Did you verify your understanding of the numerical software and material model that you are using, by say simulations of simple boundary value problems, prior to the modeling a complex soil-structure interaction problems including perhaps soil, pile, tunnel, retaining wall, nails, etc?

Do you understand your input parameters?





Ryan Yan ryanyan@hku.hk





### AGS, HKIE & HKU 1-day Seminar on Geotechnical Computer Modelling

Recent Experiences of Numerical Prediction & Assessment

– Excavation over a Tunnel of Unbolted Segmental Tunnel Lining

By Leslie Swann & J.B. Wang etc. Jacobs (China) limited





#### **Introduction:**

- A 700 m long Grade Separated Road (GSR) links the new Terminals to a new set of remote stands at an Airport in UK.
- GSR involves excavation adjacent to and over the existing live underground tunnels.
   which were built in the 1970s using an unbolted concrete segmental tunnel lining.
- 3D model together with a series of 2D models were developed to investigate the impacts on the unbolted concrete segmental tunnel lining from the GSR work.
- Both short and long term behaviour of the existing underground tunnels during and after the GSR construction was examined,
- GSR construction scheme was developed to minimise the impacts on the existing tunnels.



Figure 1 Proposed GAR – Layout Plan & Longitudinal Profile





#### **Constraints & Concerns:**

- the existing underground tunnels were built in the 1970s using an unbolted concrete segmental tunnel lining.
- Construction of the GSR involves excavation adjacent to and over the existing live underground tunnels.
- The GSR ramp crosses over the tunnels at an angle of 57 degrees and then runs approximately parallel to the tunnels with a minimum 4.3 m spacing.
- Heaving / ground movements due to the excavation causes deformation of the existing tunnels;
- Differential /distortion of the tunnel may cause damage of the live tunnel during and after the GSR construction.
- Therefore the excavation for the GSR, over and adjacent to the live tunnels, causes great concern over safe operation of the trains.





#### **Site Conditions:**

- The GSR is about 700 m in length and 12 m wide, lying above the existing live tunnels. The GSR ramp is about 3 m to 8m deep.
- The GSR ramp crosses over the tunnels at an angle of 57 degrees and then runs approximately parallel to the tunnels with a minimum 4.3 m spacing.
- The ID of the existing tunnels is 3.81 m, formed by 22 numbers of precast concrete segments. The tunnel rings are approximately 0.6 m long and 152.5 mm thick.
- Visual inspection of the running tunnels found the tunnel was in reasonably good condition generally.
- The circularity and gauge survey shows that section of the crown tunnel is out by 10-15 mm which equates to between 0.26% and 0.39% of the diameter.
- Airbus A380 / Boeing 747 aircraft loading of total 9000 kN is considered in the design of the bridge and retaining walls.



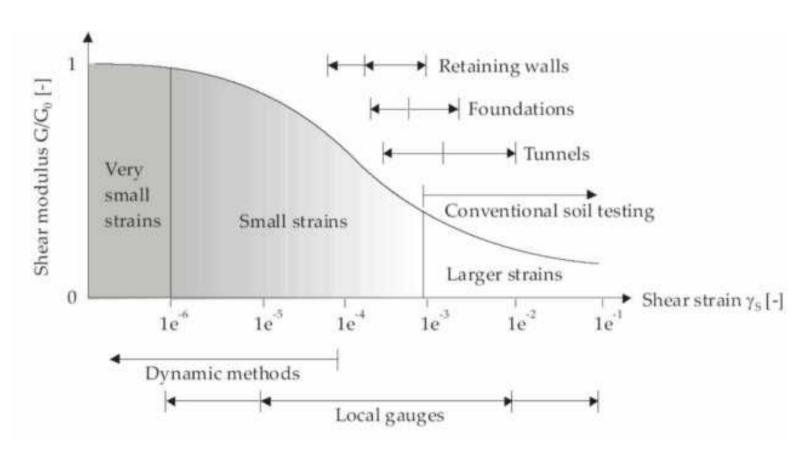


### **Ground & Groundwater Condition**

Ground level at 23.1m AOD
22m AOD
= 21m AOD
18m AOD
-40m AOD

Lambeth Group /Upper Chalk





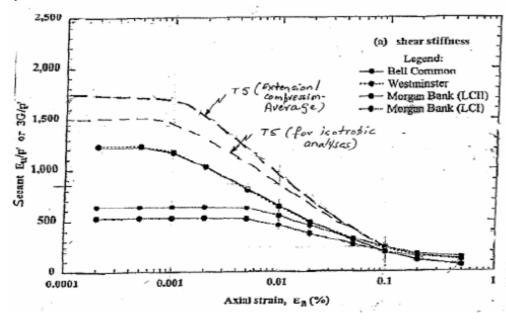
Stiffness-strain behaviour of soils for laboratory tests and application strain range of structures.





#### **Small strain stiffness of London Clay**

- London Clay has highly nonlinear elastic properties strong dependency of the soil stiffness on the strain levels experienced;
- higher stiffness at lower strains;
- The small strain stiffness characteristics of London Clay were studied in Lab testing under undrained triaxial loading; reconsolidated to its estimated in situ stresses;
- 4 pairs of Undrained triaxial tests on 100 mm diameter by 200 mm high rotary cored samples tested;







### **Proposed Construction Scheme:**

- Construction of the proposed GSR involves the installation of 900mm diameter embedded secant pile retaining walls, casting bridge decks across the underpass sections, and subsequent excavation within the walls to depths of up to 11m with temporary propping, in places, to reach formation level for casting the base slab.
- The secant piles above the tunnels will terminate at approximately 6 m above the tunnels and the piles shall also be a minimum of 3 m away from the tunnel structure as required by the tunnel exclusion zone.
- One to two layers of temporary props are proposed to support the secant pile walls during GSR construction. At the underpass area, with a bridge deck at the top, no props are proposed during excavation. Construction of the GSR shall adopt top-down method under the bridge deck and bottom-up construction sequence for other parts.





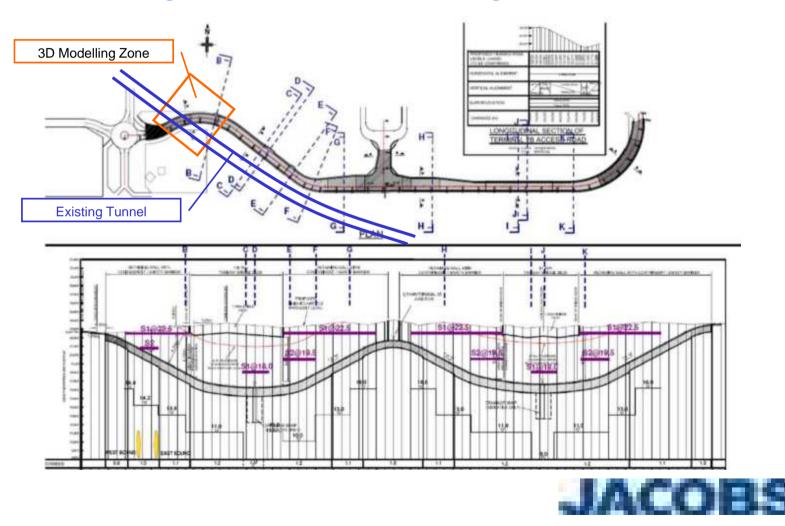
### **Numerical Analyses for GAR Construction**

- Plaxis 2-D Numerical analyses were carried out at selected critical sections to estimate the associated ground movements and to assess the impacts to the underground line.
- The western ramp of the GSR crosses over the existing tunnels at a skew, which requires a more sophisticated study. A three-dimensional numerical model was developed and analysed with Finite difference software FLAC 3D version 3.1.
- This presentation concentrate on Flac 3D modelling only.





### 2D Design Sections and 3D Modelling Zone





### **Development of Flac 3D Model**

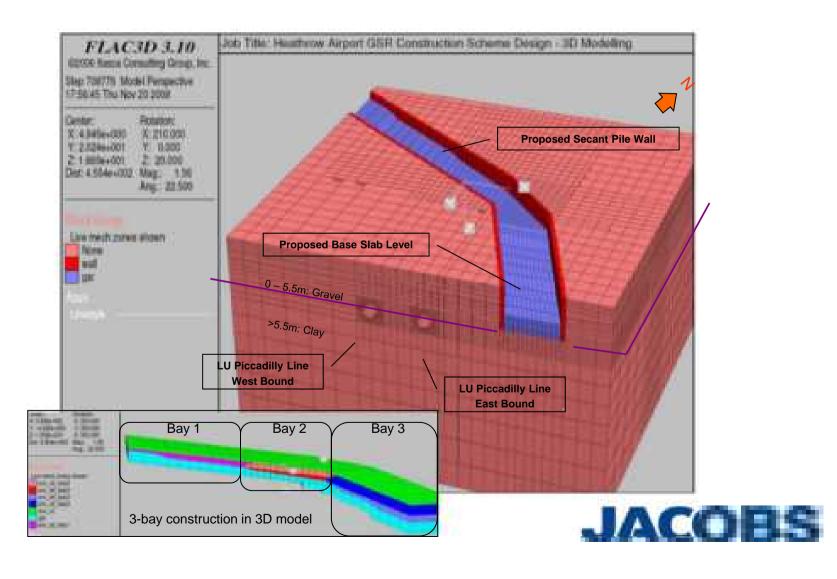
#### Modelling domain and boundary conditions

- The three-dimensional model developed is a rectangular block of 102 m long x 100 m wide x 63 m deep comprising a total of around 60,000 soil zones.
- The model simulates the western portion of the proposed GSR which runs above the existing twin tunnels at an acute angle, between chainage of 25 m and 135 m. A 100 m length of the twin tunnels are covered in the model, running parallel to the y-axis from y = -50 m to y = +50 m.
- For the four vertical external boundaries, horizontal movement perpendicular to the plane is restricted while movement in the plane of the vertical boundary is allowed.

  The vertical movement is not permitted at the base boundary of the 3D model.

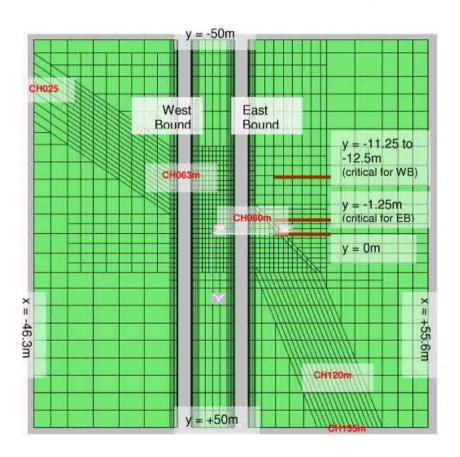


### **General view of FLAC 3D model**





### Plan view at 13.9 m bgl







### **Development of Flac 3D Model**

Soil Elements and Soil Properties in the Model

• The ground under consideration comprises London Clay overlain by Made Ground and River Terrace Deposit. A constitutive model of linear elastic perfectly-plastic with Mohr-Coulomb failure criterion was adopted for the Made Ground and the River Terrace Deposit. The nonlinear elastic properties of the London Clay shows a strong dependency of the soil stiffness on the strain levels experienced. The nonlinear tangent elastic properties of the London Clay can be described by the following equations, given by Jardine et al (1986):

$$E_{u} = c_{u} \left\{ A + B \cos(\alpha I^{\gamma}) - \frac{B \alpha \gamma I^{\gamma - 1}}{\ln(10)} \sin(\alpha I^{\gamma}) \right\}$$
 (1)

where

*cu* = *undrained shear strength* 

 $I = log 10 (\varepsilon \alpha / C)$ 

A, B, C,  $\alpha$ ,  $\gamma$  = material-specific constants, and

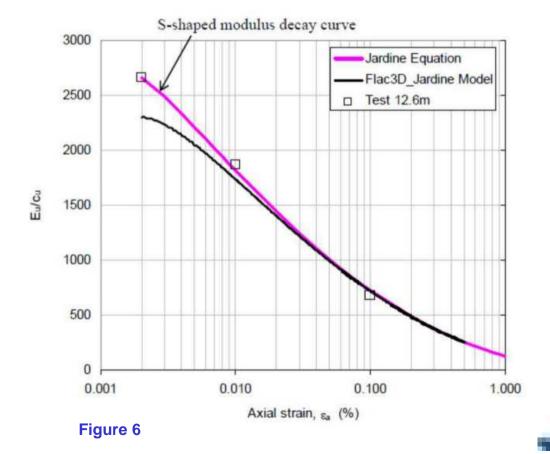
$$\varepsilon_a = \frac{\sqrt{2}}{3} \left\{ (\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2 + (\varepsilon_3 - \varepsilon_1)^2 \right\}^{0.5}$$

 $\varepsilon 1$ ,  $\varepsilon 2$ ,  $\varepsilon 3$  =  $\Box$  principal strains (or principal deviatoric strains)





• Comparison of secant Eu/Cu between Jardine's (1986) equation and Flac 3D-Jardine model :





The soil parameters adopted in the 3D model;

Table 1: Soil Parameters

Soil Type	γ (kN/m3)	υ' / υ	ko	c' /cu (kPa)	φ' (°)	E'/Eu (kPa)	K (m/s)
Made Ground & River Terrace Deposits	20	0.2	0 – 1.6mbgl: 0.5 1.6 – 5.5mbgl: 0.4	0	36	37500	2 x 10-4
London Clay	20	0.49	5.50 – 11.25mbgl: 2.6 11.25 – 31.75mbgl: 2.2 31.75 – 63.00mbgl: 1.2	Increase with depth (86 kPa at London Clay top)	-	nonlinear 2 x 10- strain- stiffness as in Equation 1	

Table 2: Jardine Model Parameters for London Clay

А	В	C(%)	α	γ	Emin (%)	Emax (%)
1350	1350	0.001	1.319146	0.66336	0.0011	0.3





### **Development of Flac 3D Model**

### Tunnel Lining in the Model

 The existing tunnel lining comprises 22 unbolted pre-cast concrete segments with a ring length of 600mm. Since it is impractical and unnecessary to build a 3D model with those lining segments modelled precisely, an "equivalent stiffness method" by Muir Wood (1975) is adopted, which suggests:

```
le = ljoint + (4 / n)2 x Isegment (2)
where
```

le = equivalent moment of inertia for a continuous "liner" element in model
ljoint = moment of inertia of joints between lining segments (= 0 if no structural connection)
lsegment = moment of inertia of segments

n = number of segments (n = 22 in current case)

 The tunnel lining were modelled as a liner structure element in the FLAC 3D model that can take the tunnel hoop stress, bending moment and shear stress and also friction between the soil and the tunnel lining. The secant pile wall and base slab of the GSR were also modeled as liner structure elements.

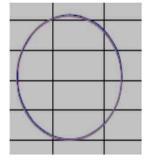




### **Development of Flac 3D Model**

#### Proposed works and modelling sequence

- (a) Establishing initial conditions
- To establish the existing conditions of the ground and the existing underground structures, the 3-D model was set up to include the major construction history of the existing tunnels including the construction year and tunnel face volume loss during tunnelling.
- The tunnel construction stage is followed by long-term consolidation in which any excess pore pressure generated due to tunnel excavation would be fully dissipated.
- At existing condition, tunnel crown-invert predicted about 4mm moving apart; similar pattern as the circularity and gauge survey.







### **Development of Flac 3D Model**

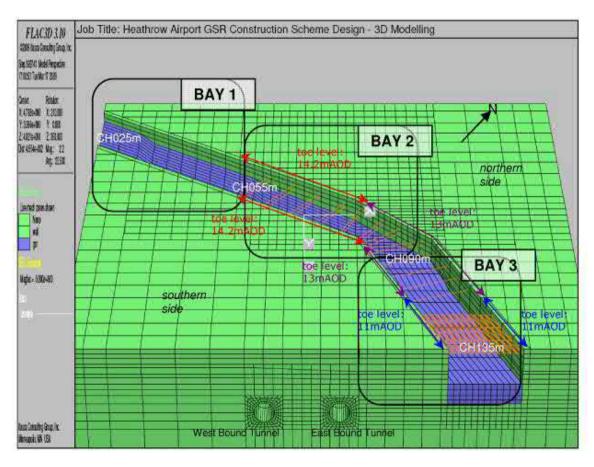
Proposed works and modelling sequence

- (b) Modelling of construction Sequence
- The excavation and GSR construction are designed to be carried out in 3 bays.
- Subsequent to the installation of secant pile wall which is assumed as "wished-inplace", excavation to 1mbgl and installation of the first layer struts and bridge deck are modelled.
- Construction of the GSR is then carried out bay by bay in three stages as shown in Figures 7 to 9.
- Upon completion of base slab construction for the Bay 3, all struts would be removed.
   Construction of the airfield pavement would then be modelled.
- Finally, a long-term consolidation is then carried out. The construction stages modelled are detailed in Table 3.

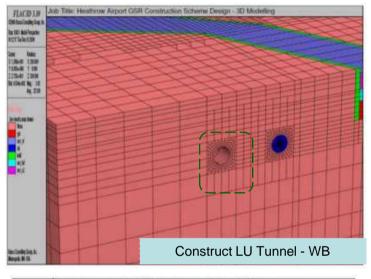


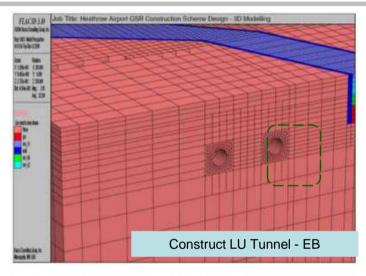


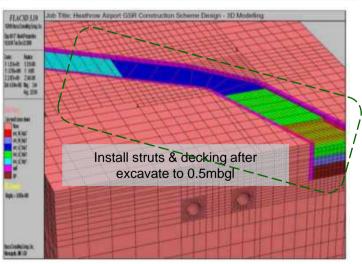
### 3-bay construction in FLAC 3D model

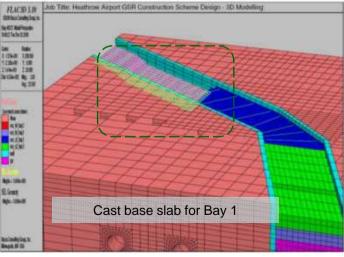






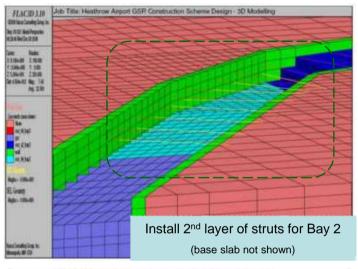


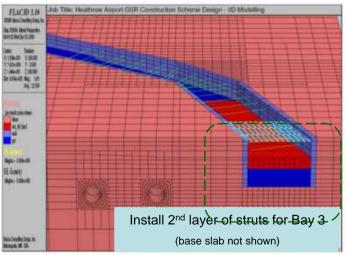


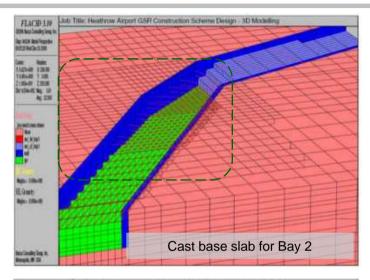


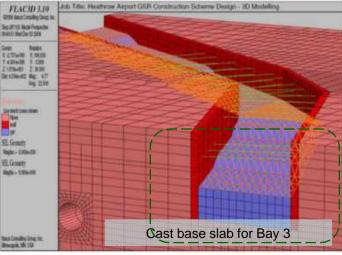
















### **Results and Discussion**

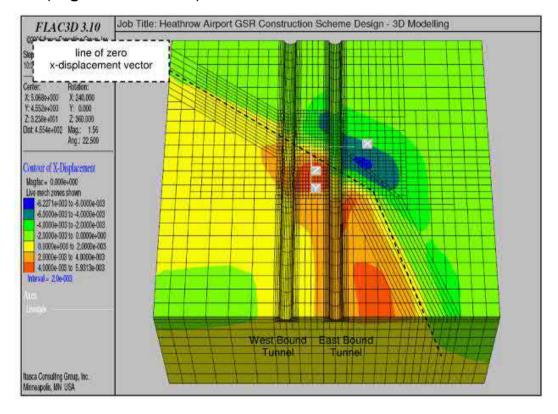
#### **Predicted Tunnel Movements**

- Long term ground movement in a horizontal plane shows that the line of zero transverse ground movement vector generally matches the centreline of GSR.
- The ground heave effect including ground movement towards the excavation from both sides;
- Maximum tunnel lining deformation of the crown and invert along the east bound
   Tunnel occurs at the area where the proposed GSR runs across the EB Tunnel.
- An upward movement of around 8.5 mm and 1.8 mm at the crown and invert, giving a differential vertical movement of 6.7 mm (moving apart).
- The maximum deformation occurs at the end of excavation in Bay 2, when the excavation is directly above the tunnel.
- The tunnel is squeezed horizontally by approximately 4.8 mm at the end of excavation in Bay 2.





• Above maximum differential lining deformation after excavation does not change much afterwards (Figures 14 &15).

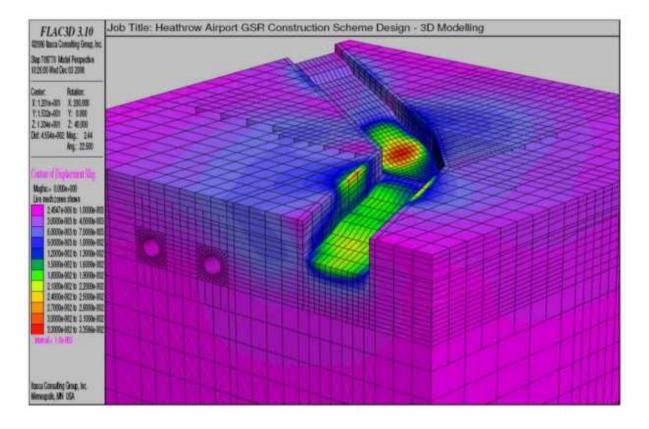


Contours of transverse ground movement in horizontal plane



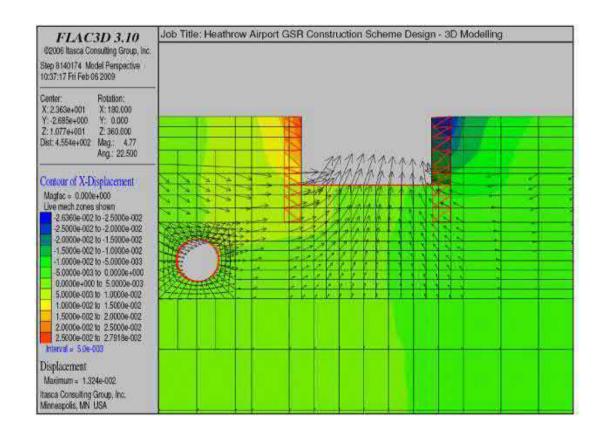


- 3D not only give movements on ground surface, but at all depth in 3D space;
- No approximation by interpolation between 2D design sections



Contours of ground movement - Zone of Influence



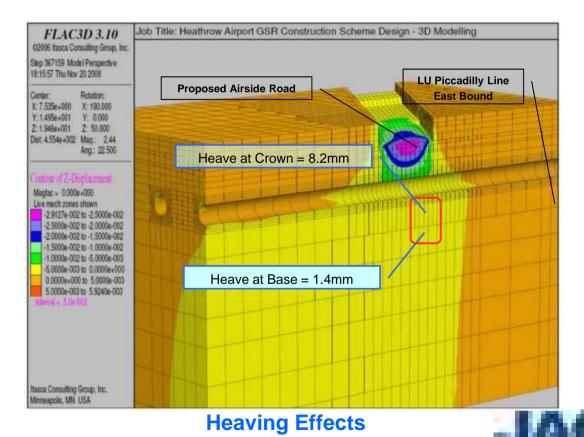


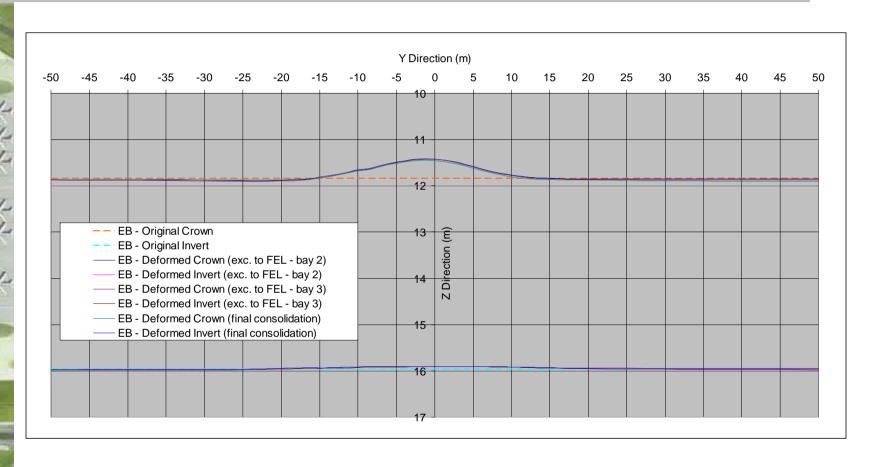
Contours of transverse ground movement in horizontal plane





- Critical East Bound (closer to deeper excavation)
- Maximum differential vertical movement between crown and base –
   6.7mm (displace apart, right beneath proposed excavation)

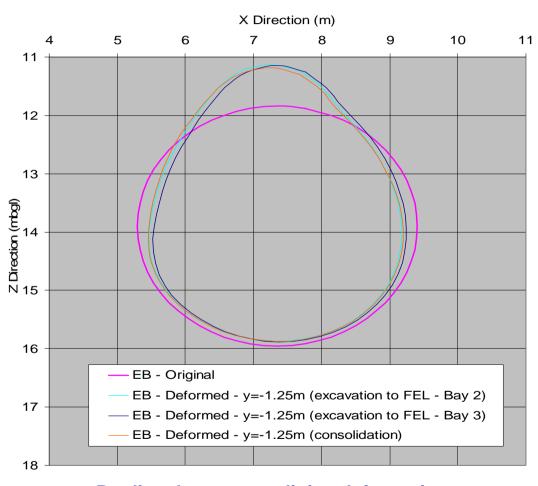




Predicted lining deformation along EB Tunnel (exaggerated by 30 times)







Predicted transverse lining deformation (exaggerated by 30 times)



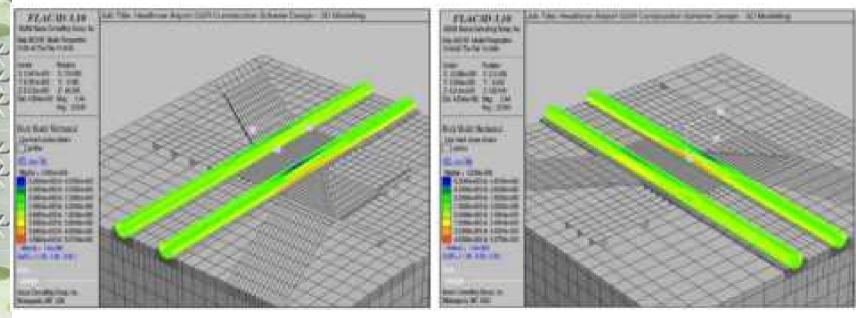


#### **Results and Discussion**

#### Predicted Tunnel Lining Forces

- The predicted bending moment of the tunnel lining in the transverse (hoop) direction after excavation completion remains small throughout the GSR construction as expected.
- The hoop force of the tunnel lining is reduced slightly after GSR excavation, from average 403 kN/m of the tunnel lining compression at the existing condition down to average of 397 kN/m.
- Therefore the overall structural force change of the existing tunnels associated with the proposed GSR construction is expected to be small.
- Estimated lining bending moment and hoop force at end of excavation to FEL in Bay
   3.

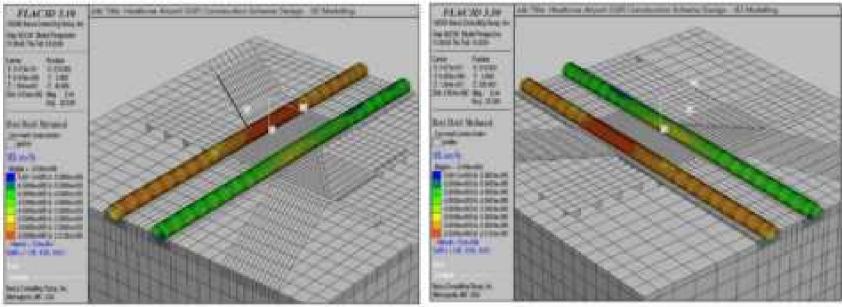




Estimated lining moment in transverse (hoop) direction at end of excavation to FEL in Bay 3







Estimated lining force in transverse (hoop) direction at end of excavation to FEL in Bay 3



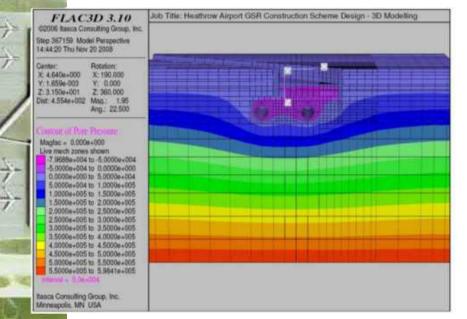


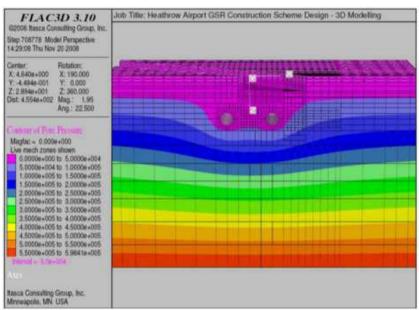
#### **Results and Discussion**

### Pore Pressure Change

- pore pressure changes cause volumetric strains to occur that influence stress;
   in turn, pore pressure is affected by the straining that takes place.
- Negative excess pore pressure is developed in London Clay due to clay swelling upon unloading in the undrained condition.
- Excess pore pressure would be dissipated within around 10 years time Contours of total pore pressure at the end of full consolidation.





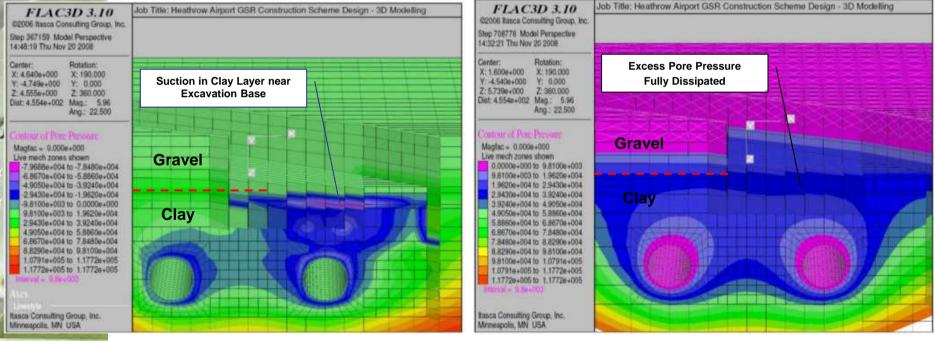


Total pore pressure immediately after construction

Total pore pressure after full consolidation







Total pore pressure immediately after construction (Immediate Response)

Total pore pressure after full consolidation (Long-term Response)



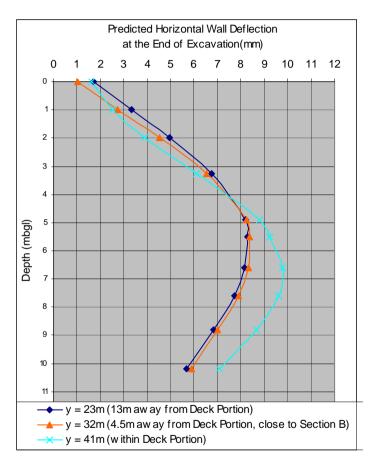


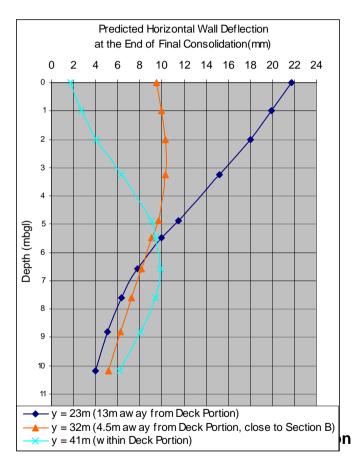
#### **Results and Discussion**

#### Wall Deflection from Flac 3D

- development of wall deflection at various locations during and after GSR construction, showing the restraining effects on the wall deflection from the bridge deck of the taxilane underpass.
- The predicted wall top deflection at the end of excavation from 3D modelling is similar at various locations.
- However, the long term wall top deflection developed from less than 2mm at the
  decking area, to around 9.5 mm and 22 mm respectively at 4.5 m and 13 m away
  from the underpass decking. Wall top deflected towards the excavation with the
  dissipation of the negative excess pore pressure.





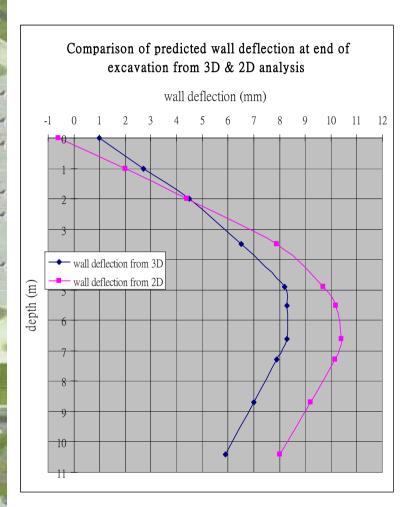


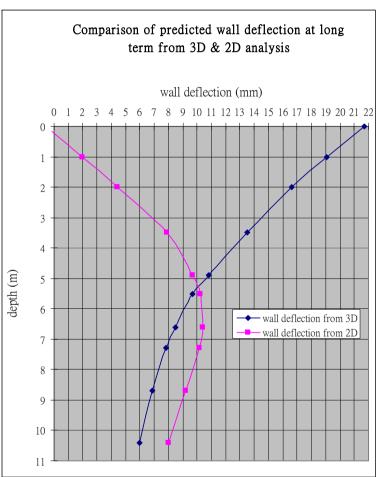
(a) During & immediate after GSR construction

(b) Long Term

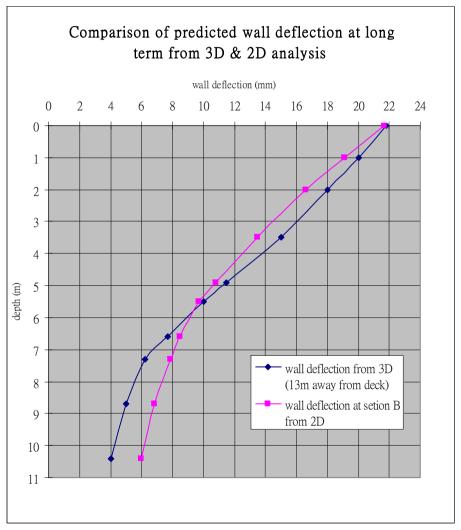
Development of lateral movements of the secant-pile wall















#### **Results and Discussion**

#### Wall Deflection – 2-D vs 3-D prediction

- 2D analysis at section B (4.5m away from the decking) was also carried out using geotechnical software Plaxis.
- The Plaxis 2D analysis adopted Hardening Soil Model with small strain stiffness (HSsmall) for London Clay while Mohr-Coulomb soil model was used for other soil stratus.
- The 2D analysis results give a wall top deflection of 23 mm at long term compared with less than 10mm predicted by 3D analysis.
- The 2D analysis of the section B is unable to consider the restraining effects from the adjacent underpass deck, hence significantly overestimate the wall movements.





#### **Results and Discussion**

#### Wall Deflection – 2-D vs 3-D prediction

- the wall top deflection from 3D modelling reached 22 mm at the location of about 13m away from the underpass deck, which is similar to the deflection of 23 mm predicted by 2D analysis at section B.
- Thus the restraining effect on the wall deflection from the underpass deck decreases to negligible at a distance of about 1.5 times of the retaining height away from the restraint.





#### **Conclusion**

- The 3D model analysis results suggest that the deformation of the segmental tunnel lining is small and the structural force change of the tunnel lining is also insignificant.
- The ELS scheme developed and the construction in sequential bays, the impact on the existing tunnels associated with the proposed GSR construction is expected to be small.
- Comparison of the 3D and 2D analysis results for the long term behaviour of the retaining wall near the underpass deck illustrated the 3D modelling ability to analysis problems in 3D environment.
- A 2D analysis for 3D problem case would overestimate the structural deformation and ground movements significantly.
- With the rapid development of computer speed and capacity, 3D modelling should be carried out to get a more realistic prediction of the structure / ground response.





## **Thank You**



# Large Cavern Design in Jointed Rock using Discrete Fracture Network and Numerical Modelling

#### Presented by:

Les McQueen (BSc (Hons), MAppSc, CPEng) | Principal | Golder Associates Pty Ltd 124 Pacific Highway, St. Leonards, New South Wales 2065, Australia (PO Box 1302, Crows Nest NSW 1585) E: Imcqueen@golder.com.au | www.golder.com

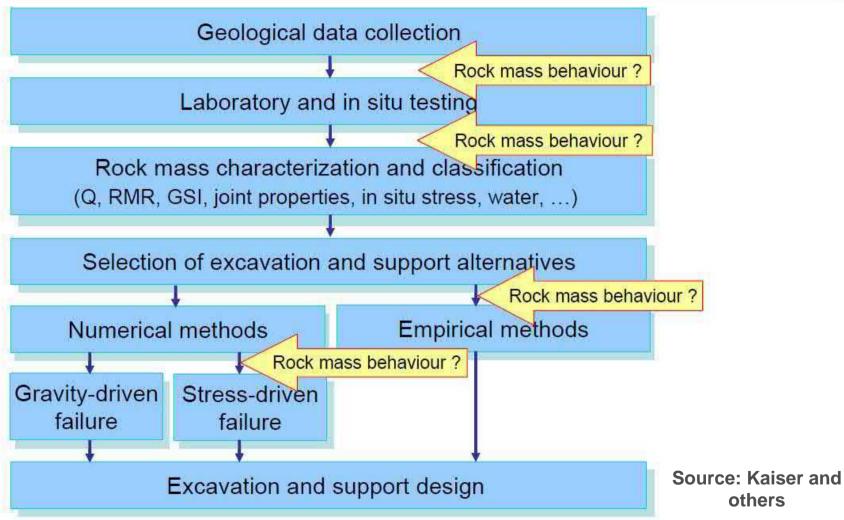
Ardie Purwodihardjo (BEng, MEng, MSc, PhD) | Principal | Golder Associates Pty Ltd 147 Coronation Drive, Milton, Queensland 4064, Australia (PO Box 1734, Milton BC, QLD 4064)

E: apurwodihardjo@golder.com.au | www.golder.com





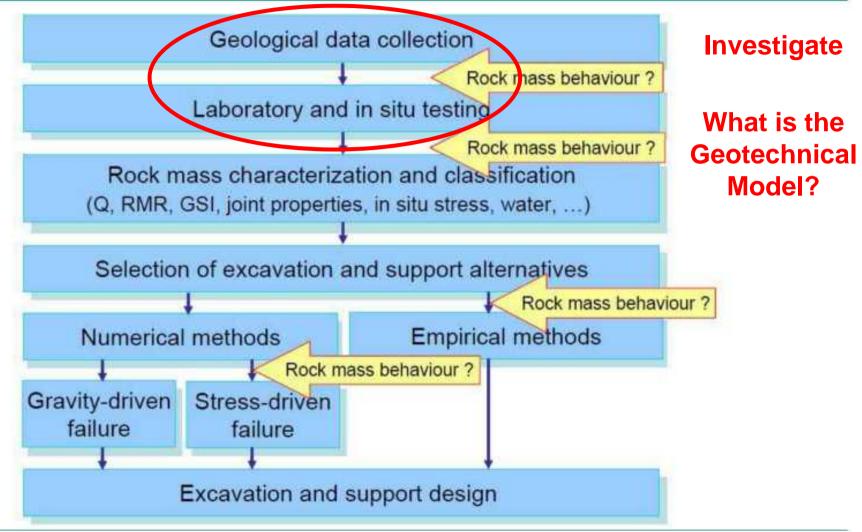
#### **Caverns – Rock Mechanics Design Process**



Site characterisation approach for standard geo-engineering projects; the arrows are where a sound understanding of rock mass behaviour is needed



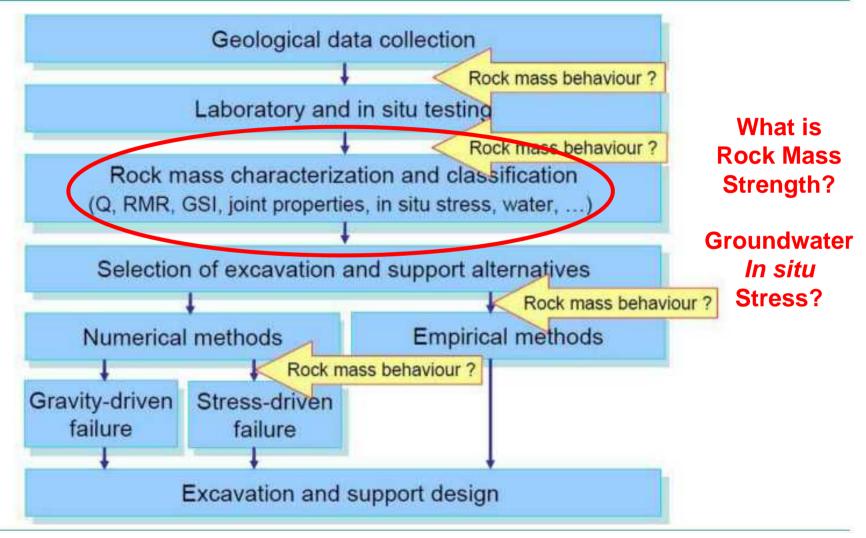
#### **Rock Mechanics Process - The Ground Model**







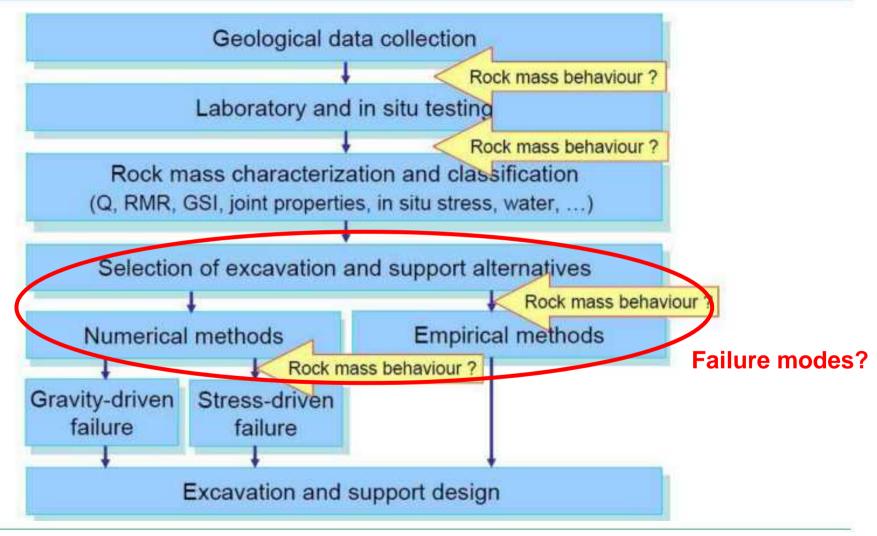
#### **Rock Mechanics Process - Classification**







#### **Rock Mechanics Process – Analysis**







#### **Rock Mass Behaviour - Tunnel Failure Modes**

	Massive (RMR > 75)	Moderately Fractured (50 > RMR < 75)	Highly Fractured (RMR < 50)	
Low In-Situ Stress $(\sigma_1/\sigma_c < 0.15)$	Linear elastic response.	Falling or sliding of blocks and wedges.	Unravelling of blocks from the excavation surface.	Low Mining-Induced Stress $\sigma_{max}/\sigma_{\rm C} < 0.4\pm0.1$
Intermediate In-Situ Stress (0.15 > $\sigma_1$ / $\sigma_c$ < 0.4)	Brittle failure adjacent to excavation boundary.	Localized brittle failure of intact rock and movement of blocks.	Localized brittle failure of intact rock and unravelling along discontinuities.	Intermediate Induced Stress $0.4\pm0.1 < \sigma_{max}/\sigma_{\rm C} < 1.15\pm0.1$
High In-Situ Stress $(\sigma_1 / \sigma_c > 0.4)$	Brittle failure around the excavation .	Brittle failure of intact rock around the excavation and movement of blocks.	Squeezing and swelling rocks. Elastic/plastic continuum.	High Mining-Induced Stress $\sigma_{max}/\sigma_c > 1.15\pm0.1$

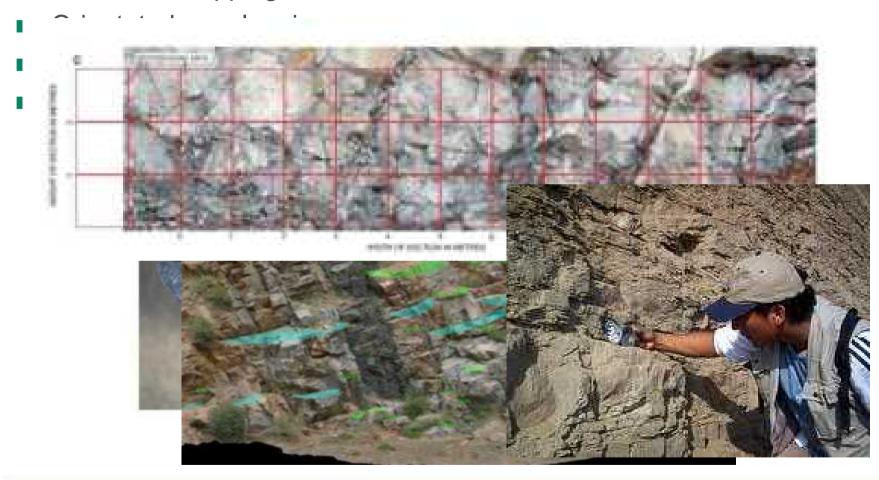
Source: Kaiser





#### **Need information on discontinuities**

Rock face mapping







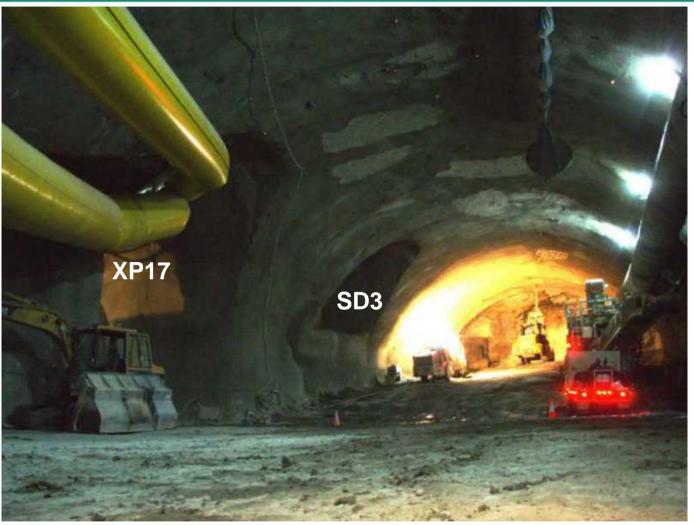
## **Caverns – Sewerage Treatment**



Bondi STP Pumping Station 12 m span Flat roof



#### **Caverns – Road Intersection Chambers**







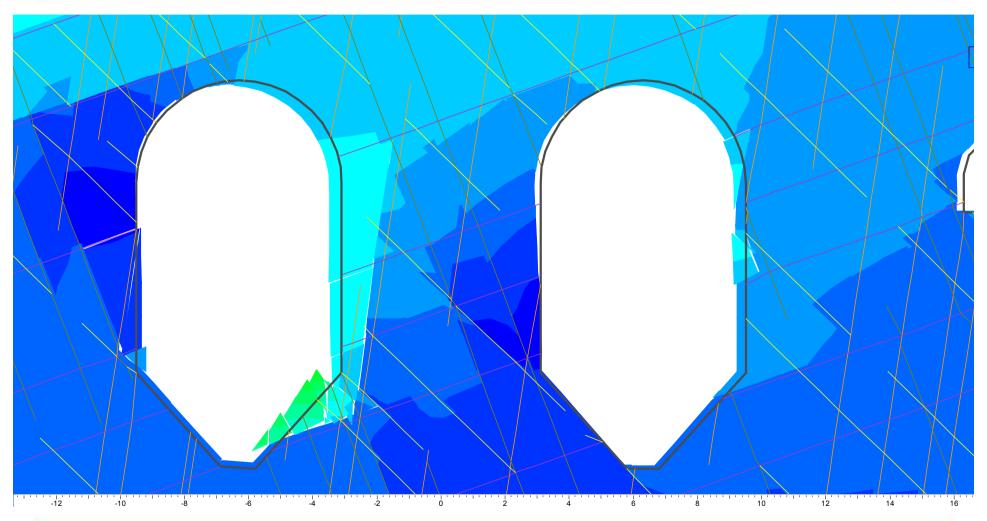
## **Caverns – Hydro Electric Power Stations**







## **Cavern Wall Design – Large wedge?**







# Caverns – Salt Water Reservoir Hong Kong University

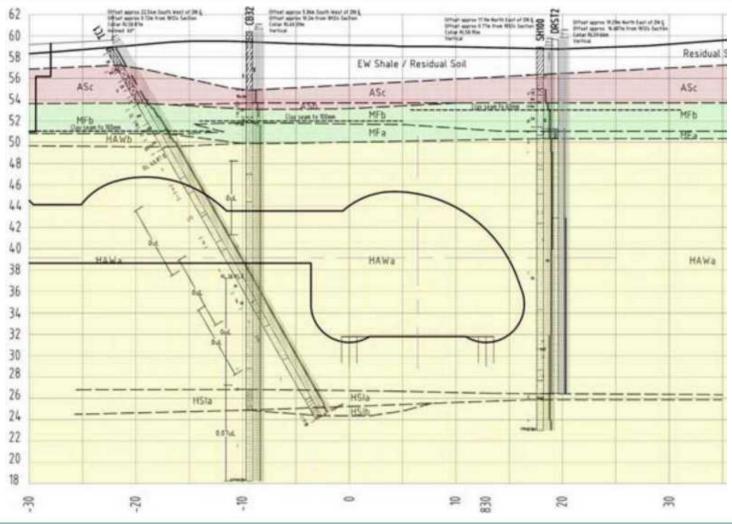


From: Chung (2011) Black & Veatch





#### **Caverns – Rail Stations**



13

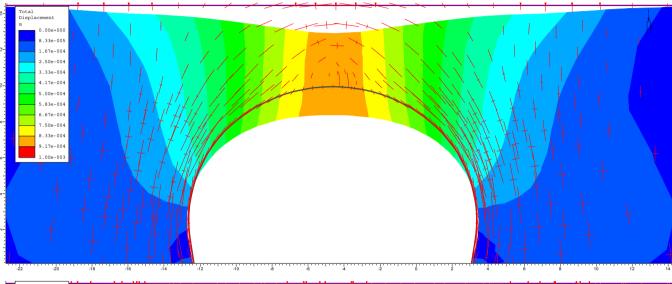




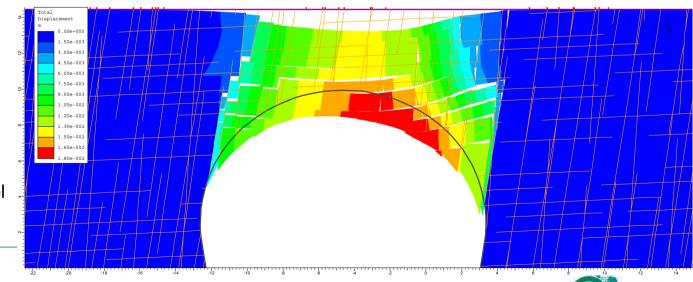


## **Numerical Tunnel Modelling – what type?**



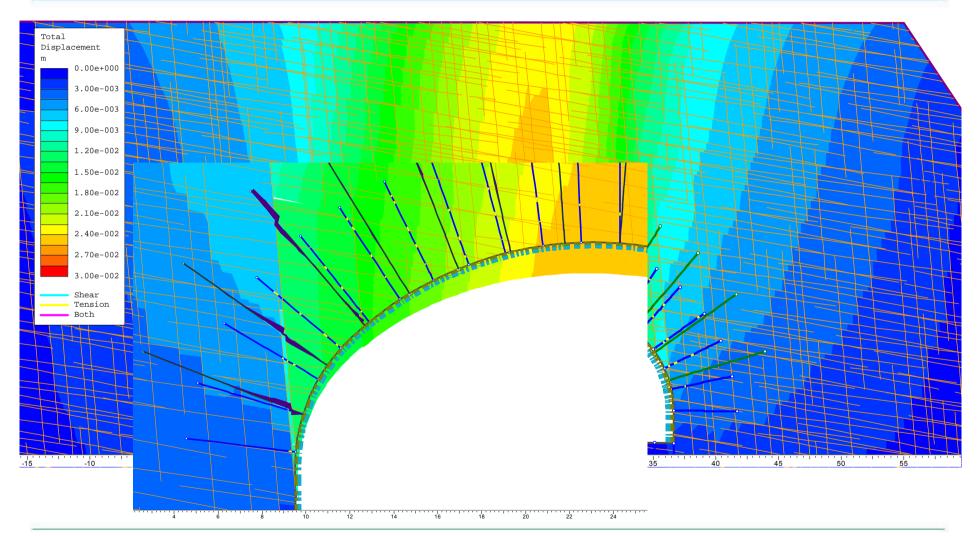


PHASE<sup>2</sup>
Joint network
Discontinuum Model





## **Cavern Roof Design – Rockbolt shear**

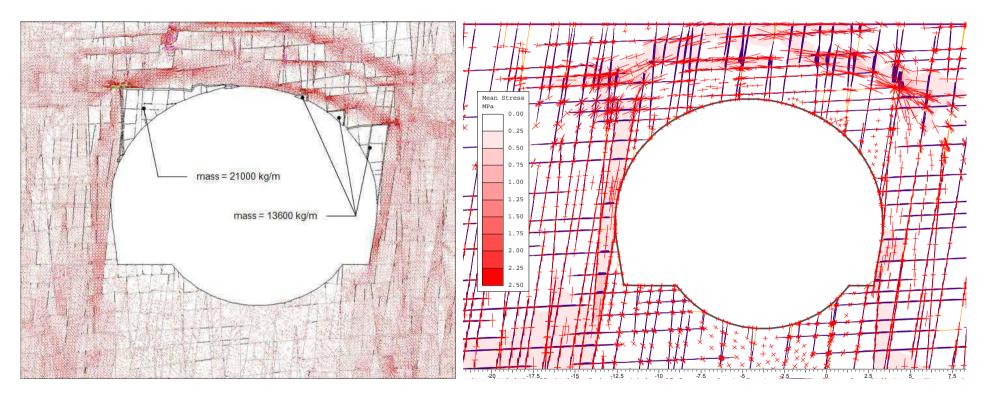






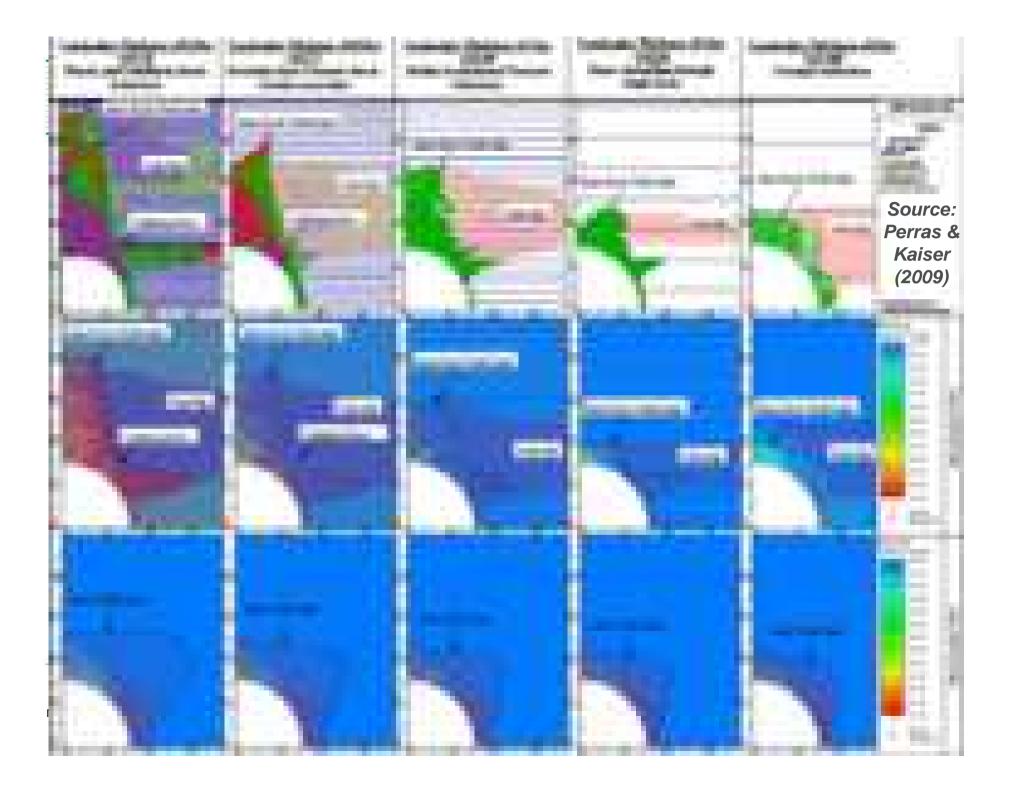
## **Cavern Roof Design - Low Cover**

UDEC PHASE<sup>2</sup>



The formation of a natural arch in jointed rock at low cover (4.5 m for 15 m span tunnel)







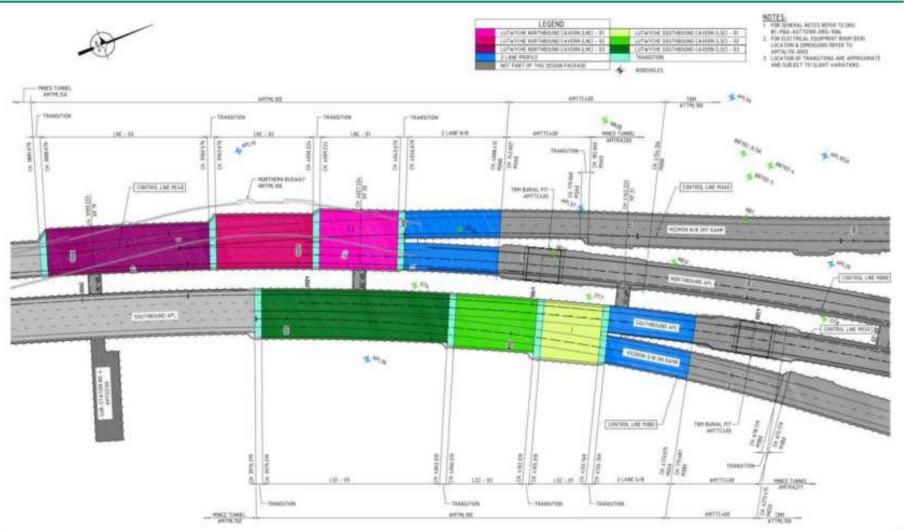
#### **OUTLINES**

- Case Study : Road Cavern
- Empirical Method
- Structural Controlled Failure Modes:
  - Discrete Fracture Network Fracman
- Stress Controlled Failure Modes
  - Boundary Element Method : Examine3D
  - Continuum and Discontinuum Models : Phase2 Analyses





#### **Key Plan: Road Cavern, Brisbane Australia**







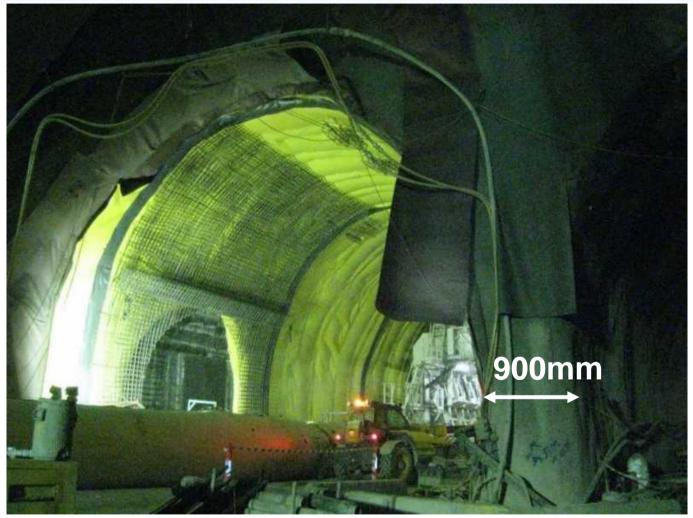
## Road Cavern, Brisbane, Australia







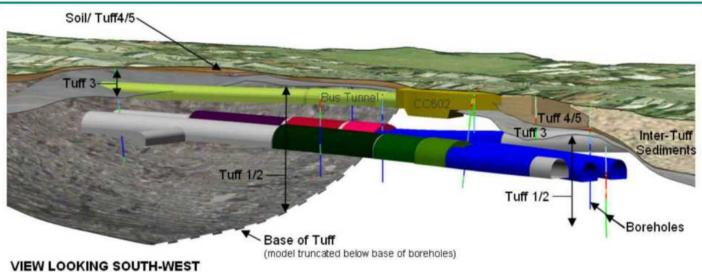
## **Pillar**

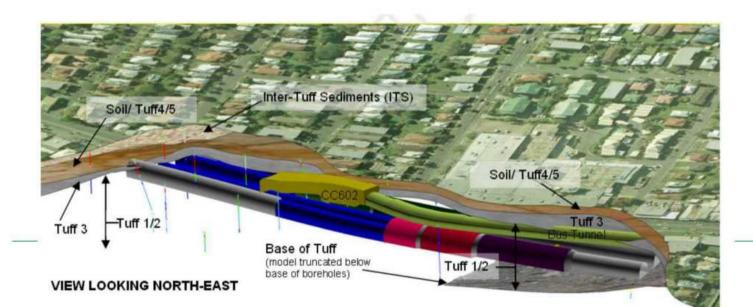






#### **Geotechnical Conditions**



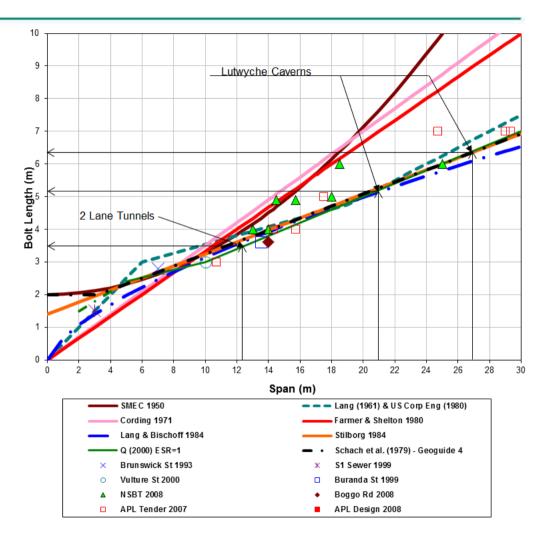






#### **Empirical Method**

- Precedent Charts, by comparing against :
  - Available empirical guidelines and
  - Other similar projects within the proposed area







#### **Structural Controlled Failure Modes**

- Unwedge Analyses : wedges are formed by only three joint sets
- FracMan Analyses:
   blocks are multifaceted (the actual number of facets depends on the number of joint sets and their orientation distribution)





#### **Discrete Fracture Network - FracMan**

- Golder Associates proprietary Discrete Fracture Network software FracMan has been used in these analyses
- To model the rock mass fabric by describing the fracture system in a more realistic way than conventional geotechnical characterization methods, allowing a description of the fracture geometry that is driven by verifiable data.
- To describe the heterogeneous nature of fractured rock masses by explicitly representing key elements of the fracture system as discrete objects in space with appropriately defined geometries and properties.
- By building geologically realistic models that combine the larger observed deterministic structures with smaller stochastically inferred fractures, DFN models capture both the geometry and connectivity of the fracture network as well as the geometry of the associated intact rock blocks.
- To condition the fracture model as much as is possible to available data, and then use Monte Carlo simulations to quantify the uncertainty of extrapolation of the fracture pattern throughout the problem volume. It is a stochastic process allowing multiple but equi-probable realisations to be created.
- To identify all formed blocks defined by the underlying DFN system and the excavation surface.

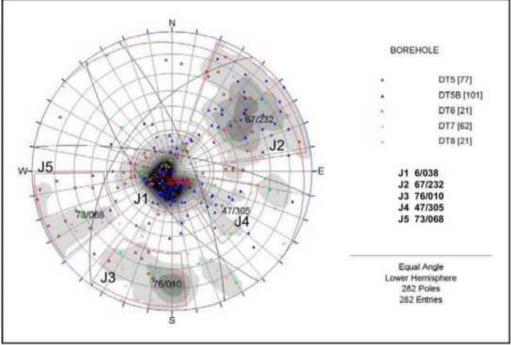




## **Input Data**

#### Summary of Defects in Brisbane Tuff - Lutwyche Cavern Area

Joint Set		Dip	Dip Direction	JRC	Spacing (m)	
J1	Avg	6	038	11	1.5	
	Range	1 - 33	000 - 360	3 - 16	0.04 - 19.4	
J2	Avg	67	232	11	3.0	
	Range	46 - 88	188 - 251	4 - 14	0.1 - 10.8	
J3	Avg	76	010	11	3.4	
	Range	62 - 87	319 - 024	8 - 16	2.2 - 4.6	
J4	Avg	47	305	12	2.0	
	Range	33 - 53	274 - 306	10 - 16	0.1 - 10.5	
J5	Avg	73	068	10	3.9	
	Range	60 - 89	43 - 76	2 - 14	0.03 - 10.9	







#### **Input Data**

DFN models require certain primary fracture properties to be defined:

- fracture orientation distribution;
- fracture size distribution; and
- Fracture intensity.

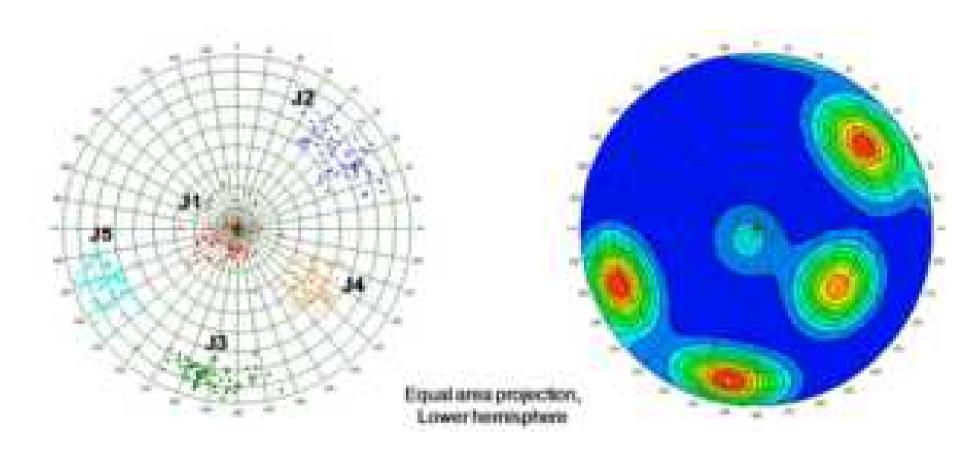
Joint Set	Orientation Distribution Used	Pole Dip	Pole Trend	Dispersion K or Dip Variation	Trend Variation
Set 1	Fisher	84	218	40	-
Set 2	Bivariate Normal	23	052	9	12
Set 3	Bivariate Normal	14	190	6	10
Set 4	Fisher	43	125	45	-
Set 5	Fisher	17	248	50	-





## FracMan Analyses

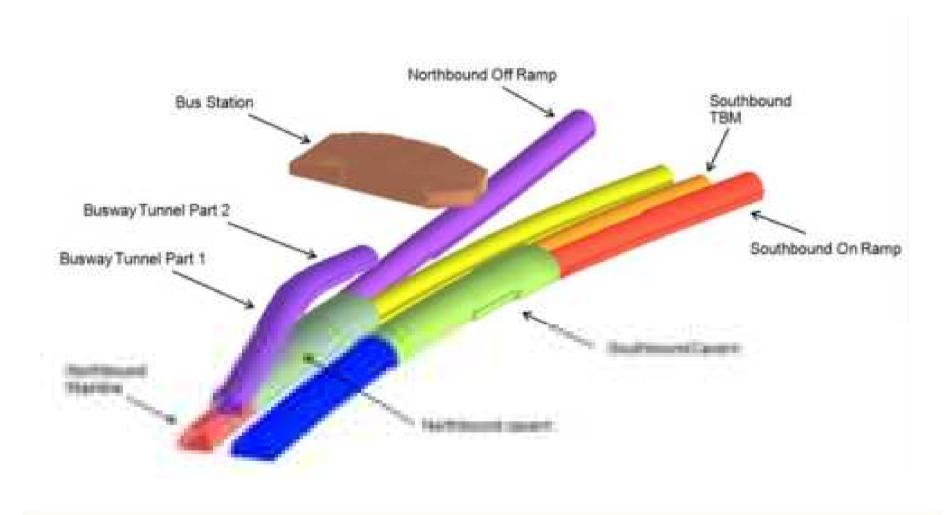
Synthesised Fracture Orientation Data in FracMan







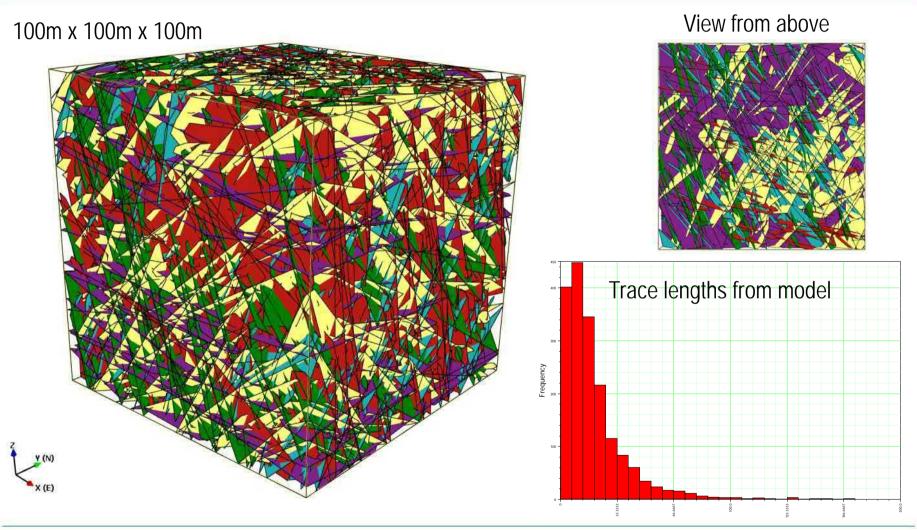
## **Geometry Used in FracMan Model**







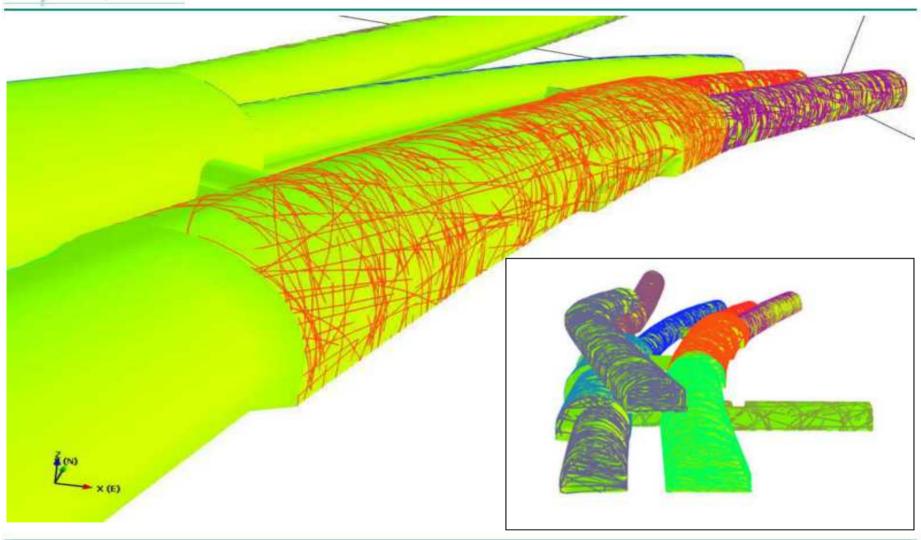
#### Visualization of small model volume







#### **Visualization of Tunnel Traces**

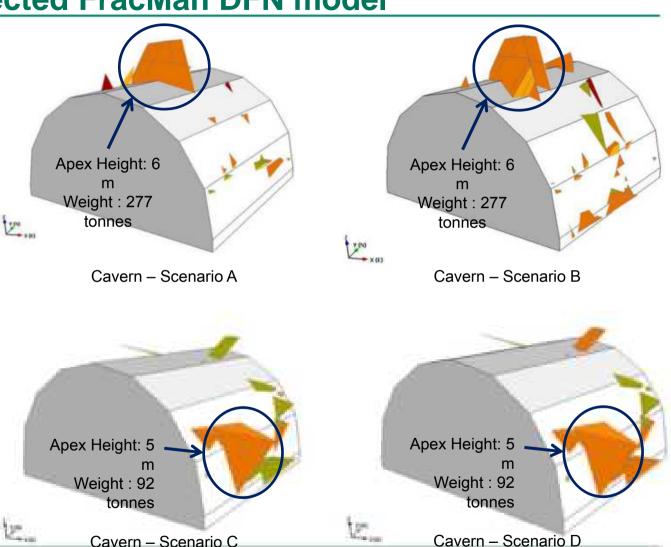






### Schematic of typical blocks formed within a selected FracMan DFN model

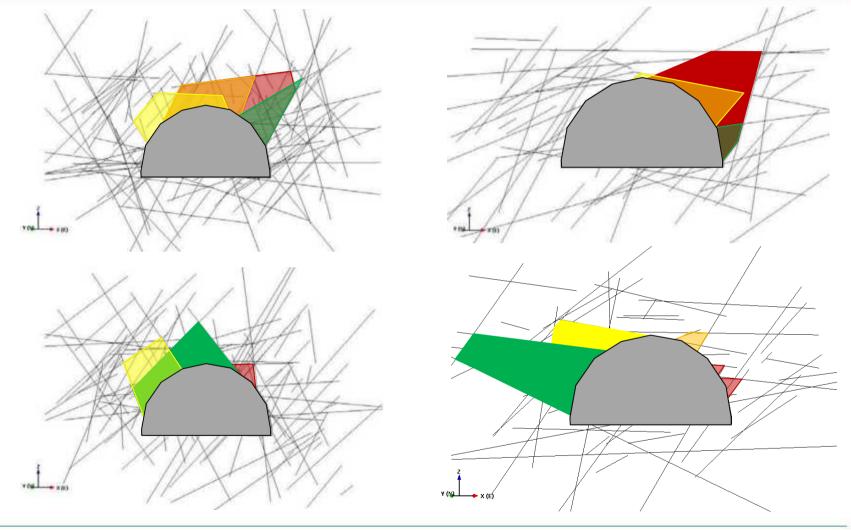
Schematic of the blocks formed within one of the FracMan models intersected by a 25 m long section of the FracMan Cavern excavation type







### Cross section taken of a typical FracMan model for the Cavern Excavation







#### **Stress Controlled Failure Modes**

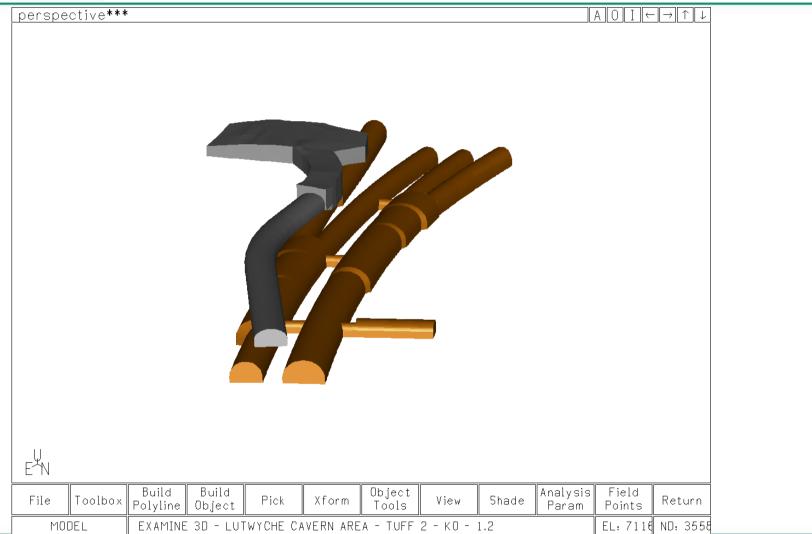
■ Boundary Element Method : Examine<sup>3D</sup>

■ Continuum and Discontinuum Models : Phase<sup>2</sup> Analyses





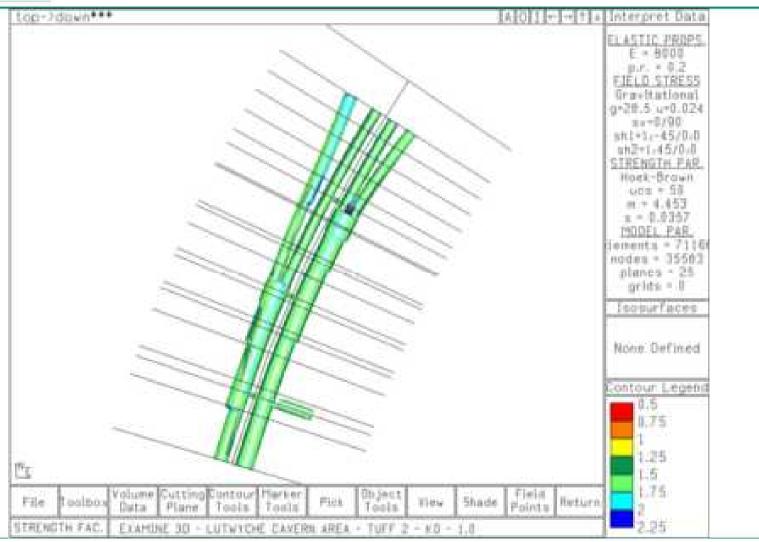
#### Examine3D







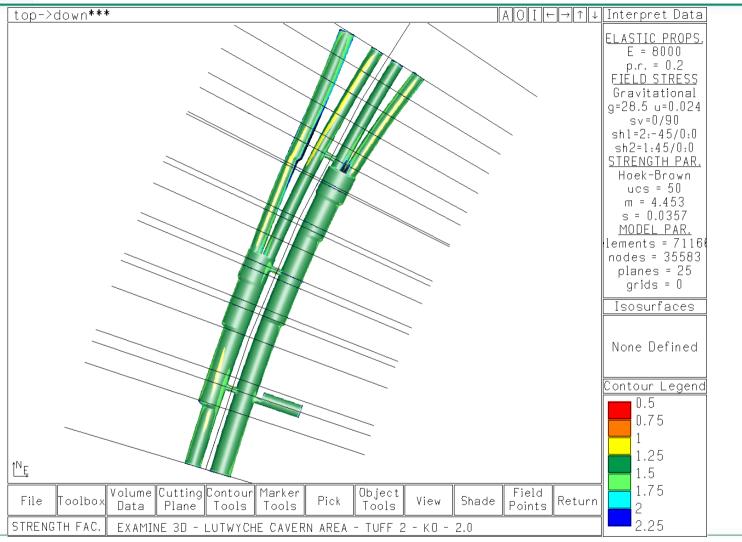
#### **Strength Factor**







#### **Strength Factor**







#### **CONTINUUM VS DISCONTINUUM MODELLING**

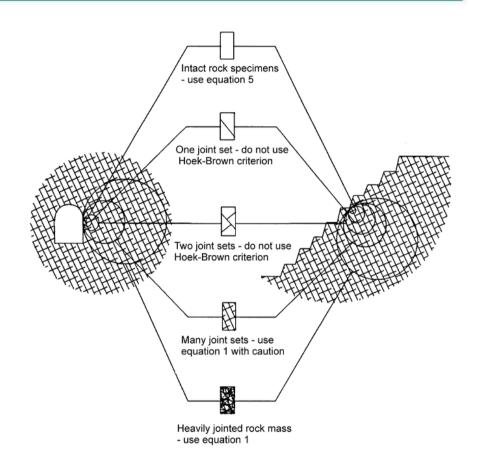
MEDIUM		MODELLING			
		CONTINUUM	DISCONTINUUM		
SOIL					
ROCK	INTACT ROCK				
	1 – 3 JOINT SETS				
	MANY JOINTS / HEAVILY JOINTED ROCK MASS				





#### **Continuum vs Discontinuum – Scale Factor**

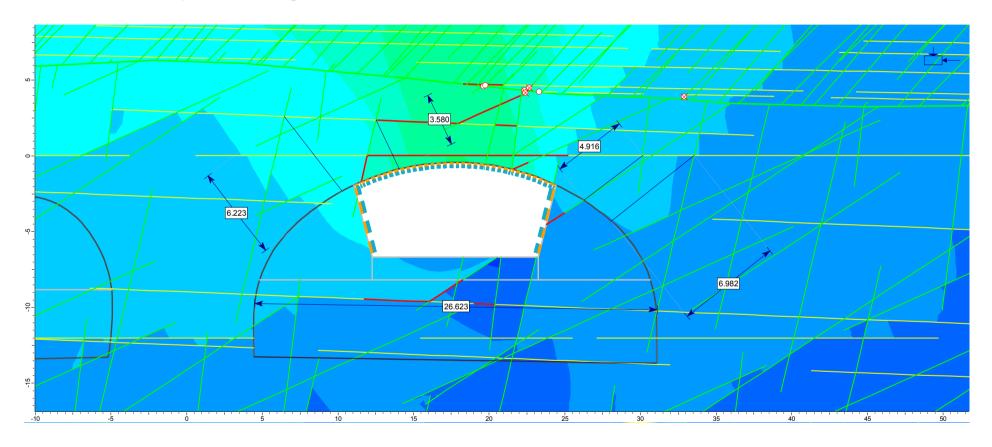
- Continuum Approach
- Continuum with Discontinuity
- Continuum with Discontinuity or Discontinuum Approach
- Continuum Approach
- Continuum Approach







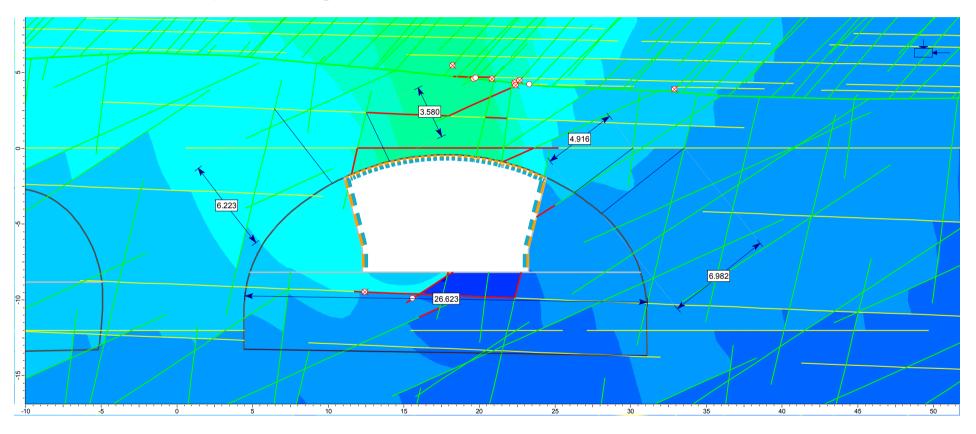
First Top Heading







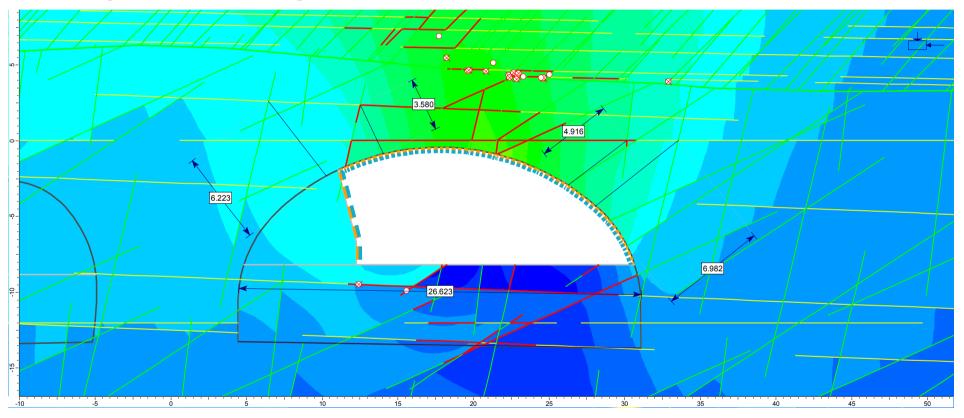
Second Top Heading







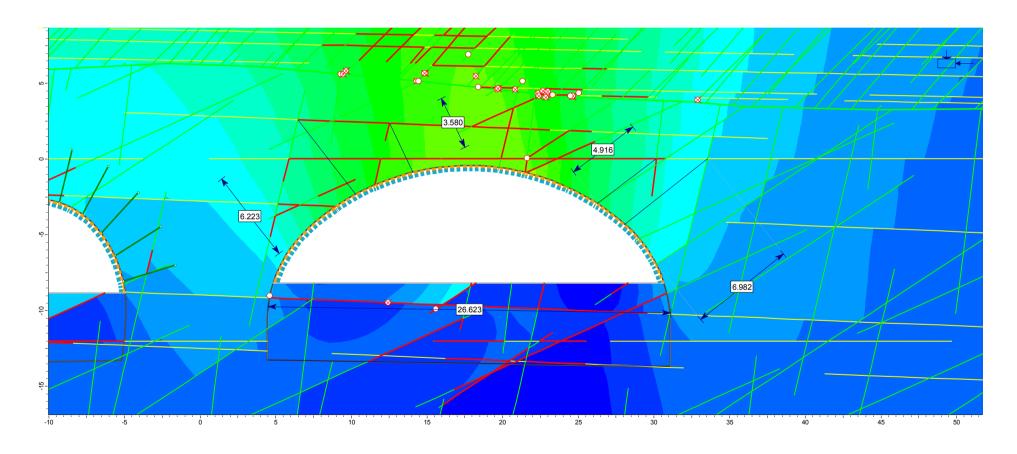
Right Side Heading







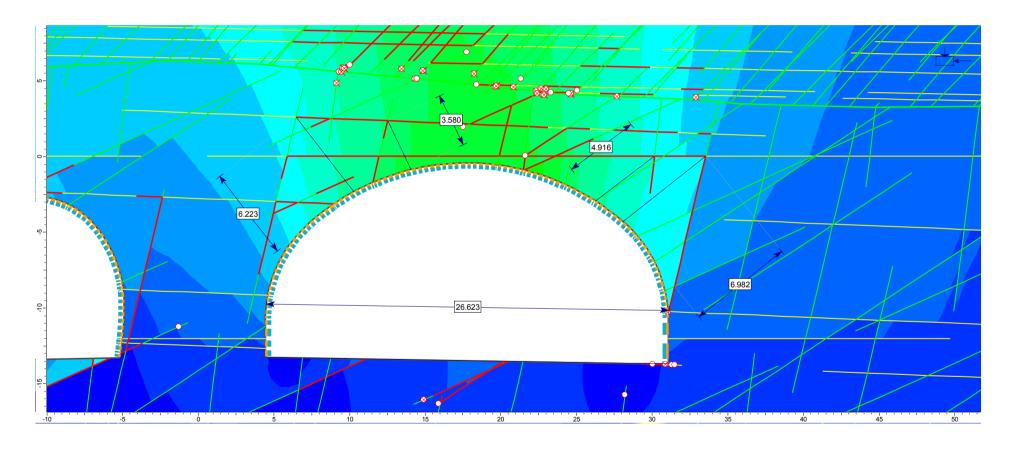
Left Side Heading







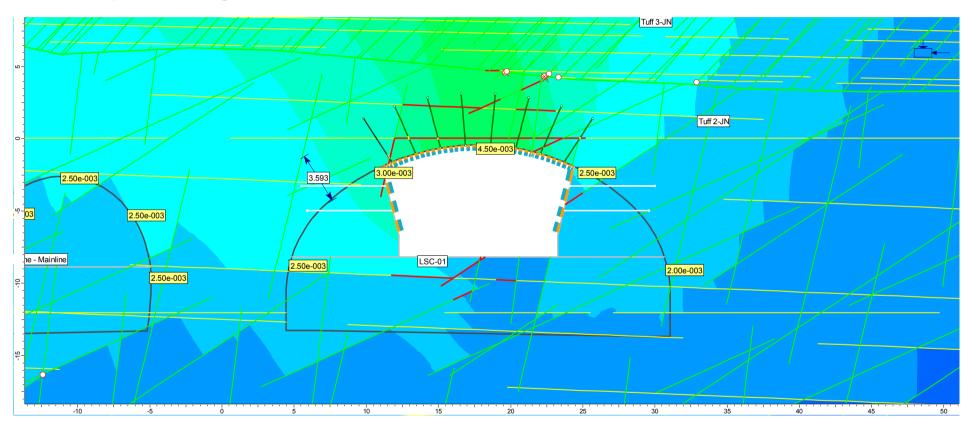
#### Bench







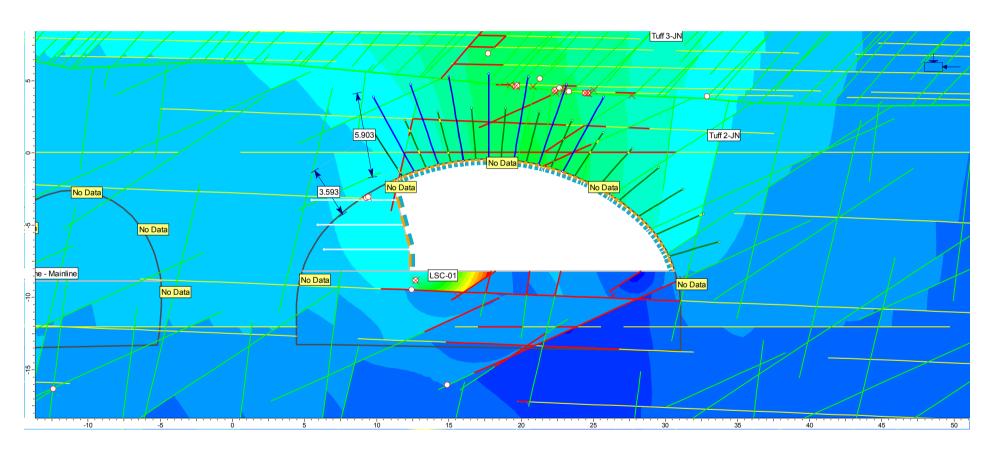
#### Top Heading







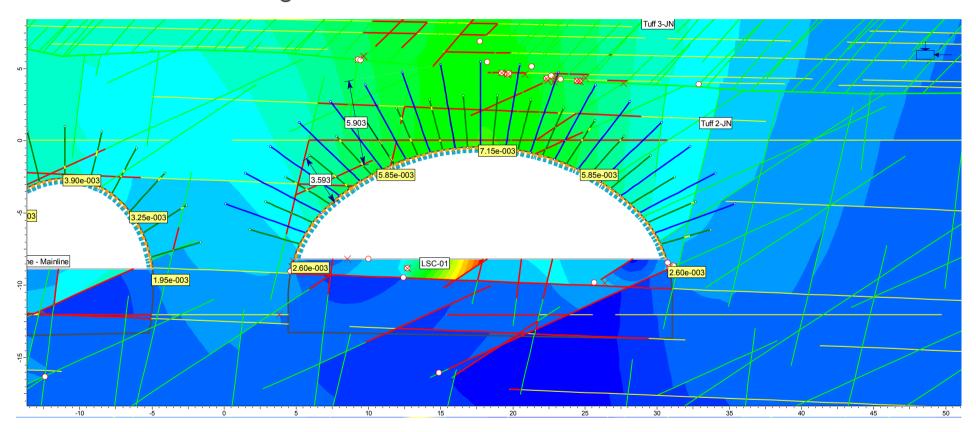
Right Side Heading







#### Left Side Heading



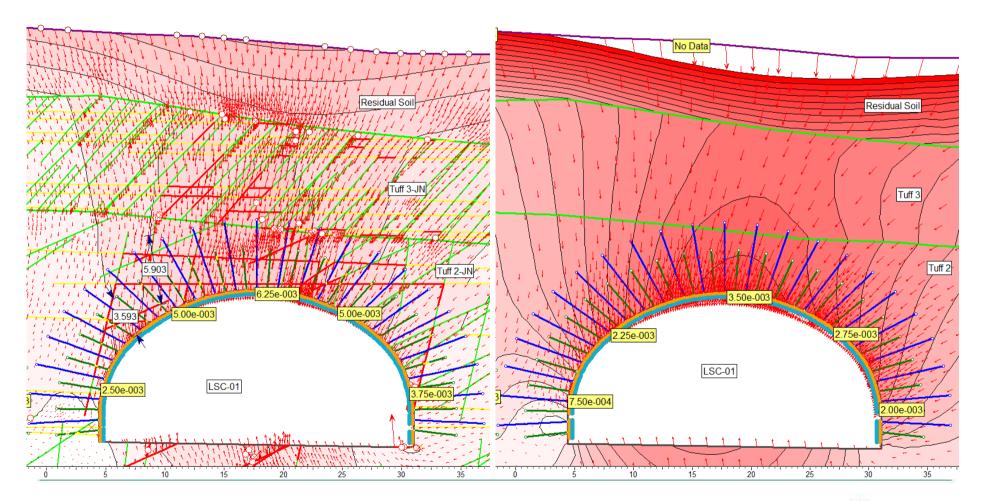




#### **CONTINUUM & DISCONTINUUM MODELS**

- Discontinuum Model: 1m³ scale 

  Continuum Model: tunnel scale

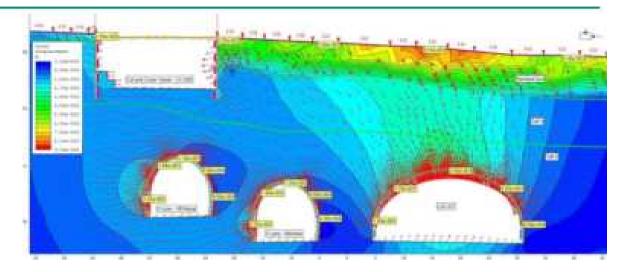




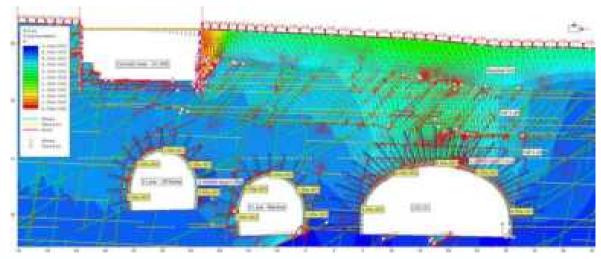


#### Phase<sup>2</sup> Model

Continuum Model : tunnel scale



■ Discontinuum Model : 1m³ scale

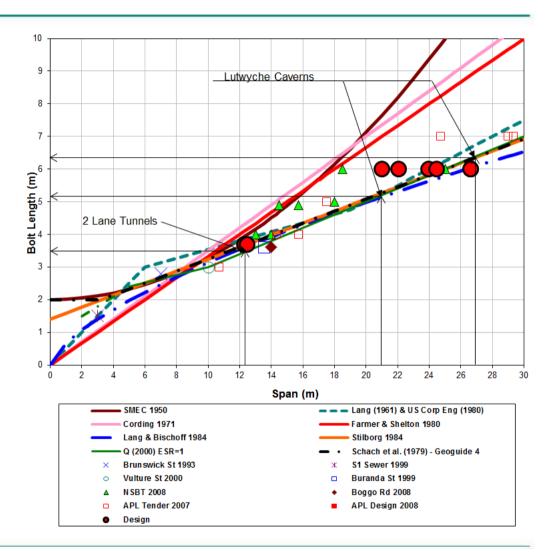






#### **Empirical Design Guidelines**

- Precedent Charts, by comparing against :
  - Available empirical guidelines and
  - Other similar projects within the proposed area

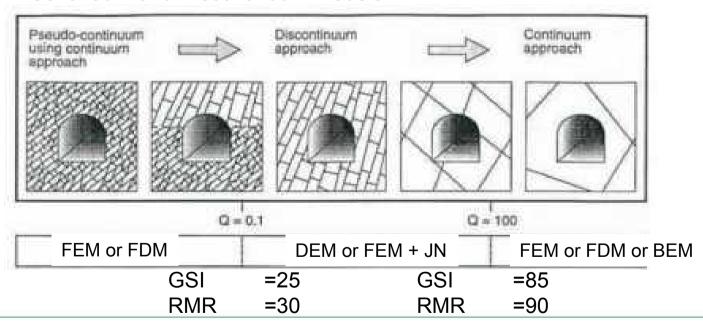






#### **Summary**

- Empirical Method : as guidelines
- Structural Controlled Failure Modes are required when :
  - Q ≥ 0.1
  - GSI ≥ 25
  - RMR ≥ 30
- Stress Controlled Failure Modes :
  - Continuum and Discontinuum Models:







# Geotechnical Computer Program Users Group Seminar on Geotechnical Computer Modeling

### "Engineering Geological Considerations for Computer Analyses for Tunnel and Cavern Stability Assessment"

Saturday, 20th April 2013

**Presenter:** 

Mr Alexander (Sandy) Mackay
Head of Geotechnics, Nishimatsu Construction Co. Ltd







#### INTRODUCTION

- 1. Tunneling Work in Hong Kong
- 2. Were do computer analyses fit into this?
- 3. Application of Computer modeling
- 4. Examples of Computer Applications to Caverns and tunnels

NEVER GIVE CREDENCE TO IDEAS THAT ARE MADE INDOORS (NIETSZCHE, 1895)







### **Tunneling Work in Hong Kong**

Project	Construction Period	Project Summary
MTR West Island Line	2009 - 2014	Sheung Wan Station to Kennedy Town (3 int. stations)
MTR South Island Line (East)	2011 – 2015	Extension Admiralty Station to Ap Lei Chau (2 int. station)
MTR South Island Line (West)	2014 – 2018	Extension from Kennedy Town to Ap Lei Chau (3 int. stations)
MTR Shatin Central	2012 - 2019	<b>Extension from Tai Wai to Central Station (7 int. stations)</b>
MTR Kwun Tong	2011 - 2015	Extension from Yau Ma Tei to Whampoa (2 int. station)
MTR Express Rail	2011 - 2020	26km tunnel in HKSAR connecting to the China rail network.
DSD Tsuen Wan	2009 - 2014	Tsuen Wan to Yau Kom Tau.
DSD Harbour Area Transfer Scheme	2009 - 2014	22km, up to 160m depth below ground, 3m int. diameter.
HyD Chek Lap Kok to Tuen Mun	2013 – 2017	Tunnel construction beneath a sub-sea shipping channel.
HyD Liantang	2013 – 2017	Dual 2 to 3 lane carriageway from Fanling towards Sha tau Kok
HyD Central Kowloon route	2013 - 2017	Dual 3 lane carriageway running from Yau Ma Tei to Kai Tak
HyD Central - Wan Chai Bypass	2011 - 2016	Dual 3 lane carriageway running from Central to North Point

#### **Main Parties:**

- 1. Mass Transit Railway Corporation Limited (MTRCL)
- 2. Highways Department (HyD)
- 3. Drainage Services Department (DSD)
- 4. initiatives from Geotechnical Engineering Office





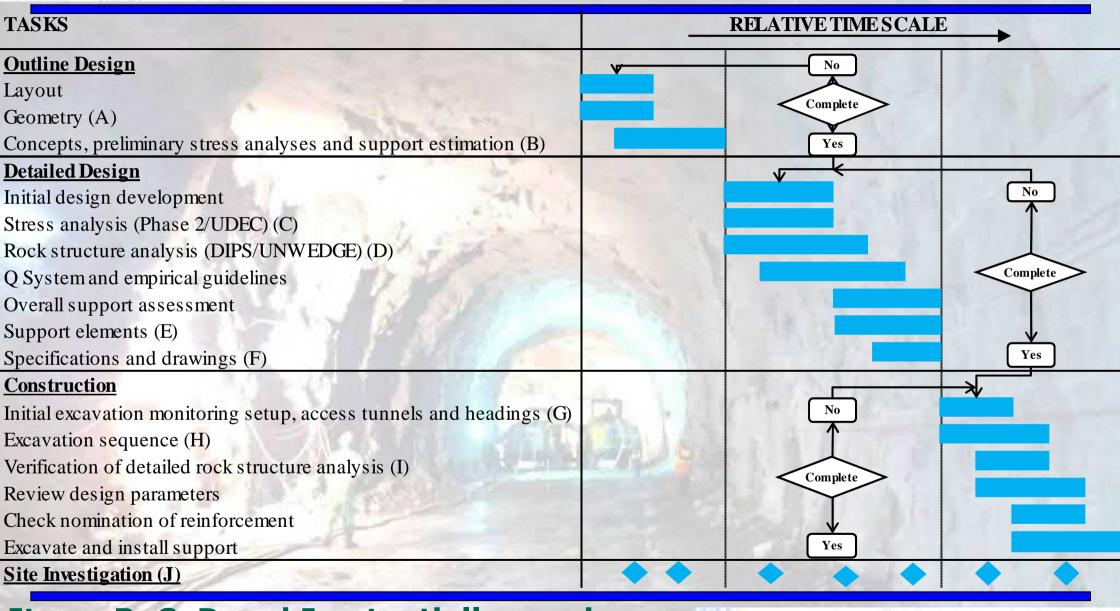
#### **Tunneling Work in Hong Kong**



Taken from Tunnels and Tunneling magazine (Thomas, April, 2008)



### Were do computer analyses fit into this? (design input stages / considerations)



Items B, C, D and I potentially require computing analyses (Swannel & Hencher, 1000)







### Were do computer analyses fit into this? (design input stages / considerations)

- B. OUTLINE DESIGN Stress analysis / support estimation (Rock mass classification assessment, stress changes, compression zones);
- C. DETAILED DESIGN Stress analysis (Stresses around excavation, intact rock failure, displacement, support requirements);
- D. DETAILED DESIGN Rock structure analysis (Failure mode identification, support requirements for un-stable blocks);
- I. CONSTRUCTION Rock structure analysis verification (Identification of potential local wedge failures during mapping. Substantial of the support adjustments using UNWEDGE as required).







### Application of Computer modeling (suitable software)

Туре	Software	Supplier	Use
Limit equilibrium	UNWEDGE	Rocscience Inc.	Requires accurate definition of kinematically feasible rock wedge release around an opening
	DIPS	Rocscience Inc.	Interpretation of the block size for use in "Unwedge"
Numerical continuum analyses	PLAXIS	Rocscience Inc.	Finite difference software to analyse stresses and displacements. Discrete discontinuities may be included in the analysis
	PHASE 2	Rocscience Inc.	2D finite element software for support in un-jointed and / or heavily jointed rock
Numerical dis- continuum analysis	UDEC / 3DEC	Itasca Consulting Gp incorporated	Jointed rock masses (2 and 3D analyses)







# Application of Computer modeling (staff / teamwork)

Engineering Geologist	Geotechnical Engineer	Overlap
Good at observation,	Applies systematic	Identification of ground
description, mapping,	approaches to problem	conditions, evaluation of
Able to create 3	solving involving analysis	engineering properties and
dimensional ground	and creative design.	design and construction
models from limited	Numerate and has a	
surface and sub-surface	sound basis in analysis	
information.	and design	
Empirical, indirect, rule-	Precise, specific,	The geotechnical engineer
of-thumb, qualitative,	analytical, rigorous,	or engineering geologist
intuitive.	calculative, quantitative.	
Tends to answer from	Tends to answer from	knowledge and flexibility
experience (viewed by a	theory (viewed by a	
civil engineer).	geologist).	





Two Engineering Geologists (EG) carrying out the same assessment - outcome:

- 1. EG 1 Q VALUE OF 0.02 IMMEDIATE COLLAPSE, 75 TO 100MM SHOTCRETE
- 2. EG 2 Q VALUE OF 5 ONE MONTH STAND UP TIME, NO SUPPORT REQUIRED

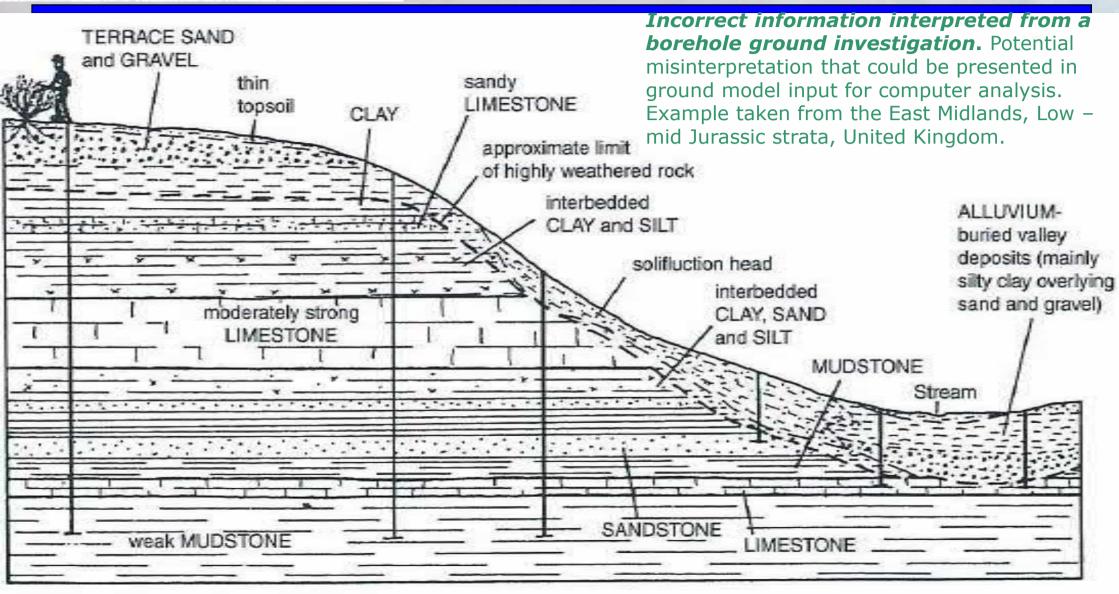
Q parameter	Engineering Geologist 1	Estimates	Engineering Geologist 2	Estimates
RQD	0 (nominal 10%)	Cleavage is a true discontinuity set.	75%	Cleavage is an incipient plane of weakness, which manifests as fine cracks.
Jn	15	Estimate the least favorable joint set over the scale of the excavation considered		Estimate of the least favourable joint set over the scale of the excavation considered
Jr	1	Persistent and smooth planar	2	Impersistent and smooth undulating.
Ja	4	Clay is seen very rarely along joints	1	Joint surfaces are typically only discolored
SRF	5	The excavation will be near surface in a relatively low stress regime.		The excavation will be near surface in a relatively low stress regime. T
Jw	0.66	Some exposures show a little water seepage.	1/1/2	Joints within the rock mass are more likely to be tight and less permeable.
Q	0.022		5	
ESR	4.5m		3.6m	
Stand up time	LE -	Immediate collapse		1 month
Support	11.	75 - 100mm mesh reinforced shotcrete		No support

Example of incorrect information and / or feedback for analysis (Fookes, 1997)







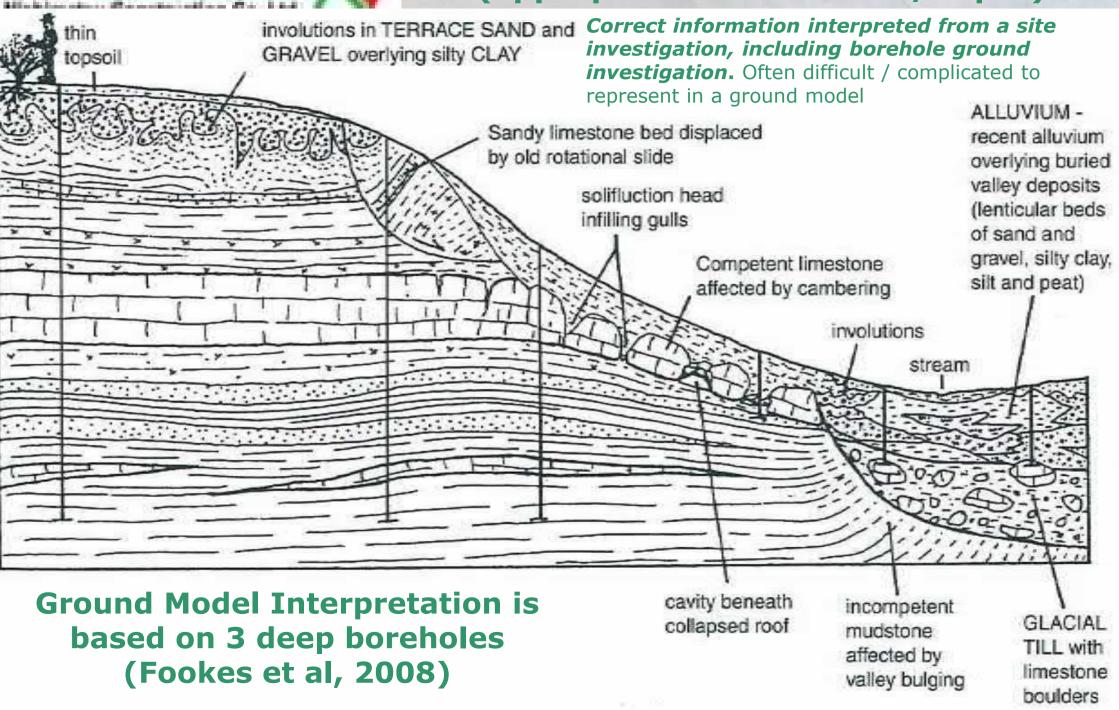


Ground model interpretation is based on 3 "deep" boreholes (Fookes et al, 2008)

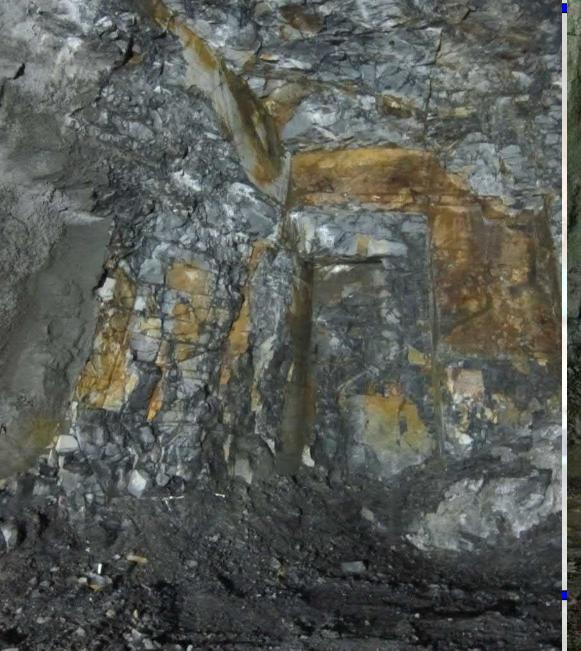


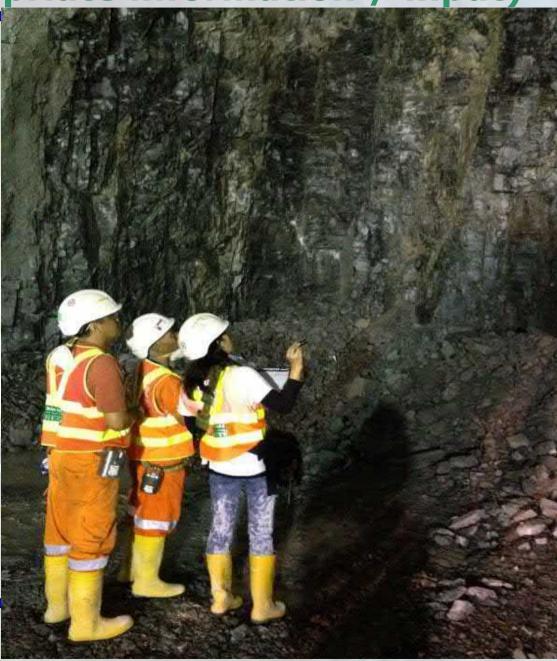












How to represent field information in a model for analysis – example of ground encountered.



### Application of Computer modeling (contractual considerations)

### MTRCL PARTICULAR SPECIFICATION (PS) requirements. Typical examples below (usually MTRCL PS 7.3.25 – 30):

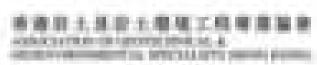
#### **Should the following criteria apply:**

- 1. The mapped Q value (empirical assessment for the tunnel support) be found to be less than 0.05 for single track tunnels and 0.13 for twin track tunnels (about 16m span)
- 2. If the tunnel is less than 1 diameter from junctions and / or intersections and / or span greater than 16m
  The Q value is supplemented with numerical analyses

### MTRCL MATERIAL & WORKMANSHIP SPECIFICATION (CIVILS) requirements. Used to supplement the PS.

Clause 3.29 (1) – in addition to the face mapping records, for every 100m of tunnel excavation summary stereo-plot of the joint data shall be submitted to the Engineer







### **Examples of Computer Applications to Caverns and tunnels**

Name / Purpose	мах. Span	Rock Type	ROCK CIASS (Q system)	Design analysis	Support
MTRCL - Quarry Bay Station Overrun tunnels	15m	Granite	Extremely good	Discrete element	Shotcrete / permanent bolt support
MTRCL - Quarry Bay Station Congestion Relief Works Diversions (NISHIMATSU)	18m	Granite	Extremely good	Discrete element	Increased from 15 to 18m span. Shotcrete / permanent bolt support
MTRCL - Quarry Bay Congestion Relief Works Diversions - temporary TBM launching cavern (NISHIMATSU)	30m	Granite	Good	Block	Shotcrete / temporary bolt support
Route 3, Tai Lam tunnel (North portal) (NISHIMATSU)	18m	( / MI)(-	Exceptionally Poor	Finite Element	New Austrian tunneling Excavation Method. Iterative monitoring / analyses optimizing construction sequence (Endicott et al, 2000). Pipe pile roof support.
KCRC - West Rail DB 350 - typical section with partition replacing central dividing wall (NISHIMATSU)	20m	Granite (*)	Fair to good	Block	Shotcrete / temporary bolt support (wedge stabilization)
KCRC - West Rail DB320 Portals			Fair	3D finite / 2D discrete element	Extensive pre-support to prevent dilation
MTRC - Tai Koo Shing Station	24m	Granite (*)	Poor to Good	Block	Permanent Concrete Arch roof
MTRC Pak Shing Kok Crossover Cavern	25m		Fair	Block and finite element analyses	Shotcrete / permanent bolt support
CEDD - Kau Shat Wan Explosives Depot	13m	Granite (+)	Poor to fair	Block	10 caverns, 12m separation. Shotcrete / permanent bolt support
DSD - Stanley cavern Sewage Treatment Works	1/m	Granite (\$)		Block	2 caverns. Shotcrete / permanent bolt support
EPD - Island West Waste Transfer Station	28m	Coarse ash	Good	Block and finite element	Shotcrete / permanent bolt support

### Summarized from GEO Publication 1/2007 (Engineering Geology) Main Parties:

- 1. Mass Transit Railway Corporation Limited (MTRCL)
- 2. Highways Department (HyD)
- 3. Drainage Services Department (DSD)
- 4. Civil engineering Development Department (CEDD)
- 5. Environmental Protection Department (EPD)

- \* weakening effects from faults and intrusion and deep weathering
- + feldsparphyric rhyolite dykes
- \$ weak zones and basalt dykes and shear zones







**Stanley Sewage Treatment Works** 

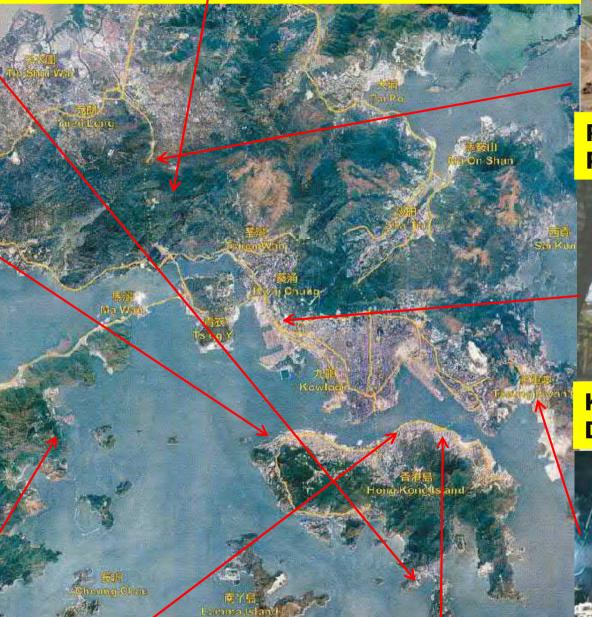


**Island West Waste Transfer Station** 



**Kau Shat Wan Explosives Depot** 





**Route 3, North Portal** 



**KCRC - West Rail DB320 Portals** 



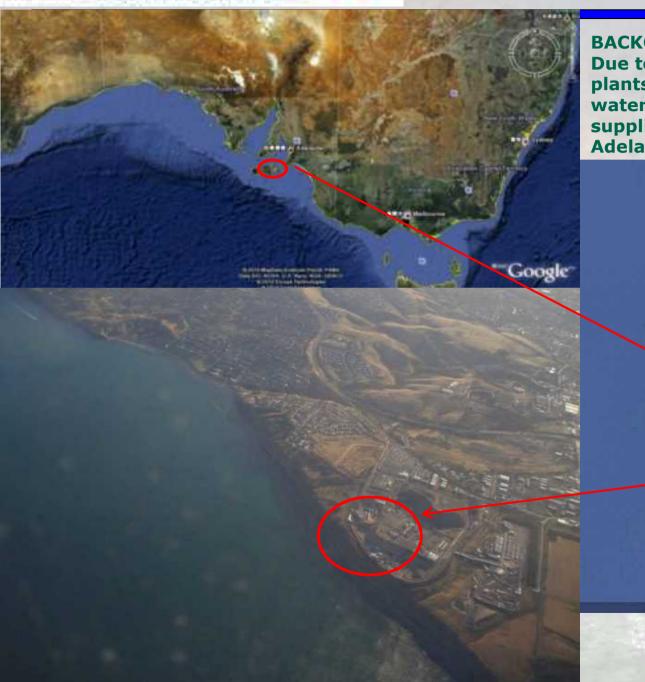
MTRCL - Tai Koo **Shing Station** 

**MTRCL - Quarry Bay Station** 

**MTRC Pak Shing Kok Crossover** 

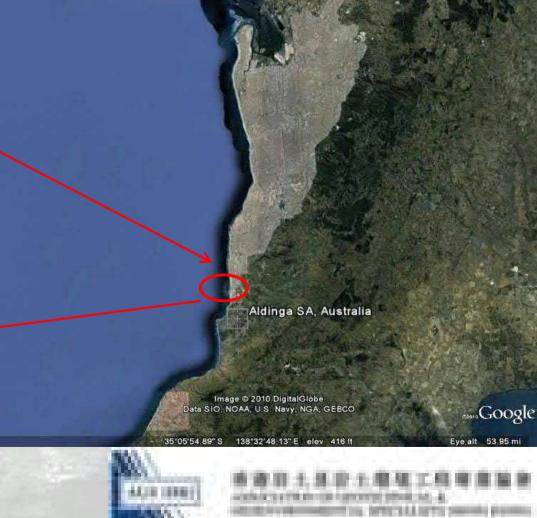


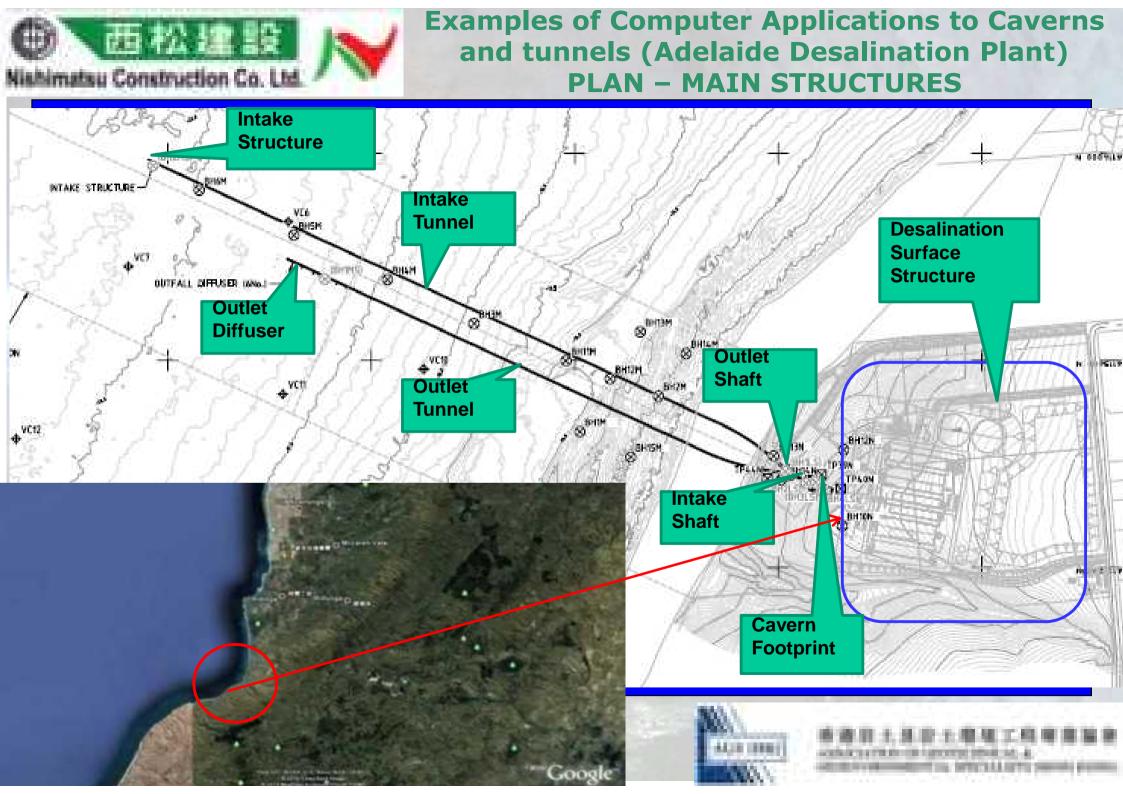
### **Examples of Computer Applications to Caverns and tunnels (Adelaide Desalination Plant - LOCATION)**

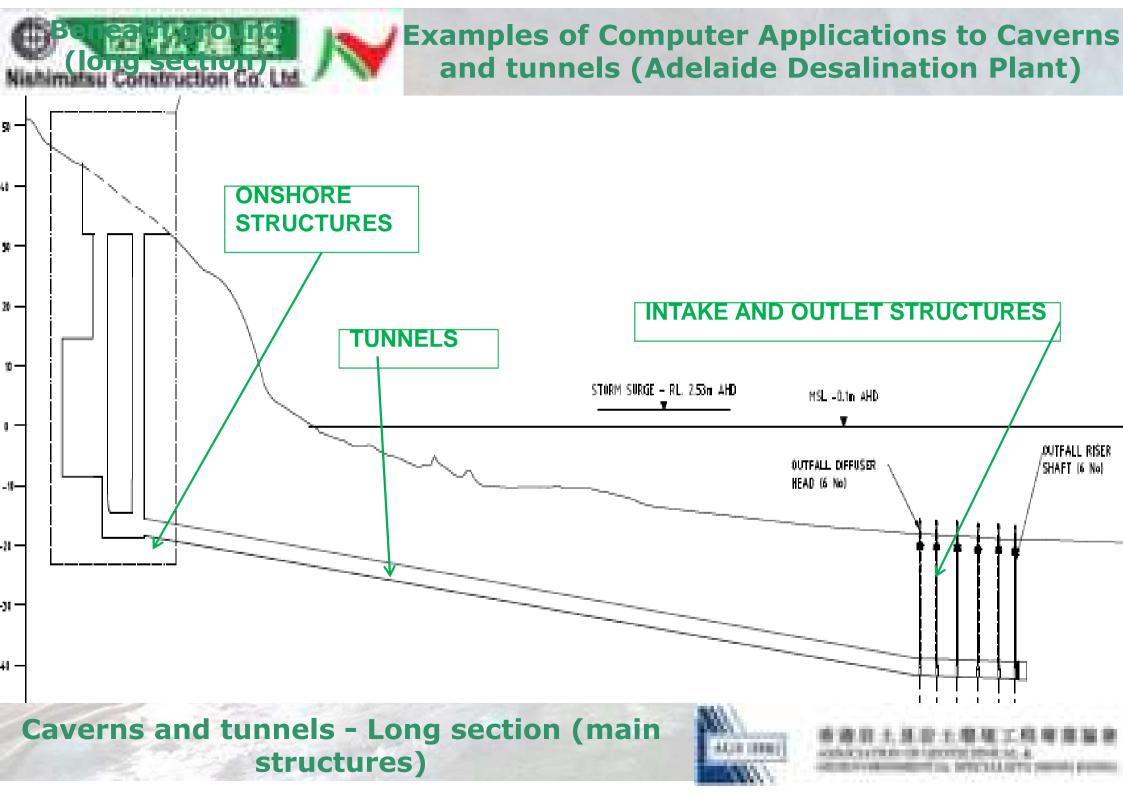


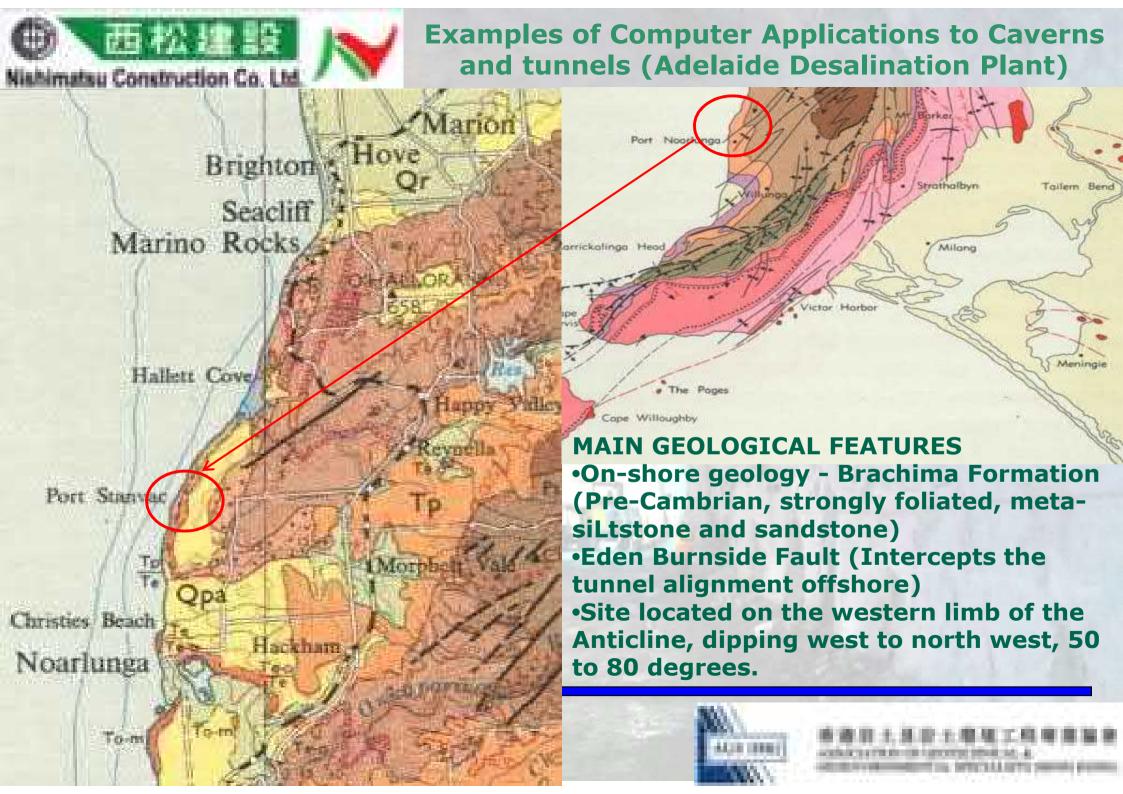
#### **BACKGROUND**

Due to reduced rainfall in Australia, desalination plants have become a popular solution to supply water in Australia. The Adelaide Desalination Plant supplies 50 billion litres of water, or 25 % of Adelaide's annual water demand.











**Examples of Computer Applications to Caverns and tunnels (Adelaide Desalination Plant)** 

**PRE-CAMBRIAN - Brachima Formation and Port Stanvac Sandstone** 

**PERMIAN - Glacial Sediments (sands and subordinate clays)** 



#### **LONG SECTION - MAIN GEOLOGICAL FEATURES**

- On-shore geology Brachima Formation (Pre-Cambrian, strongly foliated, meta-siltstone and sandstone)
- Eden Burnside Fault (Intercepts the tunnel alignment offshore)
- Site located on the western limb of the Anticline, dipping west to north west, 50 to 80 degrees.

T – TERTIARY – T1b – Undifferentiated;

T2 - Pericana Member (Calcareous Mudstone / Siltstone);

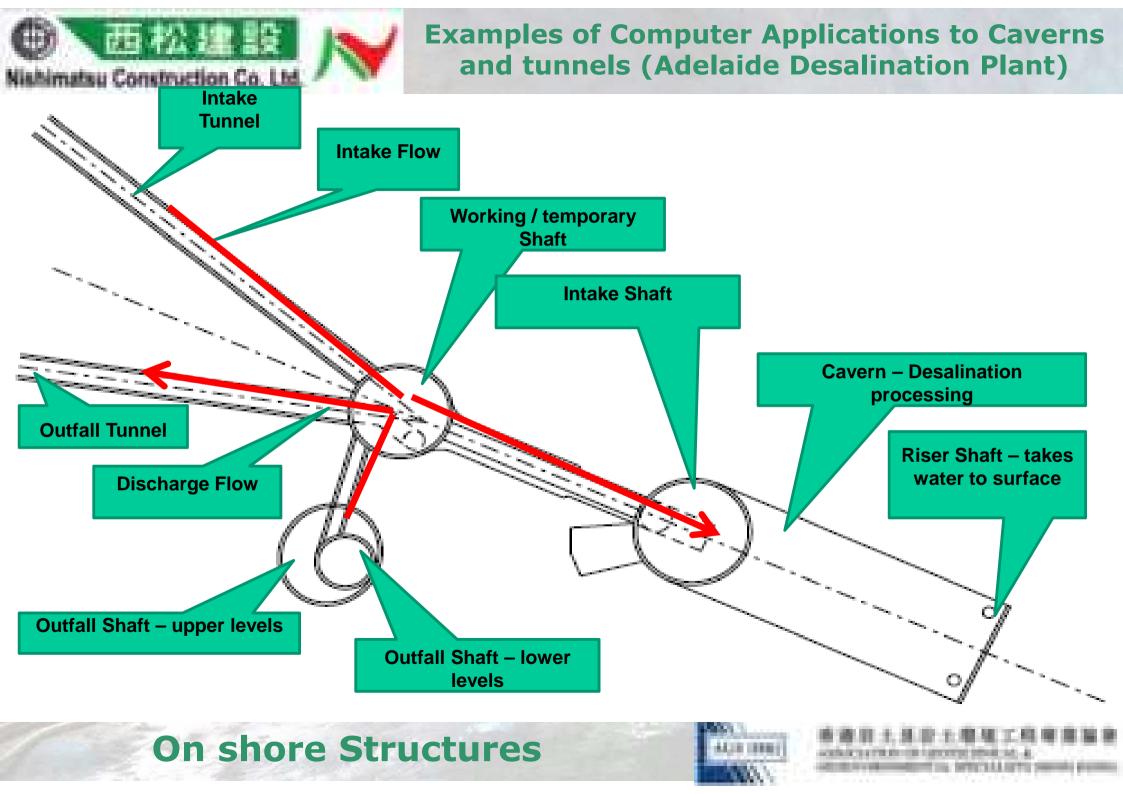
T4 – Tuketia Member (Glauconitic Calcareous Mudstone and thin Limestone);

**T5 – Tortachilla Limestone**;

**T6 - Maslin Sand** 





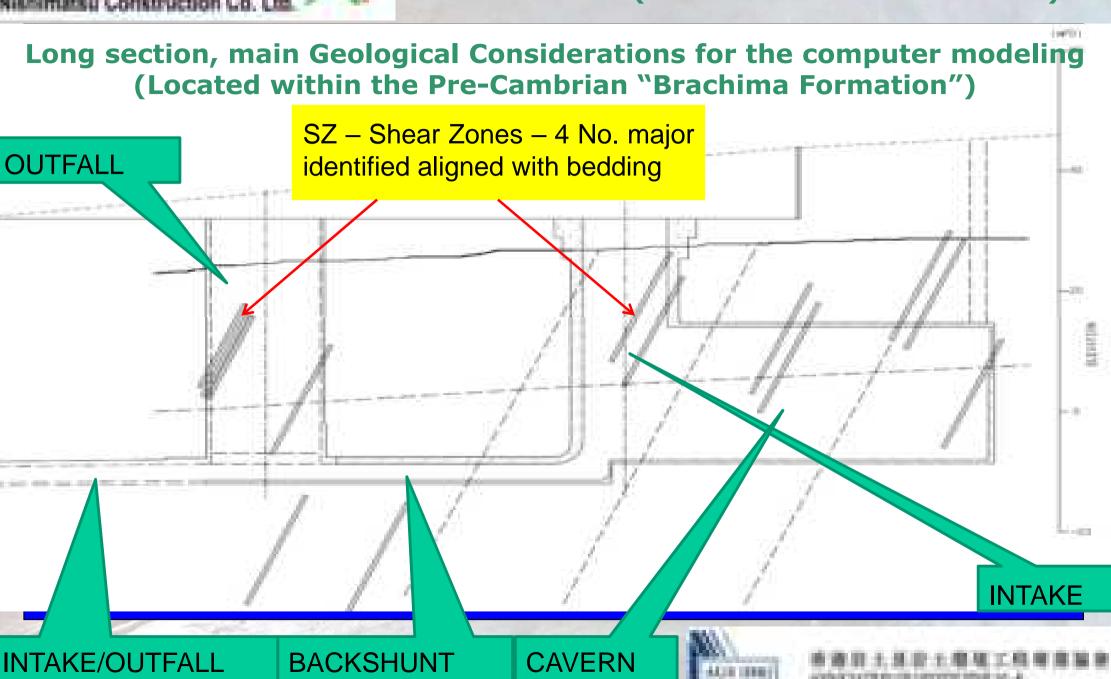




**TUNNELS** 

**TUNNEL** 

### **Examples of Computer Applications to Caverns and tunnels (Adelaide Desalination Plant)**





### **Examples of Computer Applications to Caverns and tunnels (Adelaide Desalination Plant)**

Shaft	Purpose	Configuration	Interpreted Ground Conditions			
	from the surface to the discharge	Uppermost shaft 16m max. and 13m min ID to 19m depth; 8m ID below this level.	•			
		16.36m ID, compatible with the cavern ID.	<ul> <li>A. 0-6m silty clay,</li> <li>B. 6-11m BF4,</li> <li>C. 11-17m BF3a, 1</li> <li>D. 7 - 25m BF2a and 2</li> <li>E. 4 – 40m BF1/2</li> </ul>			
Cavern	the desalination	Span 16.36m ID (about 18m excavation span). Length 70m, Height30m				
Summary of the structures and ground						

conditions (rock mass classifications -

identified by "Brachima Formation" (BF) units)



### **Examples of Computer Applications to Caverns and tunnels (Adelaide Desalination Plant)**

Rock Mass	Description, based on British Standard (BS 5930, 1999)	Density (kN/m3)	UCS (MPa)	Young's Mod. (Mpa)
BF1	High to very high strength, slight to fresh weathering, slight fracturing and 300 to 600mm discontinuity spacing	27 - 28	50 - >200	28000
BF2	High to very high strength, moderate weathering, slight fracturing and 100 to 300mm discontinuity spacing	26 – 27	25 – 50	16500
BF2a	High to very high strength, slight weathering, slight fracturing and 100 to 300mm discontinuity spacing	26 - 27	50 - 100	
BF3a	High to very high strength, moderate weathering, 30 to 100mm discontinuity spacing, locally more intensely fractured.	26 – 27	25 – 50	3800
BF3b	Very low to very high strength slightly weathered and highly fractured (SHEAR ZONE).	27 - 28	>100	1500
BF4	Low to high strength moderately weathered and highly fractured.	23 - 25	25 - 50	1200

Parameters adopted for the analysis (derived from the "Brachima Formation" (BF) units)







# Examples of Computer Applications to Caverns and tunnels (Adelaide Desalination Plant) "Brachima Formation units" on site





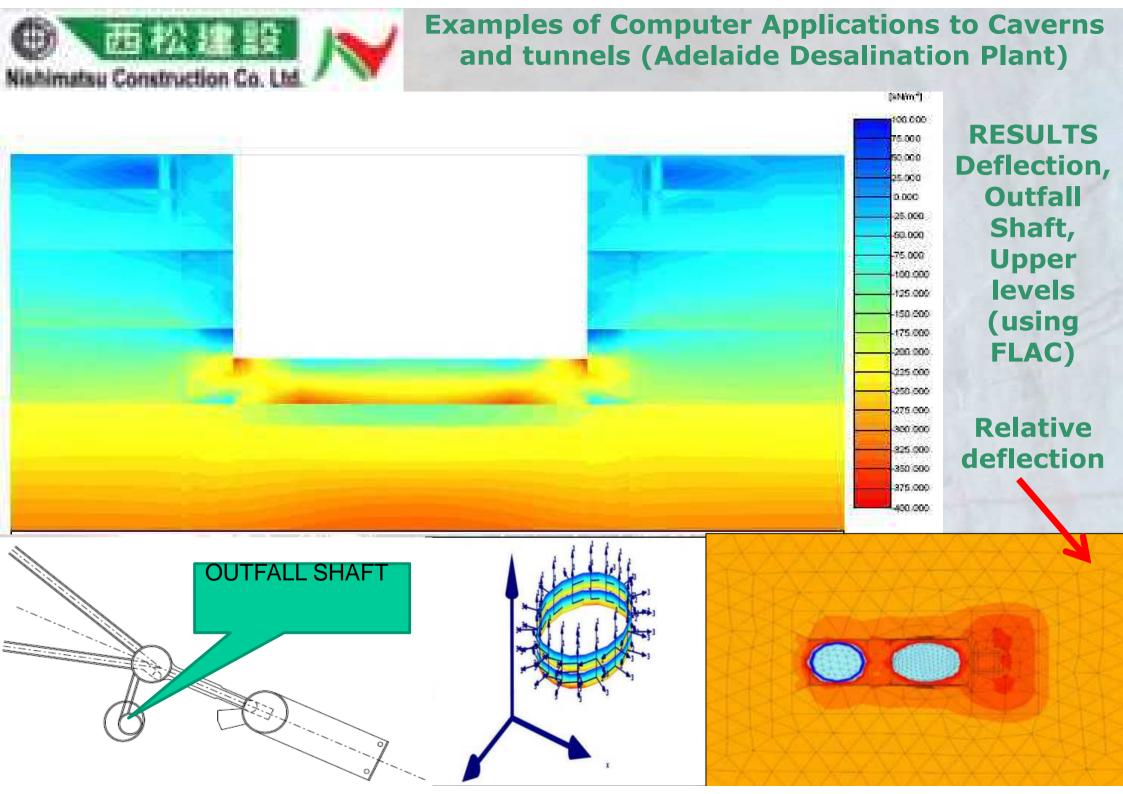
### **Examples of Computer Applications to Caverns and tunnels (Adelaide Desalination Plant)**

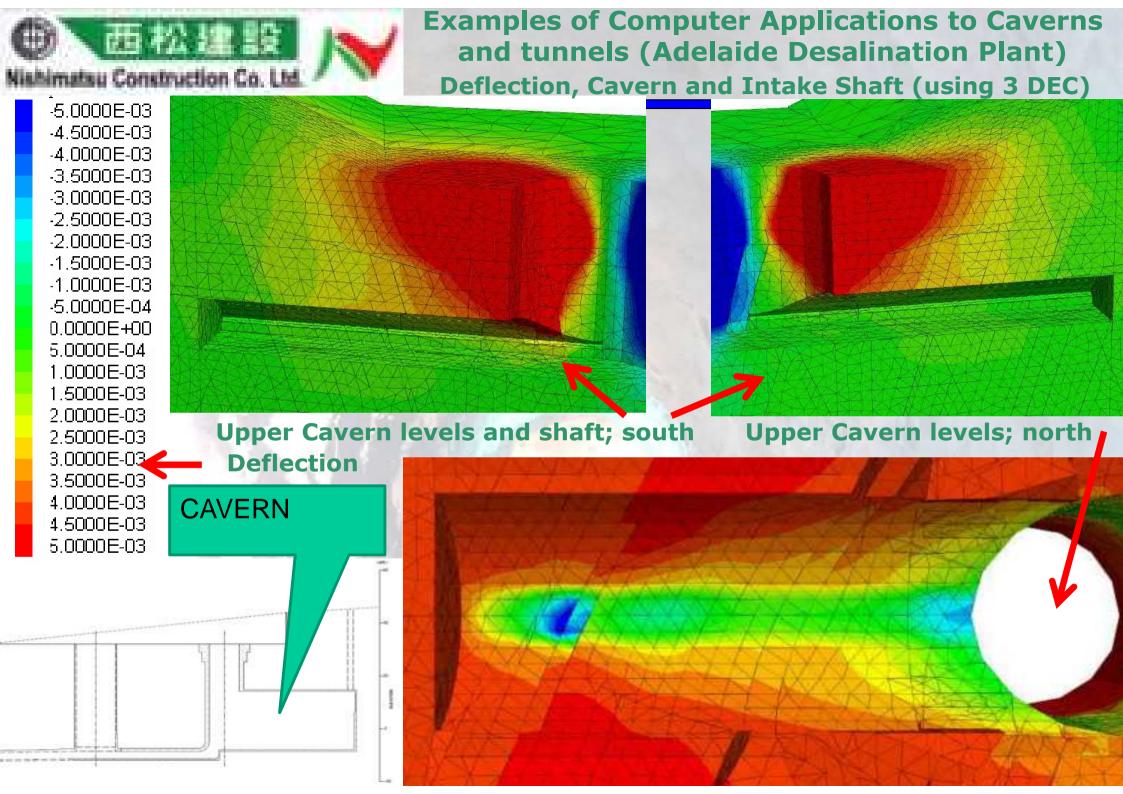
The authorities and the state of the state o		
ANALYSES	SOFTWARE /	COMMENTS
	FORMULAE	
Continuum	Fast Lagrangian	Used to analyze weak rock
(Linear	Analysis of	(UCS<10MPa), located in upper levels.
Elastic)	Continua (FLAC)	
Discontinuum	Universal	For the Cavern, located entirely in rock,
(structural)	Distinct Element	3DEC analysis was adopted. This
	Code (UDEC)	assumed a simplified block assemblage
		bounded by deformable discontinuity
		systems.
Empirical	Barton and	Used as a comparison for the analytical
	Grimstad, 1994	methods.
Rock Loading	Unwedge 2.01	Rock block loads estimated from
Shall are the		discontinuity spacing.

PERMANENT SUPPORT - Permanent Lining based on the above analyses (Mackay, 2010)





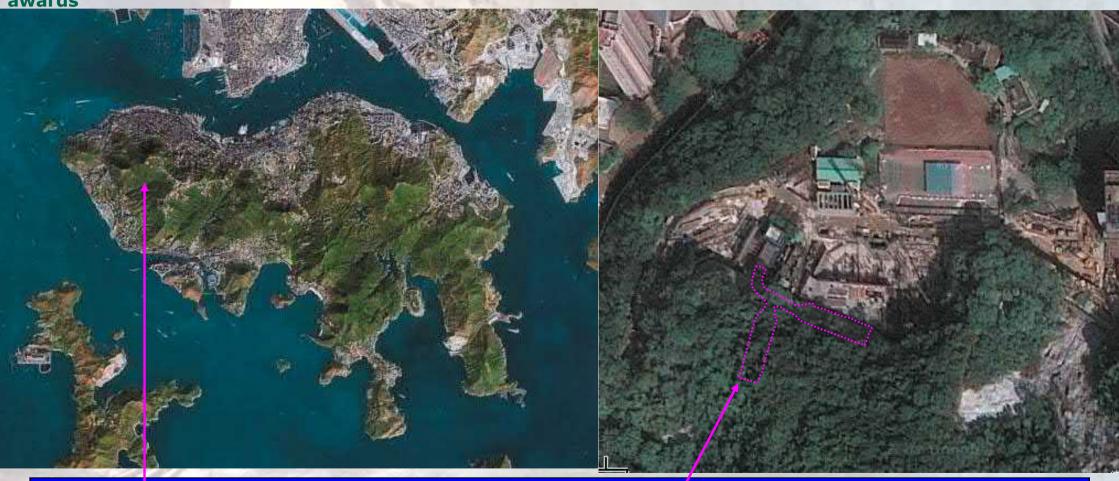






# Examples of Computer Applications to Caverns and tunnels (Hong Kong University Caverns - Location - Chung et al, 2010)

BACKGROUND – Following the University of Hong Kong Master Plan Review, carried out 2000, it was decided that an extension to the University Centennial Campus was required. To accommodate this, the existing Salt Water Reservoirs, previously located in a terrace adjacent to the University. Following a further review, 2006, it was considered preferable to accommodate the reservoirs into Caverns. The project has since gained sustainability awards

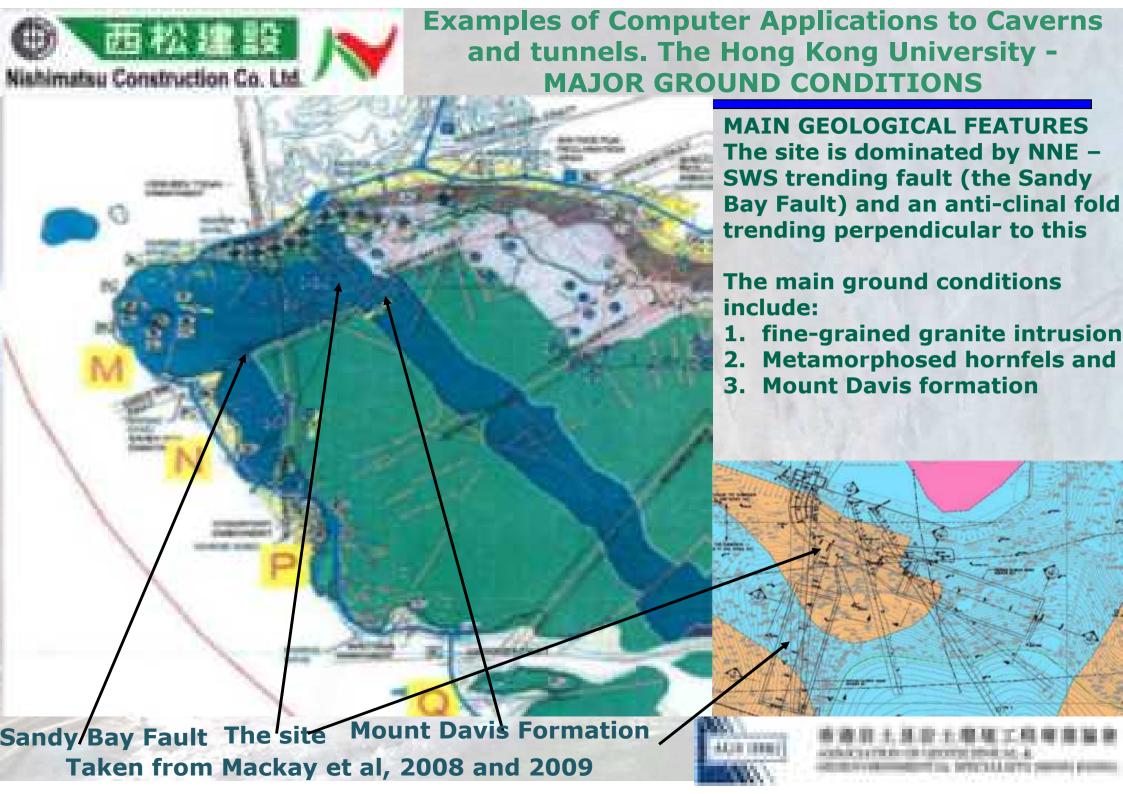


**Site Location** 

Salt Water Reservoir Tunnels – footprint beneath Lung Fu Shan Mountain









Examples of Computer Applications to Caverns and tunnels (Hong Kong University – considerations for the ground model)



#### THE GROUND

The discontinuities were influenced by the effects of: faults and intrusions. This caused an intense anisotropy which needed consideration in the analysis.



# Examples of Computer Applications to Caverns and tunnels (Hong Kong University)

Joint Spacing	Intact UCS	Constant (m)		GSI Medium	GSI Very Closely
(Js)	(Mpa)	(111)	,	spaced	Spaced
II or better	100	25	60 to 70	50 to 60	35 to 50
11 / 111	50	20	55 to 65	45 to 55	35 to 45
III	25	15	50 to 60	40 to 50	30 to 40
III/ IV (III dominant)	25	15	40 to 50	30 to 40	20 to 35
IV / V	10 (notional)	10	GSI N/A	GSI N/A	10 to 25

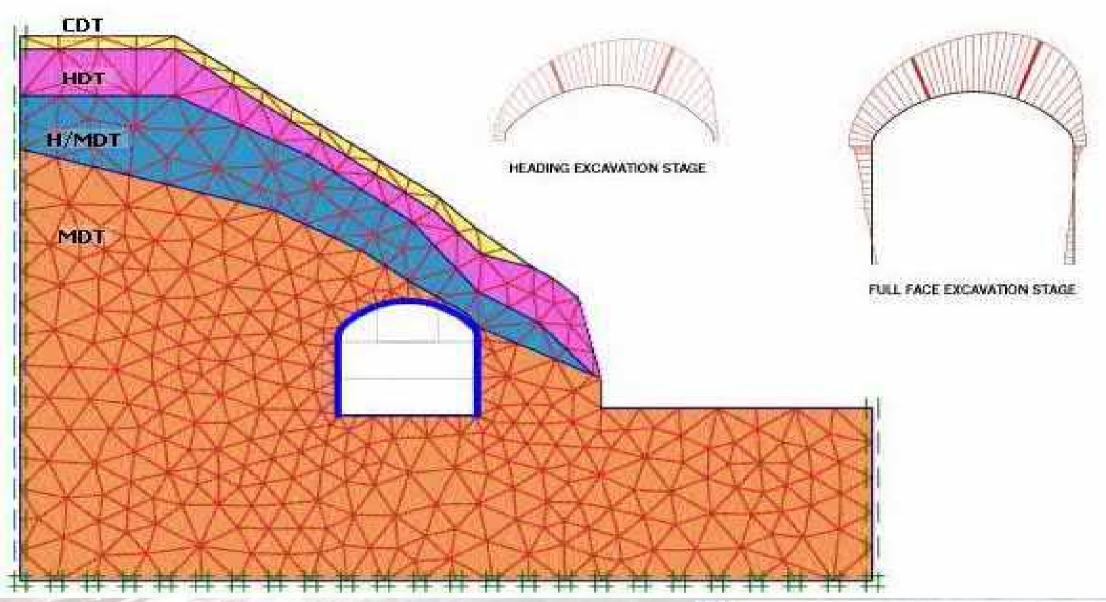
### **Computer analysis (PLAXIS)**







## Examples of Computer Applications to Caverns and tunnels (Hong Kong University)



**Computer analysis (PLAXIS)** 





# Nishimatsu Construction Co. Ltd.

#### **PUBLICATIONS**

- 1. Chung, E & Chan, C.C, (2008). *Innovative and Sustainable Solutions for the Hong Kong University Centennial Campus Construction,* the Hong Kong Institution of Engineers (HKIE) Asia Pacific Seminar Geological Conservation, Hong Kong, pp230-242.
- 2. Fookes, P.G. 1997. The First Glossop Lecture: Geology for Engineers: The Geological Model, Prediction and Performance. The Quarterly Journal of Engineering Geology; Geological Society: 30, 293-424.
- 3. Fookes, P.G., Lee E.M., Griffiths J.S., 2007. Engineering Geomorphology Theory and Practice. Whittles Publishing
- 4. Geotechnical Engineering Office, Civil engineering and Development Department Engineering, 2007, Engineering Geological Practice in Hong Kong, GEO Publication No. 1/2007, GEO.
- 5. Mackay A. D., Steele, D. & Toh, G. (2008). *Innovations in the Temporary Support Design for Weak Zones Encountered during the Salt Water Reservoir Tunnel Excavation.* Hong Kong University Centennial Campus, HKIE 28th Annual Seminar, Innovative Technologies in Geotechnical works, pp203–211.
- 6. Mackay A.D. Chow W., Steele, D & Chan T. (20-21/11/09). The Design and Construction of the Hong Kong University Underground Salt-Water Reservoir Support Requirements, Pok Fu Lam, HK SAR. IMMM, Tunneling Conference, HK; pp 169- 178.
- 7. Mackay A.D. (4/5/10). Geotechnical Design and Construction Considerations for the Adelaide Desalination Plant Shafts, Australia., HKIE Geot. Conf, 30th Ann. Sem., Geot. Aspects of Deep Excavations, pp 163 169.
- 8. Swannell, N.G. and Hencher S.R., 1999, Cavern Design Using Modern Software. The Australian Institution of Engineers, 10th Australian Tunneling Conference, 1999, Melbourne, Victoria, pp 269 278.
- 9. Thomas, T., 2008. It's not all bad. Tunnels & Tunneling, October 2008 Ed., British Tunneling Society.





# Code Based Design: Examples in Practice for Retaining Walls



**URS Benaim Limited** 

Prepared by Nigel Pickering 20 April 2013

www.ursglobal.com www.benaimgroup.com

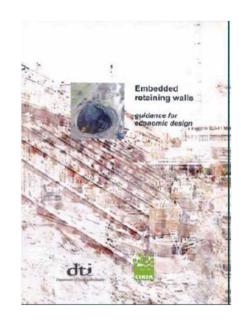


- Standards & Guides
- Software Analysis & Verification
- Example Application of CIRIA C580

## Relevant Standards & Guidance for the Design of Retaining Walls







CIRIA C580



GCO 1/90; Geoguides

Eurocode EC7, Parts 1 & 2

### **Geotechnical Design Approaches**



Publication	Date	Design Approach	Notes
GCO 1/90	1990	GFA (OFS)	Ref. CIRIA C104
Geoguides	1993 (Second Ed.)	PSF	Ref. Geoguides 2 & 3 for Hong Kong Application
CIRIA C580	2003	PSF	Ref. BS8002
Eurocode EC7	2007	PSF	Part 1 : Design Part 2 : Investigation & Testing

Overall or lumped FoS has proved satisfactory for many years and is intended to cover all uncertainties in the design. A limit state approach requires consideration of possible modes of failure and uncertainties in a more systematic way.

### **ULS Design Factors Compared**



	Actions	Material Partial Parameters		
Design Approach	Surcharge	Tan. Φ'	C'	Su
GCO 1/90	Overall FoS			
Geoguide 1	1.5	1.2	1.2	2.0
CIRIA C580*	Minimum 10kPa	1.2	1.2	1.5
EC7 DA1(2)	1.35	1.25	1.25	1.4

<sup>\*</sup> Unmodified

Method		Design Approach A		Design Approach B		Comments
		Recommended range for moderately conservative parameters (c', ø', or Cu)		Recommended minimum values for worst credible parameters (c'=0, Ø')		
		Temporary works	Permanent works	Temporary works	Permanent works	
(a) Factor on Embedment Depth, F <sub>d</sub>	*Total stress	1.1 to 1.2 (usually 1.2)	1.2 to 1.6 (usually 1.5)	Not recom – mended	1.2	This method is empirical. It should always be checked against one of the other methods.
(b) Factor on Moments Based on Gross Pressure, Fp	Effective stress $\phi' \ge 30^{\circ}$ $\phi' = 20 \text{ to } 30^{\circ}$ $\phi' \le 20^{\circ}$ * Total stress	1.2 to 1.5 1.5 1.2 to 1.5 1.2	1.5 to 2.0 2.0 1.5 to 2.0 1.5	1.0 1.0 1.0 1.0	1.2 to 1.5 1.5 1.2 to 1.5 1.2	These recommended $F_p$ values vary with $\phi'$ to be generally consistent with usual values of $F_s$ and $F_r$ .
(d) Factor on Moments Based on Net Available Passive Resistance, Fr	*Total stress	1.3 to 1.5 (usually 1.5)	1.5 to 2.0 (usually 2.0)	1.0	1.5	Not yet tested for cantilevers. A relatively new method with which little design experience has been obtained.
(e) Factor on Shear Strength on Both Active and Passive Sides, F <sub>g</sub>	Effective stress			1.0	1.2	The mobilised angle of wall friction, $\delta_m$ , and wall adhesion, $c_{wm}$ , should also be reduced.

Total stress factors are speculative, and they should be treated with caution.

### **Modified C580 in Hong Kong**



- •BD/GEO Review 2004, Trial Period 2005 –
- •Partial factors, surcharges, soil properties and groundwater as per Geoguide 1 (2<sup>nd</sup> Ed).
- Structural load factors from SLS increased to 1.4 (from 1.35)
- Sensitivity for single props +/- 0.5m in level
- Ground movements, wall installation and dewatering effects as per HK practice.

### **Design Factors for Temporary Works**

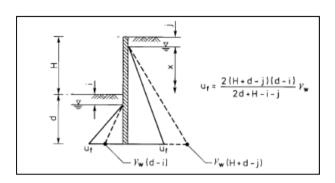


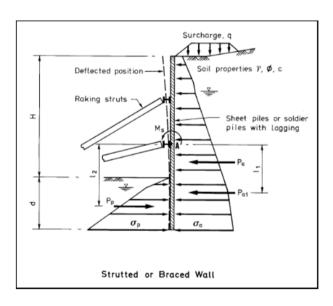
- Distinction made in GCO 1/90
- •CIRIA C580:
  - -The Observational Approach (Method C) in conjunction with Method B (Worst Credible)
  - -i.e. Most Probable characteristic values with contingency measures based on Method B
- •Eurocode EC7:
  - Factors may be adjusted to be more severe in case of abnormal risks or exceptionally difficult ground, or less severe for temporary structures or transient conditions where conditions justify it

### Other Design Aspects...



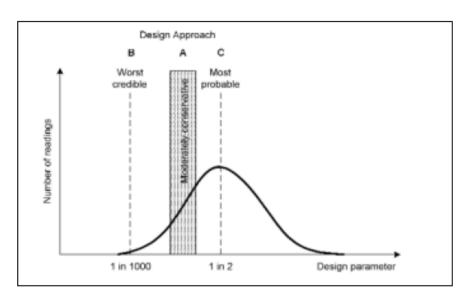
- Groundwater profile balanced, hydrostatic, worst credible, most unfavourable
- Surcharges e.g. min 10kPa
- EP Coefficients NAVFAC, Caquot
   & Kerisel
- Wall friction
- Undrained → Drained
- Unplanned excavations 0.1H, 0.5m
- Passive softening zone
- Minimum earth pressures in undrained conditions
- Wall stiffness El adjustments
- Approach for multi-propped walls
- Soft Clays
- Constitutive model
- Risk Level
- Soil parameters





#### **Characteristic Values**





(CIRIA C580)

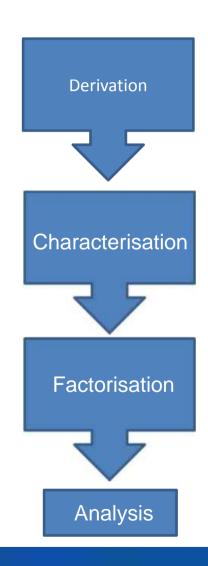
Statistical assessment of geotechnical properties:

- Normal or log normal distributions
- Usually most interest in the 95% confidence limit of the data mean (Moderately conservative, cautious estimate)
- 5% fractile (Worst Credible)
- Sample size?
- Trends & local variations?
- Exclusion of rogue data?

Statistical methods may be used but they are not mandatory

### **Geotechnical Parameters**





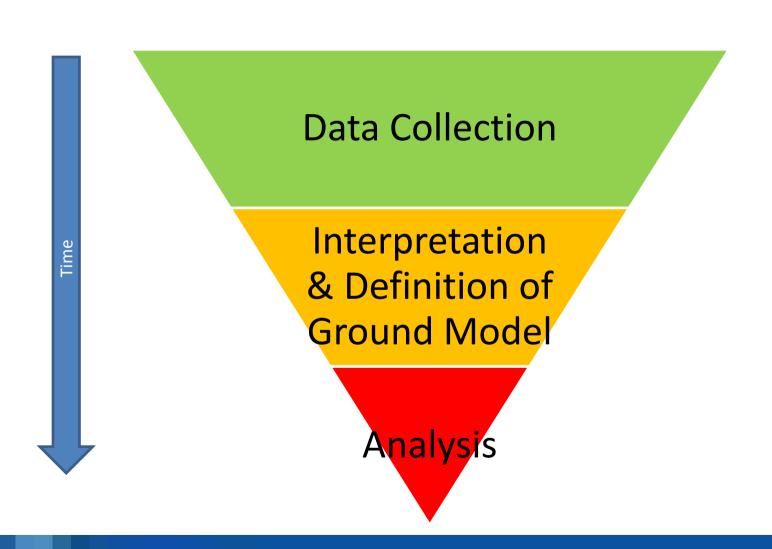
Desk Study, Field Investigation, Laboratory Testing, Correlation, Empirical, Field/model Testing

Interpretation, statistical review, Engineering Judgement, Experience, Back Analysis, Criticality Assessment, Design Approach, Risk Assessment CAUTIOUS ESTIMATE

Code / Standard Defined Factors

Analysis & Review







### Modified C580 Design

Multi-propped Wall

Reduced Toe Level

Software Verification

### **Multi-propped Deep Excavation**

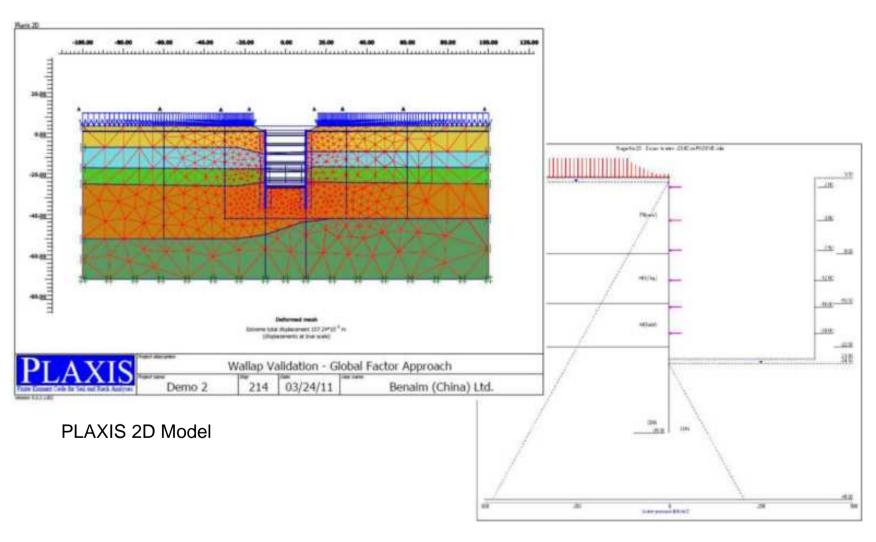




The Site

### **Analysis Software**





**WALLAP Section** 

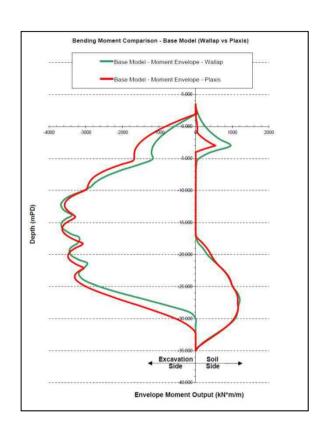
### **Derived Soil Parameters**



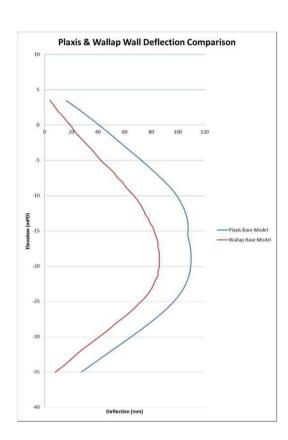
Stratum	Soil Type	Stiffness Derivation (kN/m2)	Typical Strength Values
Fill	Clay	Eu = 400. Cu (8,000)	Cu = 20 kN/m2
	Sands	E' = 1.N (10,000)	φ' = 35°
Marine Deposits	Clay	Eu = 400. Cu (12,000)	Cu = 30 kN/m2
Alluvium	Sands	E' = 1.5.N (12,000 - 45,000)	φ' = 36°
CDG	Non cohesive	E' = 2.0.N (28,000 - 80,000)	$\phi' = 36^{\circ}$ c' = 5 kN/m2

### **Software Comparison**





**Bending Moments** 



Wall Deflections

#### **GFA & Modified C580**



#### • Section analysed for both GFA and CIRIA C580

Strut Force				
	C580 (ULS) [kN/m]	GFA [kN/m]	C580 ULS / GFA	
T1	697	690	101%	
T2	1404	1593	88%	
Т3	1149	1306	88%	
T4	2769	3384	82%	
T5	2735	3018	91%	
Т6	2906	2043	142%	

<sup>\*</sup> Increase in T6 strut force highly related to over excavation allowance required by C580

Wall Bending Moment					
	C580 (ULS)	GFA			
Max. Wall Bending Moment [kNm/m]	5890	5928			

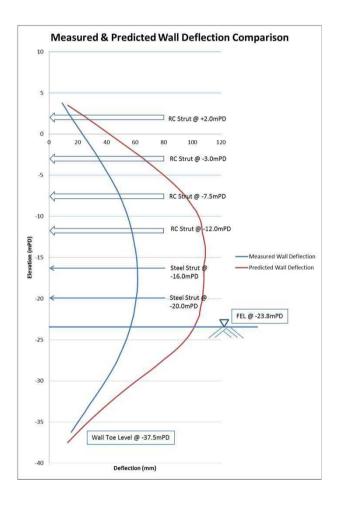
Toe Level (mPD)		
Global Factor Approach with FoS=1.5	Global Factor Approach with FoS=2.0	C580 ULS case
-34.0	-42.0	-34.5

#### **Predicted & Actual**



#### **Strut Force**

	Predicted SLS Strut Force (kN/strut)	Measured Strut Force by Strain Gauge (kN/strut)	Measured / Predicted
T3	7150	3300	46%
T4	10500	6100	58%
T5	10350	6400	62%



#### **Strut Arrangements**





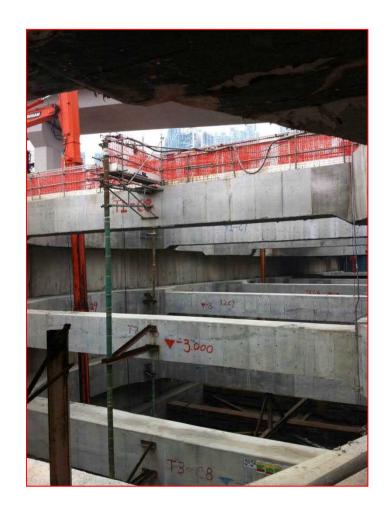
Upper RC Struts



Lower Removable Strut

#### **Strutting & Excavation**









**Excavation Progress** 

#### **Concluding Remarks**



- Knowledge of the ground conditions depends on the extent and quality of the ground investigations. Such knowledge and the control of workmanship are usually more significant to fulfilling the fundamental requirements than is precision in the calculation models and partial factors.
- 2. Statistically derived soil parameters should be understood in context of quantity and quality of the results and viewed as a back-up to Engineer derived parameters.
- 3. Generally better to use a simple analysis with appropriate soil parameters than a complex approach with inappropriate values.
- 4. Derivation of geotechnical parameters is typically conservative; more records of observed wall performance and back analysis should be reported
- 5. The provision of digital data should be mandatory for ground investigations and this should be available for downstream Engineers an Constructors.
- 6. Increased guidance on application to temporary works and design in soft clays is required.



**Data Collection** 

Interpretation & Definition of Ground Model

Analysis



## **URS Benaim**

**Local Expertise, Global Resources.** 









## **Thank You**

# Advanced 3D Modelling for Debris Mobility and Flexible Barrier Structures

AGS (HK) 1-Day Seminar on Geotechnical Computer Modelling 20<sup>th</sup> April 2013

Jack Yiu



### Background



2008 Yu Tung Road debris flow

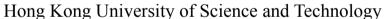


1999 Sham Tseng San Tsuen debris flow

- Relatively steep natural terrain in Hong Kong
- Close to development and major infrastructure facilities
- A need for mitigating such risks using flexible barriers

### The Challenge









Illgraben, Switzerland (Extracted from Geobrugg)

- A comprehensive design guidance for flexible barriers is lacking
- A better understanding of the interaction between debris and flexible barrier structures is needed
- The numerical analysis for this problem is complex and requires advanced numerical skills and modelling technique.

### Advanced 3D Numerical Study

- Research-level initiatives required to develop design guidance
  - Instrumentation and back analysis
  - Field tests
  - Laboratory tests
  - Numerical Analysis

#### Purpose of the Study

- To come up with an appropriate modelling technique for the investigation of the interaction between landslide debris and flexible barrier structures
- To enable parametric study of different sizes and velocity of debris flow scenario for the development of design guidance for flexible debris-resisting barriers

### Advanced 3D Numerical Study

- Driven the initiative of the Geotechnical Engineering Office (GEO), Arup is undertaking an pilot numerical investigation of the landslide debris / flexible barrier interaction.
- A staged approach with benchmarking exercise for validation
  - 1. Simulation of rockfall field tests
  - 2. Simulation of laboratory flume tests and real debris flow cases in Hong Kong
  - 3. Simulation of an instrumented case of debris flow impacting a flexible barrier
  - 4. Parametric study of different sizes and velocity of debris flow impacting a flexible barrier

#### LS-DYNA

#### Crashworthiness Simulation

For many automotive companies LS-DYNA is a tool for understanding the deformation of complex systems such as vehicle structures. The ability of LS-DYNA to model contacts and its wide range of material models make it ideally suited for this type of analysis. It also includes a number of specific features for automotive applications such as

- Spotweld Models
- Airbag Models
- · Seatbelt System Models

#### Seismic Analysis

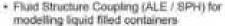
LS-DYNA provides engineers with a tool for modelling the complex nonlinear behaviour of a building during seismic events. Non-linear response history analysis can be performed using element types and functions including:

- Lumped plasticity
- · Fibre elements
- Nonlinear dampers
- Buckling elements
- Frequency-dependent damping



#### **Drop Testing**

LS-DYNA has been used to simulate impact events of different containers for many years. Ranging from small electronic products such as mobile phones and laptop computers, up to large nuclear fuel containers. Features include:

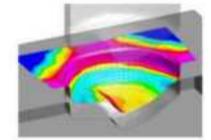


- Element Free Galerkin (EFG) for modelling gracks
- Explicit-implicit switching for studying steady state deformation



#### Metal Forming

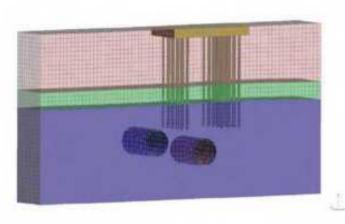
LS-DYNA has been used for sheet metal stamping since the late 1980's and can be used to assess a proposed forming process and tool design. Along with the forming process you can also simulate trimming and springback. LS-DYNA has the capability to analyse a variety of different forming processes including:



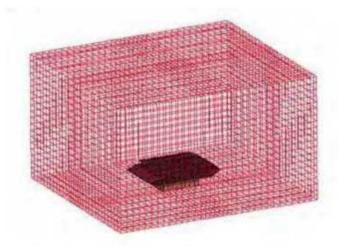
- · Rigid Tool Stretch and Draw Forming
- · Sheet and Tube Hydro Forming
- · Flex Forming
- · Roll Forming
- Superplastic Forming
- LS-DYNA has been extensively used in automotive, rail, civil, structural, wind and vibration engineering.
- Able to simulate highly dynamic and large deformation problems



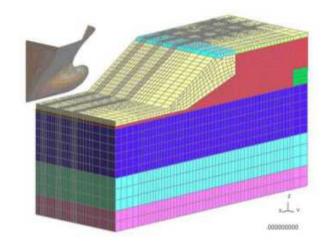
### LS-DYNA

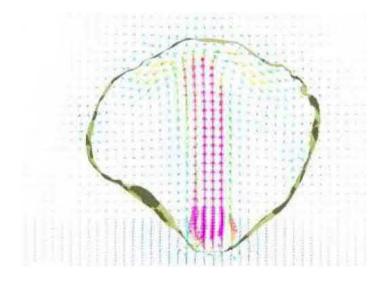


Geotechnical analyses



• Fluid-structure interaction





## Modelling of flexible barrier structures



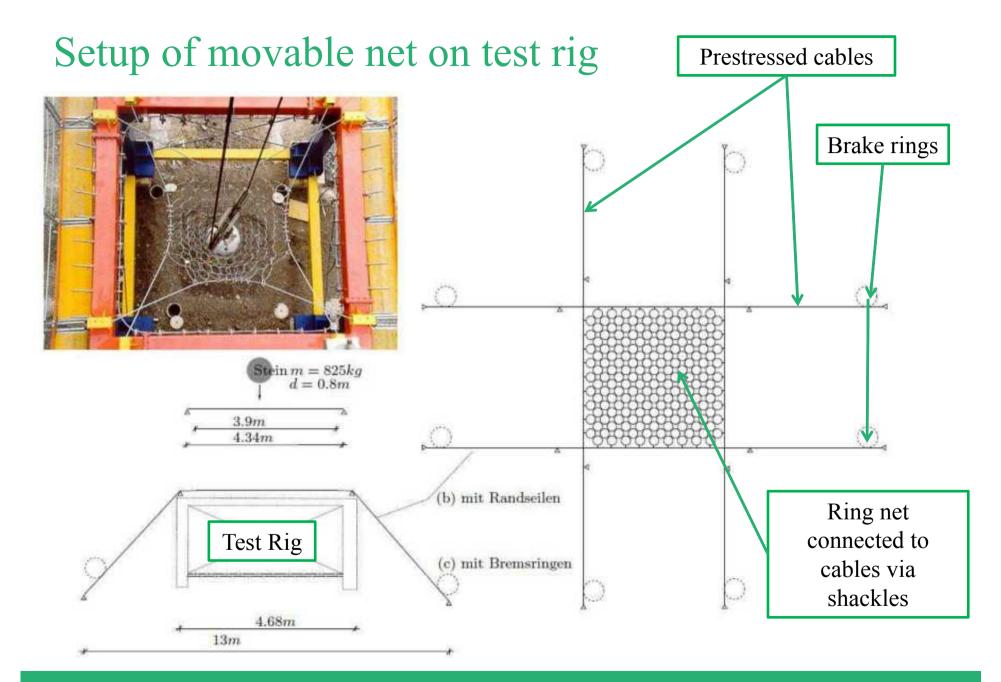
#### Modelling of flexible barrier structures

- Referenced from Grassl (2002) and Volkwein (2004)
- It discussed his numerical simulation of the following field tests:
  - Rock fall test on immovable net mounted on test rig
  - Rock fall test on movable net mounted on test rig (with & without brake rings)
  - Rock fall test on a full scale flexible barrier
- Cases adopted for LS-DYNA simulation:
  - Weight dropped at 16m height (both with and without brake rings)
  - Weight dropped at 32m height (only with brake rings)



Selected for LS-DYNA simulation, because:

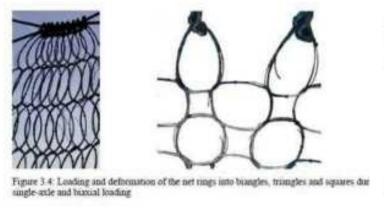
- not overly complicated
- test results with / without brake rings available

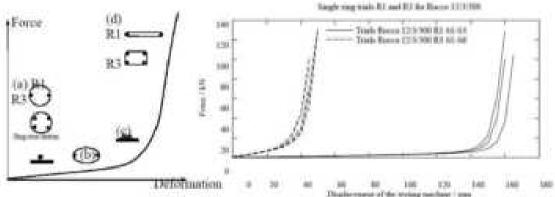


#### Steel wire net

- A wire bent to several windings to form a solid ring by dint of clamps
- Rings are interconnected but freely to move / slide against each other
- 4 connection points for inner rings and 3 for outer ones
- Under loading, rings deform in bending and subsequently in tension

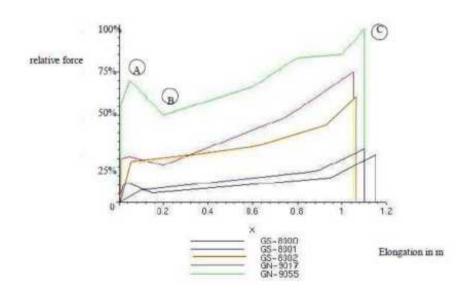






#### Brake elements

- Designed to elongate for preventing damage to other barrier components
- The stiffness can be approximated by multi-linear force-elongation relationship
- Static and dynamic test results could be different







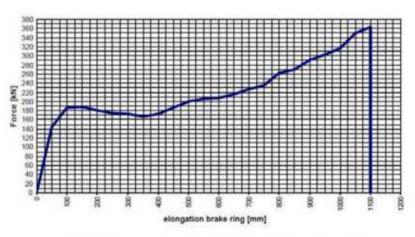
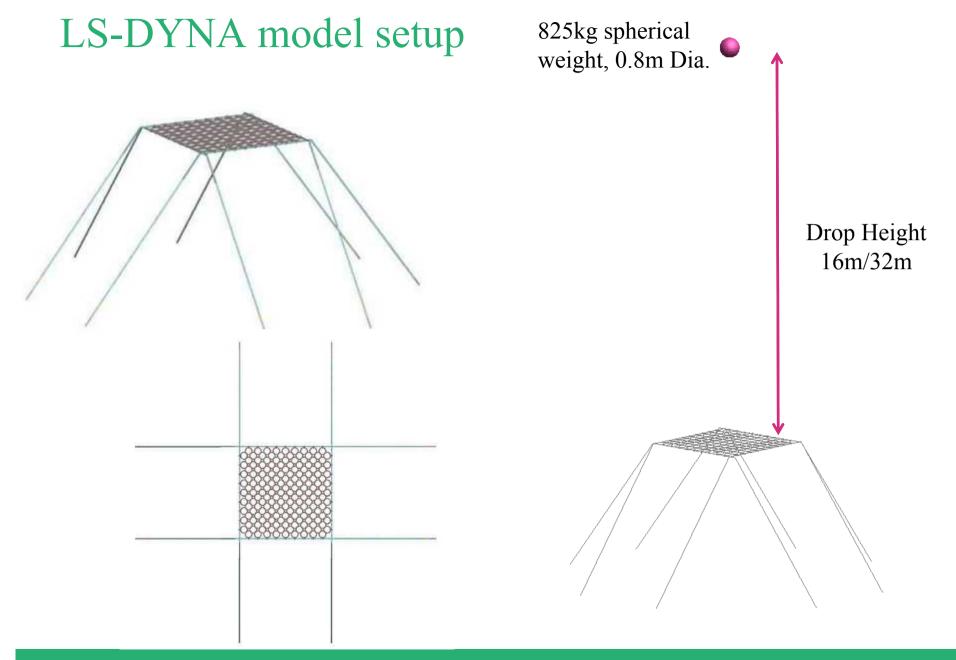
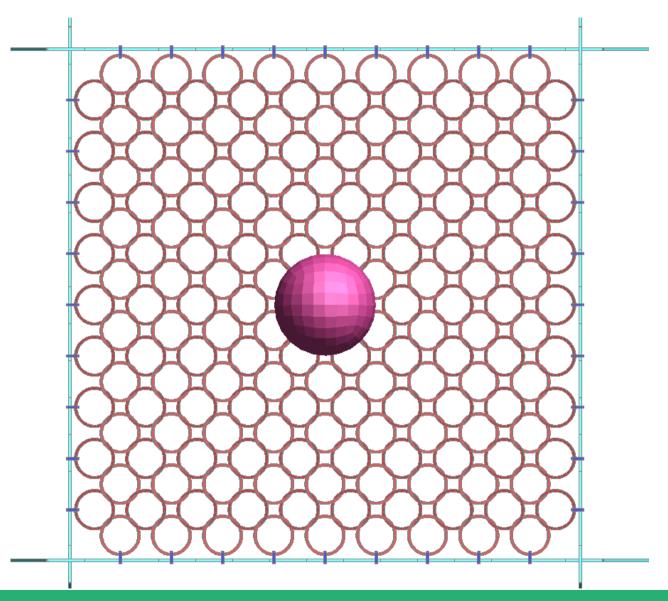


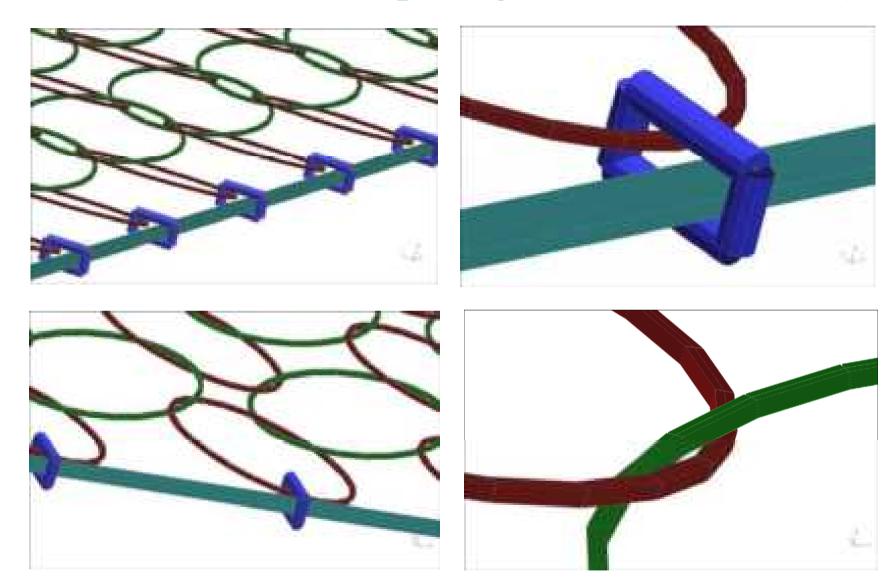
Figure 8 Brake Ring GN-9055 Material Test (Mean) with Geobinex 22 mm Rope

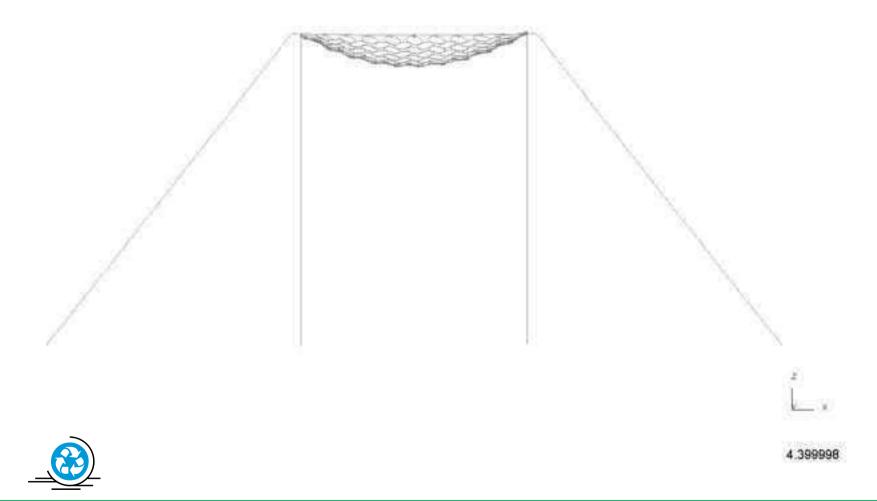


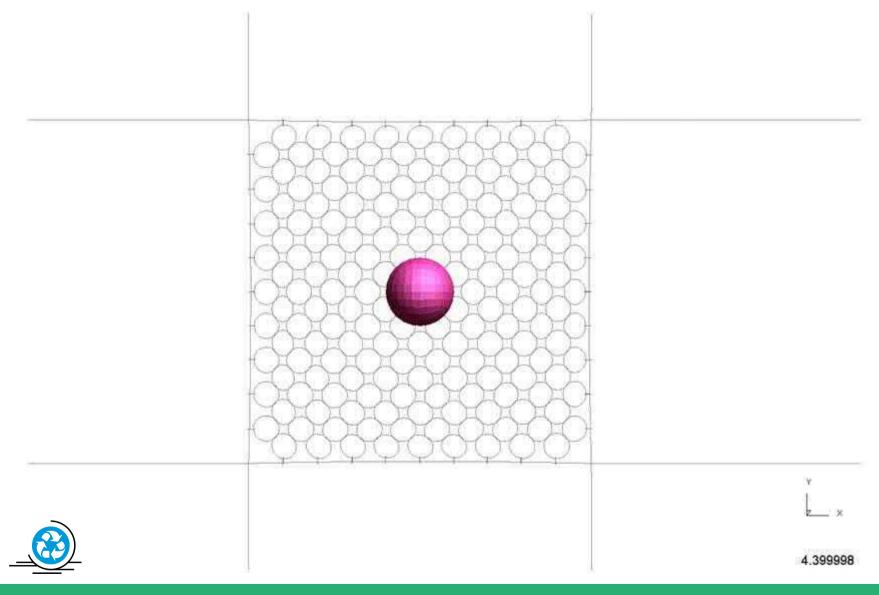
## LS-DYNA model setup (plan view)

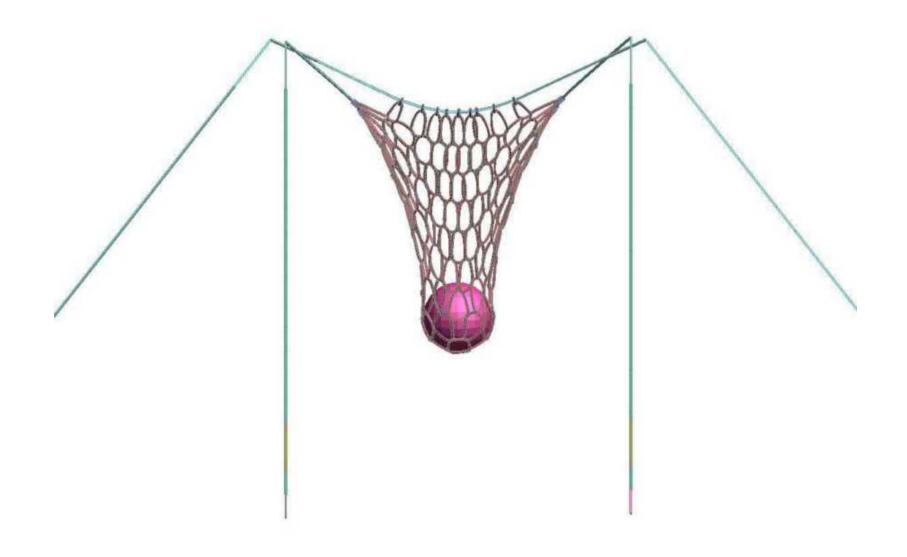


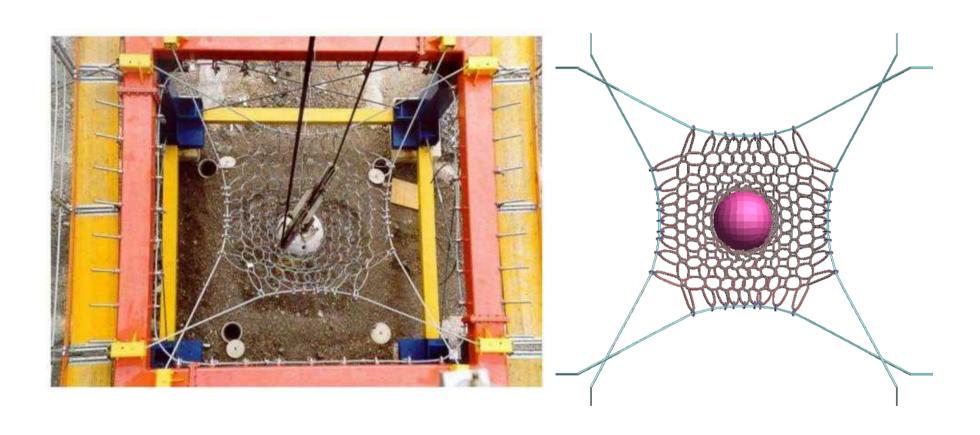
### LS-DYNA model setup (ring and shackle details)





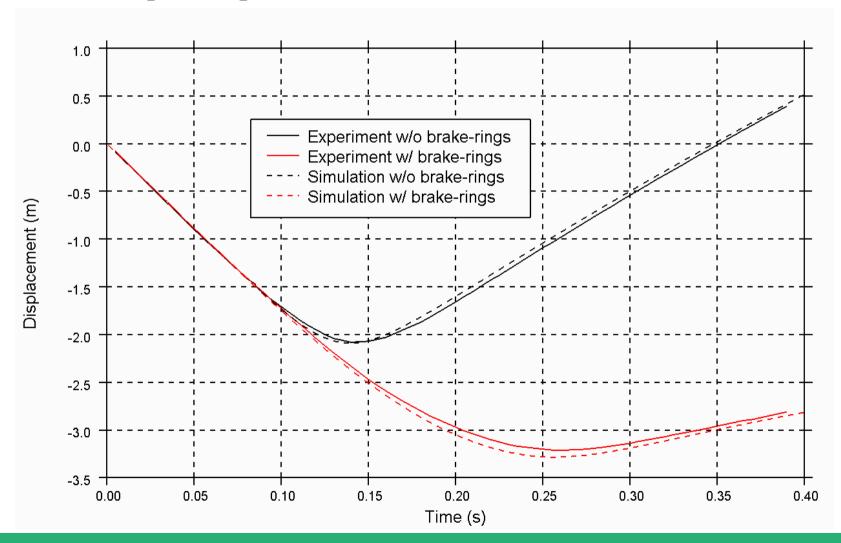






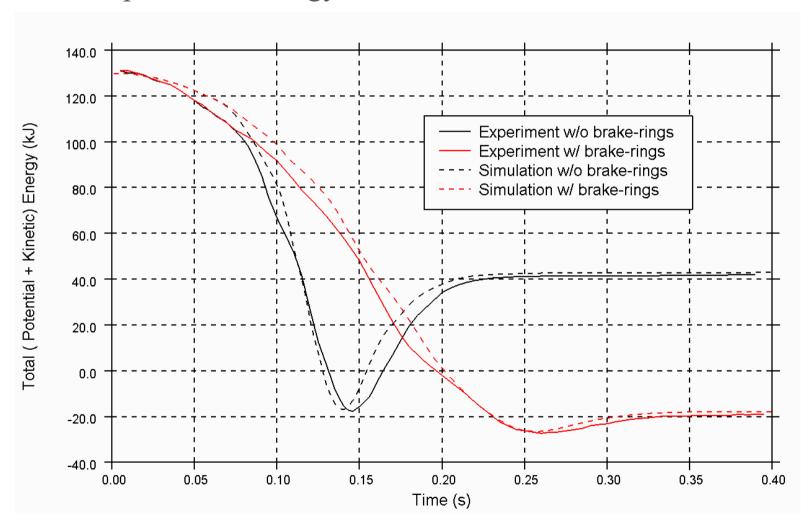
### Test result vs. LS-DYNA simulation

• 16m Drop – Displacement vs. Time



#### Test result vs. LS-DYNA simulation

• 16m Drop – Total Energy vs. Time



## Modelling of landslide debris



### Modelling of landslide debris

- Conventional meshing technquies may not be able to handle large deformation of landslide debris
- Arbitrary Lagrangian-Eulerian Method (ALE) has been adopted

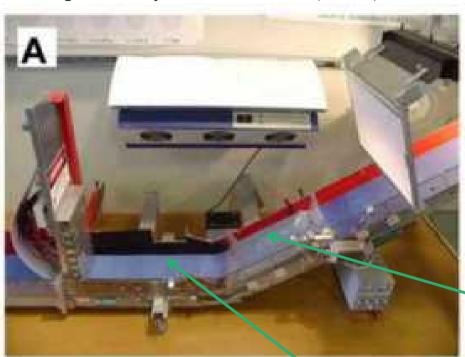


Debris flow simulation using conventional Lagrangian meshing method

### USGS laboratory flume tests

Sand loaded behind the flume head gate

• Reported by Iverson et al (2004)



B

head gate

Formica base

Urethane insert to form topography

- 2 nos. experiment carried out:
  - i) Reversed topography; ii) Angular / rounded sand; iii) gate opening size

## LS-DYNA Model Setup – Experiment A

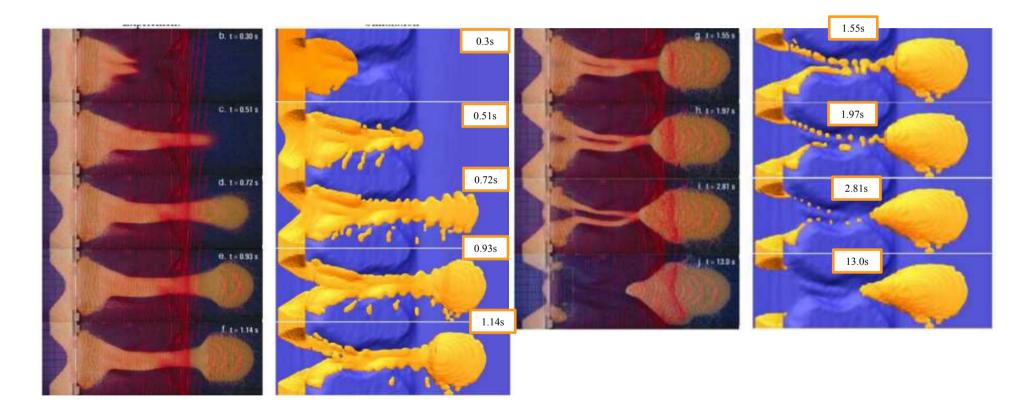


### LS-DYNA Simulation – Experiment A



## Experimental Result vs. LS-DYNA Simulation

• Experiment A



# Yu Tung Road debris flow on 7 June 2008 (GEO Ref. No. LS08-0241)

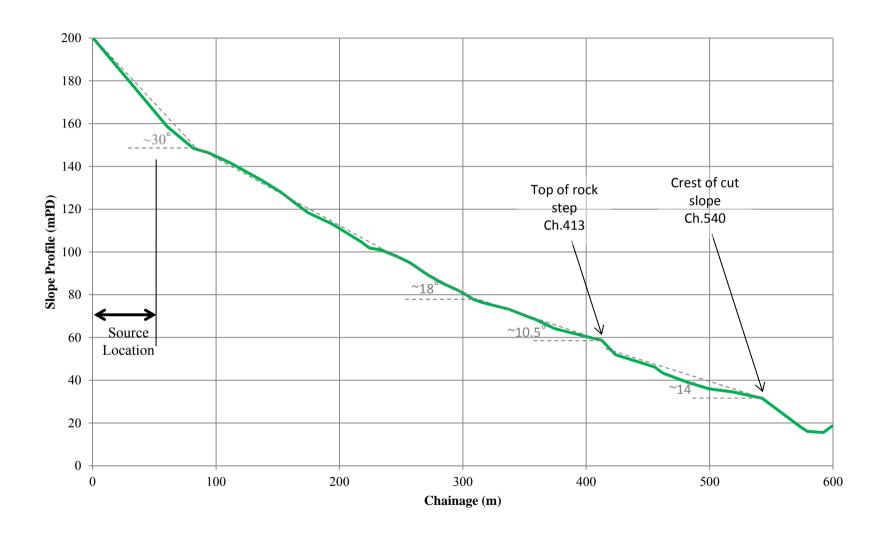




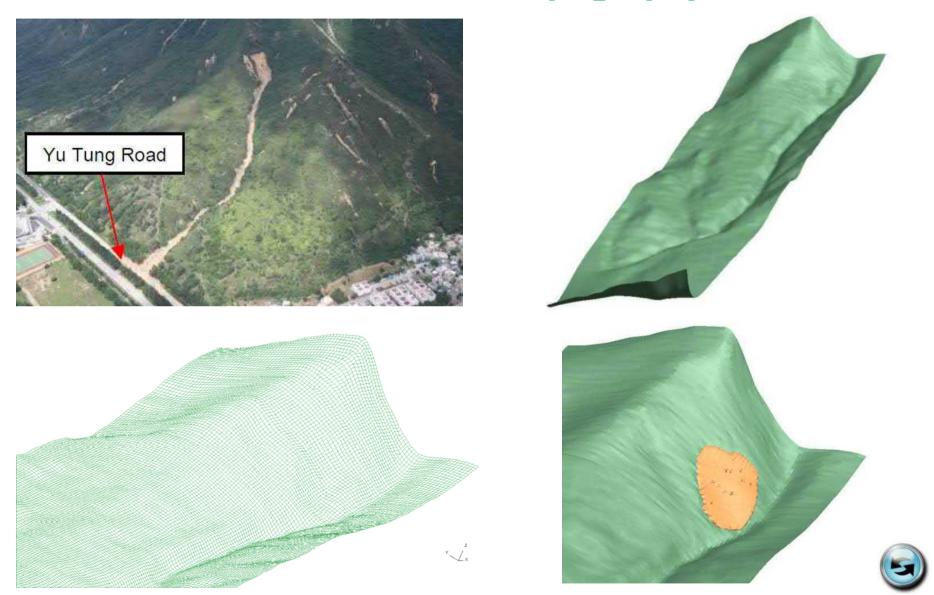




### Yu Tung Road landslide – slope profile



# The LS-DYNA model – the topography



## The LS-DYNA model – runs summary

- Frictional model adopted i.e. basal resistance is controlled by contact friction between rigid shell (the topography) and ALE solid (debris mass) only
- Debris mass movement captured at regular time intervals
- Entrainment and secondary slides not included
- The simulation was repeated with different contact friction and debris mass internal friction

# Results and findings

• Simulation "Run 13"  $- \phi_b = 25$  ,  $\phi = 5$ °

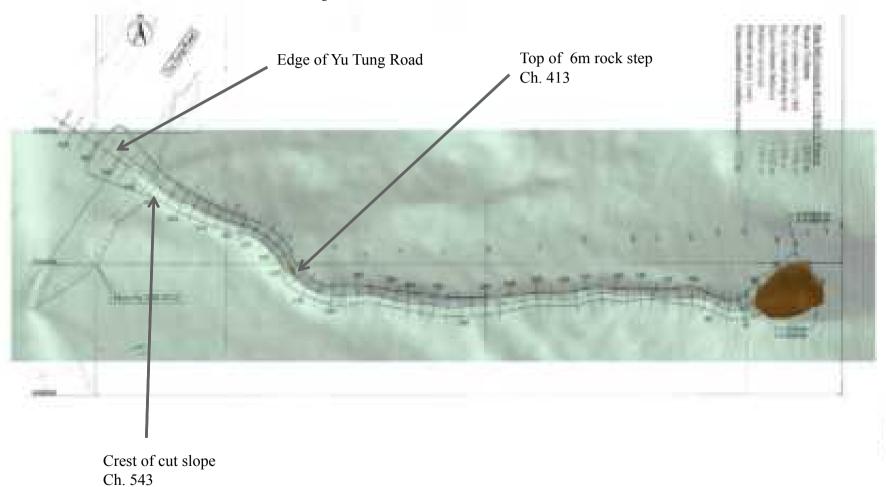




# Results and findings

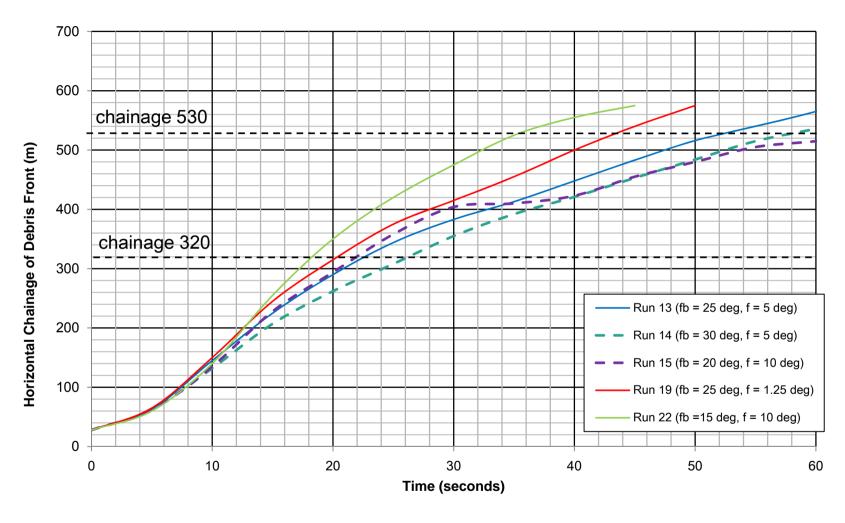


• Simulation "Run 13"  $-\phi_b = 25$  ,  $\phi = 5$ °



.0000000000

## Results and findings



• Frontal displacement vs. time plot

## Voellmy Rheology in LS-DYNA

- Development of Voellmy rheology in LS-DYNA
  - Including an additional resistance term that is proportional to the square of the debris velocity

$$T = A_{i} \left[ \gamma H_{i} \left( \cos \alpha + \frac{a_{c}}{g} \right) \tan \phi + \gamma \frac{v_{i}^{2}}{\xi} \right]$$

- Question: where and how should we apply this resistance term?
  - The existing friction is applied at the ALE solid / rigid shell (i.e. topography) interface. Can we do the same for the Voellmy term?

### In DAN/W or similar software

• Extracted from Hungr (1995)

Fig. 2. The Lagrangian mesh in curvilinear coordinates. Boundary blocks are numbered i = 1 to n, mass blocks j = 1 to n - 1.

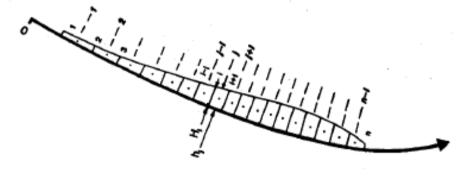
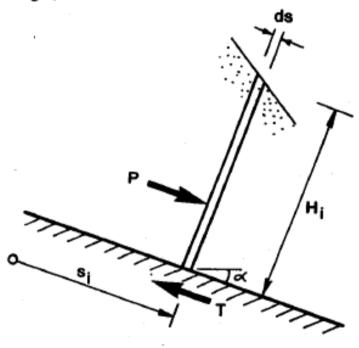


Fig. 3. Forces acting on a boundary block (other than weight).



# Voellmy-like damping function within ALE solid

- Therefore, consider adding a damping term within the ALE solid instead
  - $F_{damp,n} = D_{v2}.m_n.v_n^2$
  - $D_{v2}$  is the new input parameter controlling the velocity-squared-proportional damping
  - $m_n$  is the mass of node n,  $v_n$  is the velocity vector of node n
- Remember the Voellmy term is  $(\gamma/\xi)v^2$

$$D_{v2}.L.B.T.(\gamma/g).v^{2} = L.B.(\gamma/\xi)v^{2}$$

$$D_{v2} = A_{i}\left[\gamma H_{i}\left(\cos\alpha + \frac{a_{c}}{g}\right)\tan\phi + \gamma\frac{v_{i}^{2}}{\xi}\right]$$

$$D_{v2} = g/(\xi T)$$

Where  $\gamma$  = unit weight,  $\xi$  = turbulence term, v = flow velocity, g=acceleration due to gravity

• The correlation requires  $\xi$  as well as the T (the thickness of debris)

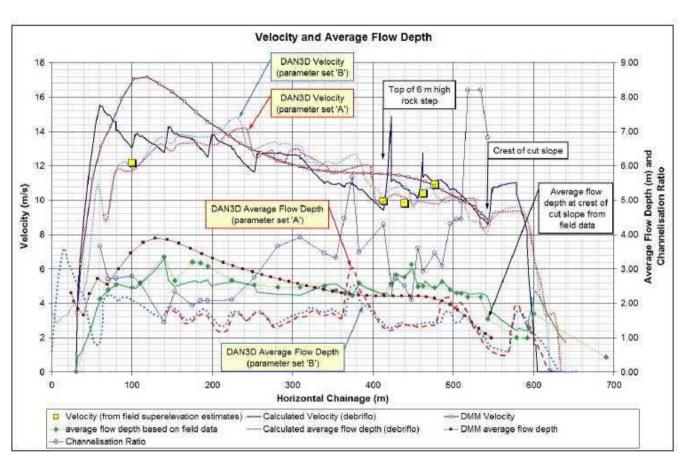
# Trial on 2008 Yu Tung Road landslide

• The simulation was re-run using the following parameters (typical values suggested in GEO Report 104):

- 
$$\phi_b = 11$$
°

$$\xi = 500 \text{m/s}^2$$

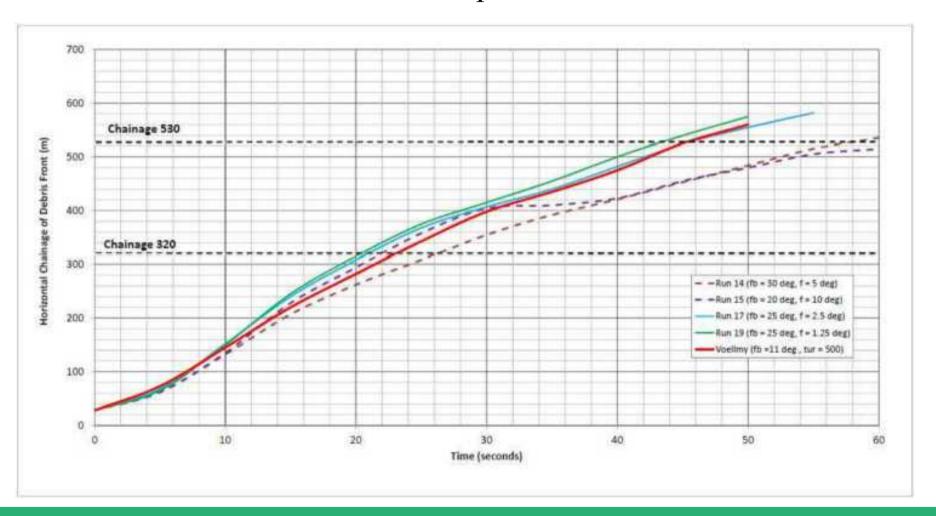
- T = 2m



Tattersal et al. (2009)

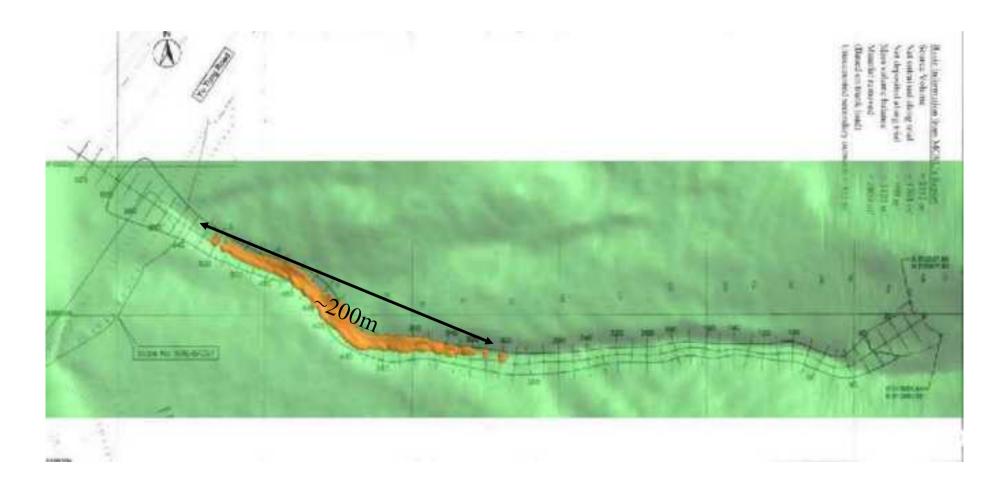
# Trial on 2008 Yu Tung Road landslide

• Debris front location vs. time elapsed



# Trial on 2008 Yu Tung Road landslide

• Distance between the front and the tail of the landslide debris



# Debris-Structure Interaction



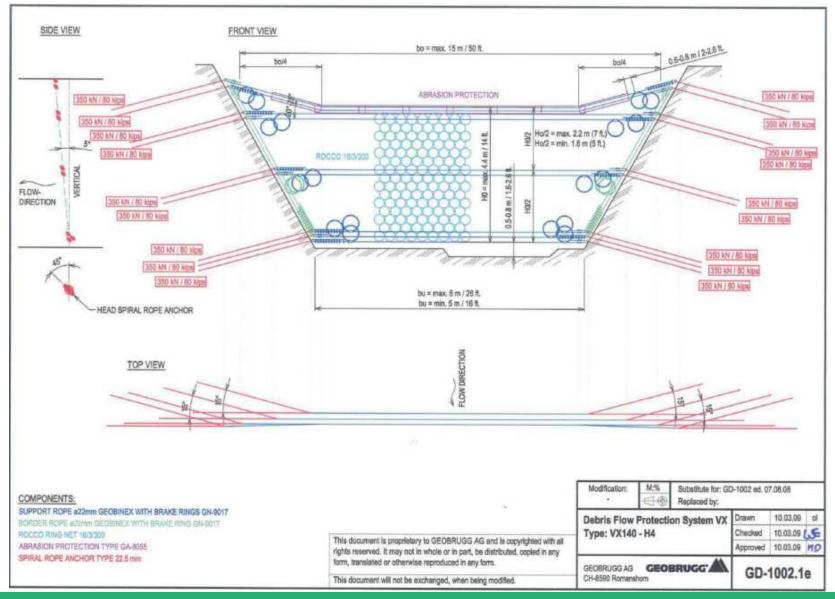
### The flexible barrier

• Looking from the front



The test site in Illgraben, Switzerland

# Model setup – barrier type VX-140-H4



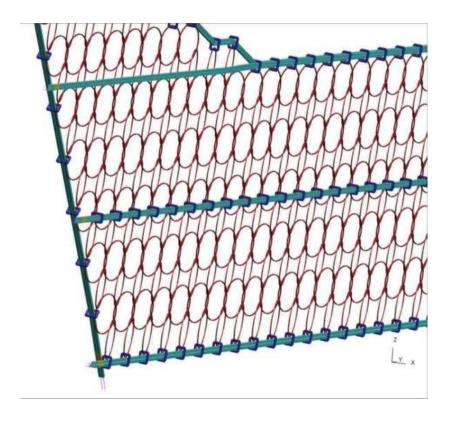


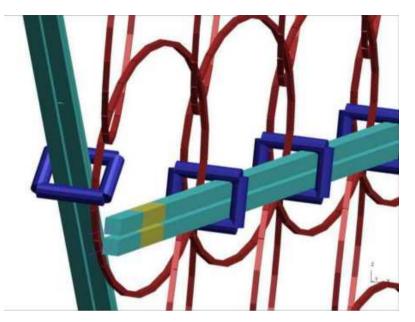
# Model setup in LS-DYNA

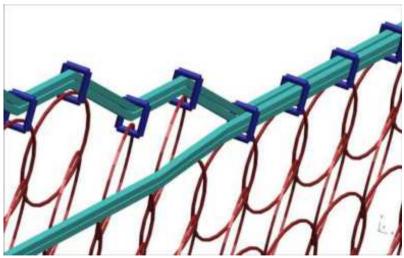


# Model setup in LS-DYNA

• Details of the barrier

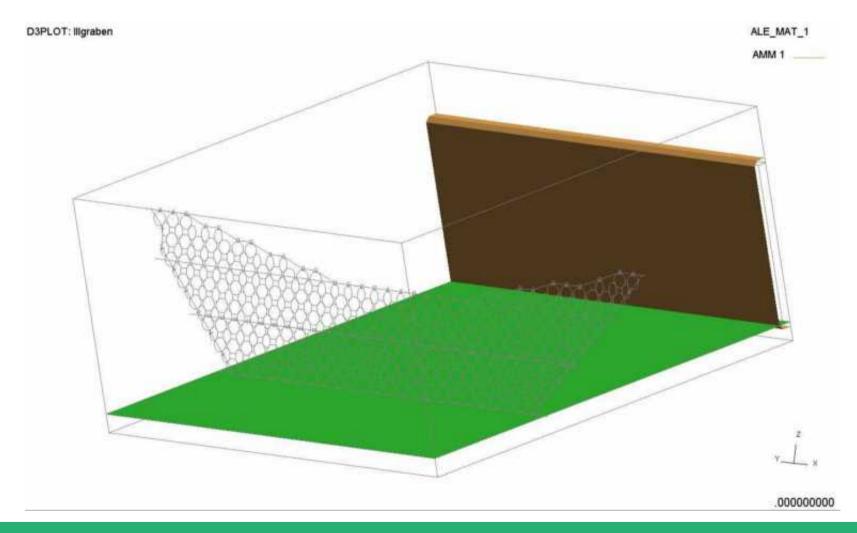






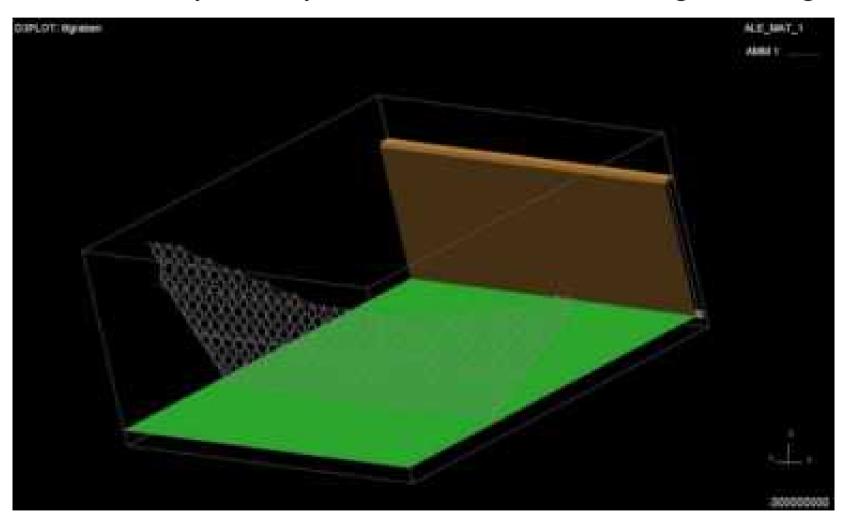
### Trial simulation - results

•  $1^{st}$  trial – very "thick" debris, internal friction angle = 40 deg



### Trial simulation - results

•  $2^{nd}$  trial – very "watery" debris, internal friction angle = 5 deg

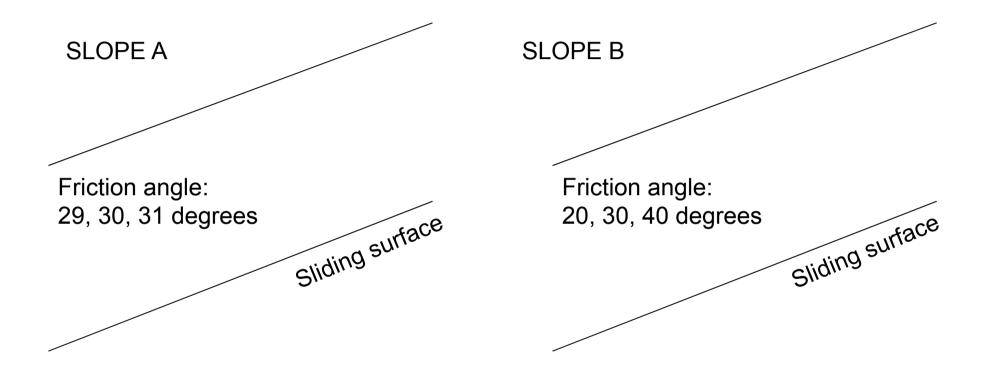


Thank you

# Probabilistic slope stability analysis and seismic hazard assessment with Excel applications

J.P. Wang
Dept. Civil & Environmental
HKUST

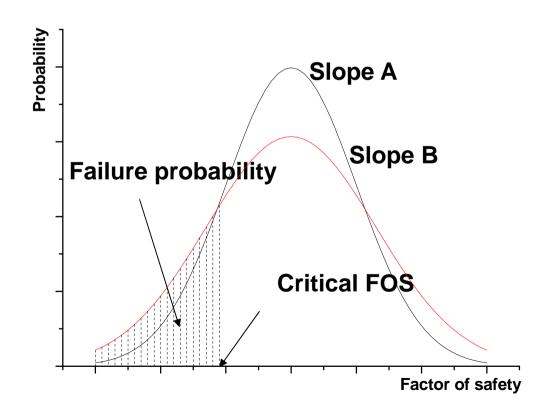
# **Deterministic analysis**



=> Given the same sample's mean, the two slopes are associated with the same factor of safety

# **Probabilistic analysis**

 Probabilistic analysis accounts for the sample's variability as well, estimating the FOS's distribution



# Methods for probabilistic analyses

- Monte Carlo Simulation
- First-order-second-moment
- Point-estimate method or Rosenblueth's method
- => One thing in common is the tedious computation involved during analysis

# **Monte Carlo Simulation (MCS)**

- What is the probability getting "1" when tossing a dice?
- Below is the result of tossing the dice 100 times:

1	1	2	1	6	1	2	4	3	5
5	6	2	4	5	5	1	3	4	2
1	5	5	6	3	3	5	6	3	5
5	5	6	1	6	2	6	3	5	1
3	4	4	1	3	1	5	3	3	6
6	5	3	3	2	2	2	3	1	2
6	2	2	4	1	2	1	3	3	6
2	3	4	1	3	2	4	1	4	1
3	3	6	2	4	5	1	4	5	6
4	2	3	2	3	4	2	3	5	4

• MCS solution = 17 / 100 = 0.17

### Monte Carlo Simulation (MCS)

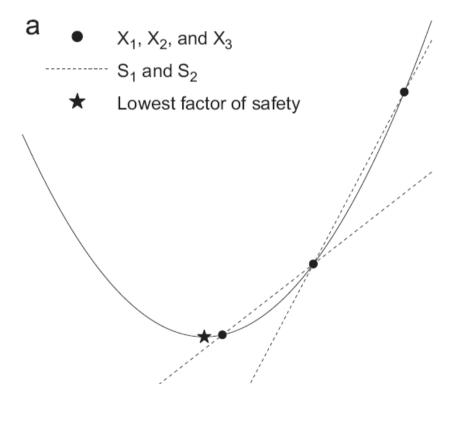
- The larger the sample size, the more reliable the result
- Although there is some suggestion about MCS's sample size from theoretical points of view, sizes such as 50,000 are good enough
- As a result, it is lots of calculation
- To improve the computational efficiency in MCS:
  - 1) more powerful hardware
  - 2) better software (algorithms)

# An efficient algorithm in searching for the "pole" in circular slope stability

### **Trial and Error:**

# ★ Pole with lowest FOS ○ Trial poles Н Slope

### **New algorithm**



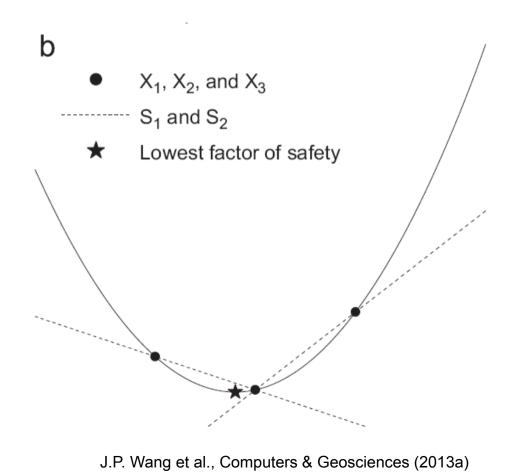
J.P. Wang et al., Computers & Geosciences (2013a)

# An efficient algorithm in searching for the "pole" in circular slope stability

### **Trial and Error:**

# ★ Pole with lowest FOS ○ Trial poles Н Slope

### **New algorithm**

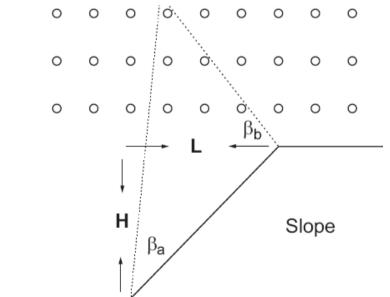


# An efficient algorithm in searching for the "pole" in circular slope stability

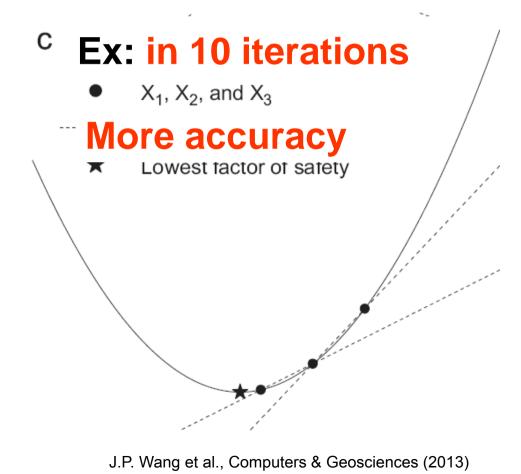
### **Trial and Error:**

Ex: in 1,000 iterations

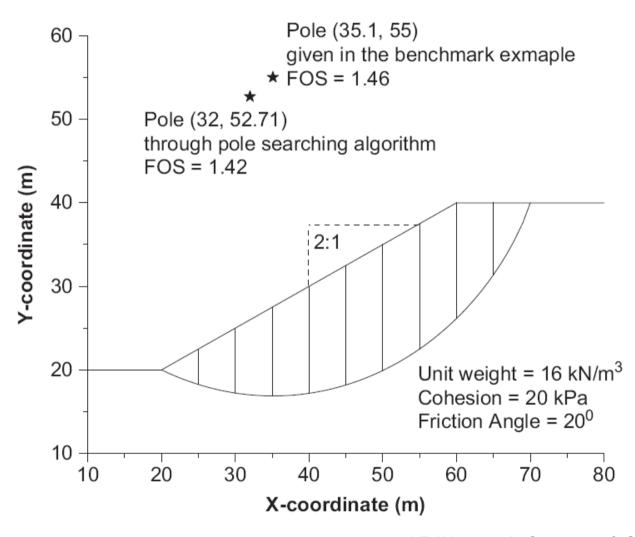
Less accuracy



### **New algorithm**

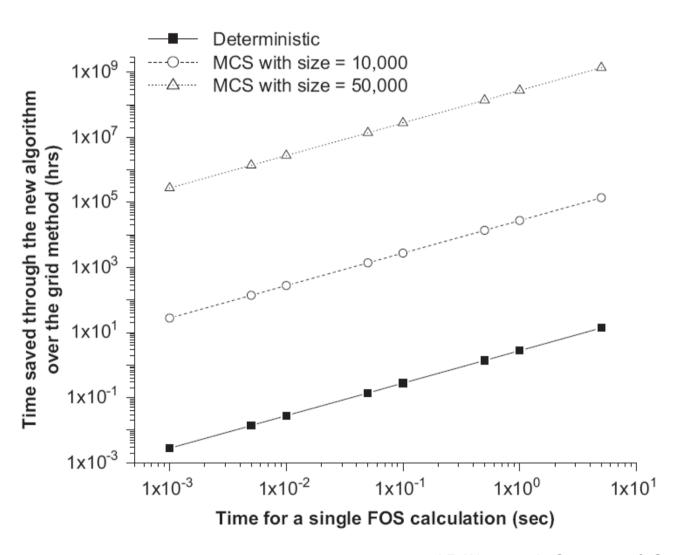


# **Testing example:**



J.P. Wang et al., Computers & Geosciences (2013a)

# Testing example



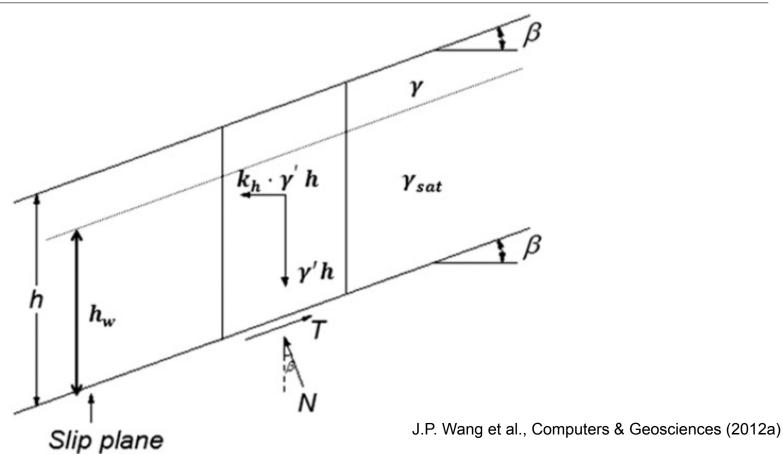
# Rosenblueth method

- When the number of random variables in a problem is not too large (say less than 10), Rosenblueth method is less computational expensive compared to MCS
- Given the number of random variables = 10, this method still requires  $2^{10}$  iterations (deterministic analysis = 1, MCS = 50,000
- Considering cohesion and friction angle as random variables, there are four combinations in point estimates

lnı	out	Output		
c+	Ф+	FOS1	"+":	=> me
c+	Ф-	FOS2	""	=> me
C-	Ф+	FOS3		-/ me
C-	Ф-	FOS4		

Statistics of the eight parameters of an infinite slope; the values in the parenthesis were used in sensitivity analysis.

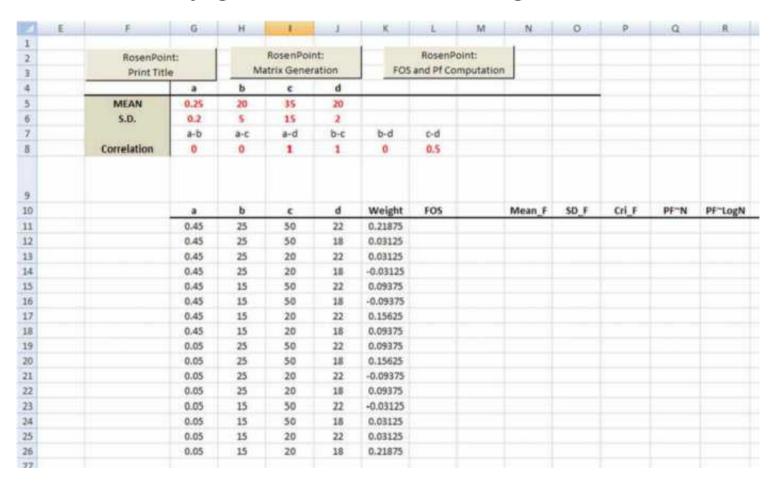
	$k_h(-)$	c (kN/m <sup>2</sup> )	φ (°)	h (m)	$\gamma_{\rm sat}~({\rm kN/m^3})$	β (°)	$h_{w}(\mathbf{m})$	$\gamma  (kN/m^3)$
Mean	0.25	20	35	10	26	10	8	20
S.D.	0.1 (0.2)	2 (4)	3.5 (7)	0.5	2.6	0.01	0.8	2
Carried at land	$h - h_w$	$\gamma_{sat} - \gamma$	$c-\phi$	other 25 c	orrelations			
Correlation	0.8	0.9	0(-0.7)	0				

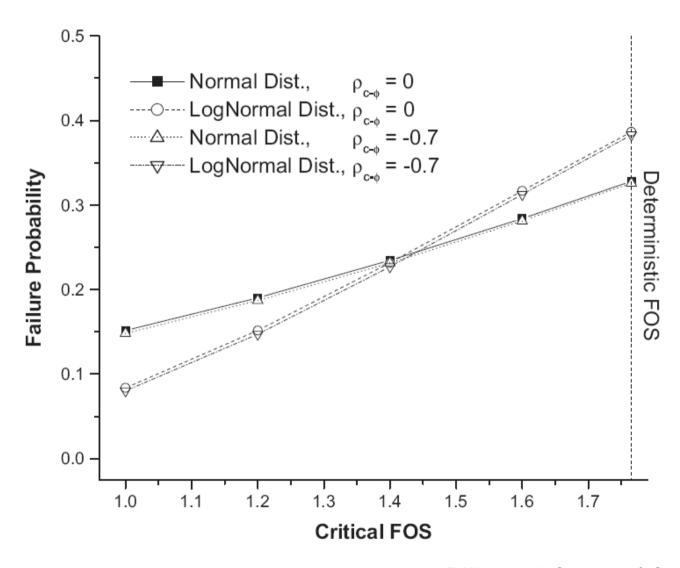


### Automatically generate the following matrix:

	X1	X2	Х3	X4	X5	X6	X7	X8
Trial 1	+	+	+	+	+	+	+	+
Trial 2	+	+	+	+	+	+	+	-
Trial 3	+	+	+	+	+	+	-	+
Trial 4	+	+	+	+	+	+	-	-
Trial 5	+	+	+	+	+	-	+	+
Trial 6	+	+	+	+	+	-	+	-
Trial 7	+	+	+	+	+	-	-	+
Trial 8	+	+	+	+	+	-	-	-
Trial 256	-	-	-	-	_	_	-	_

Automatically generate the following matrix:



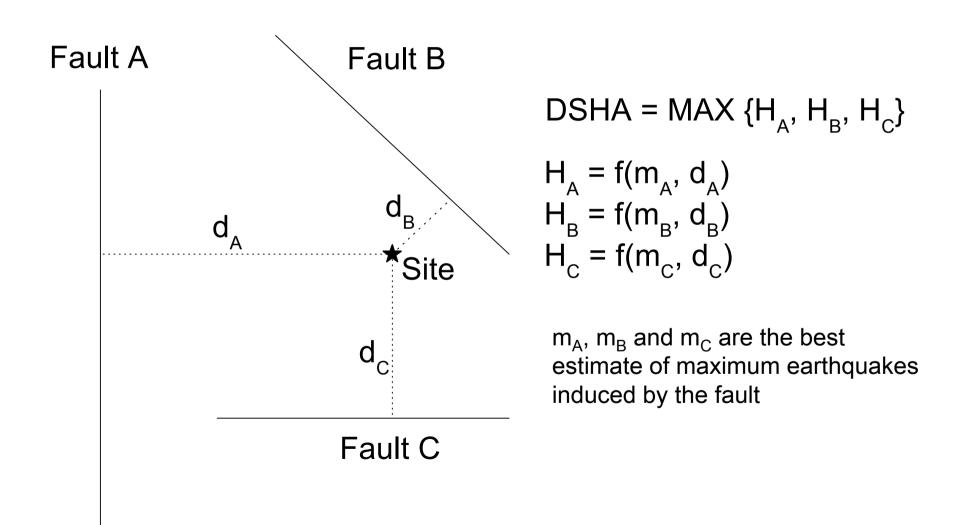


J.P. Wang et al., Computers & Geosciences (2012a)

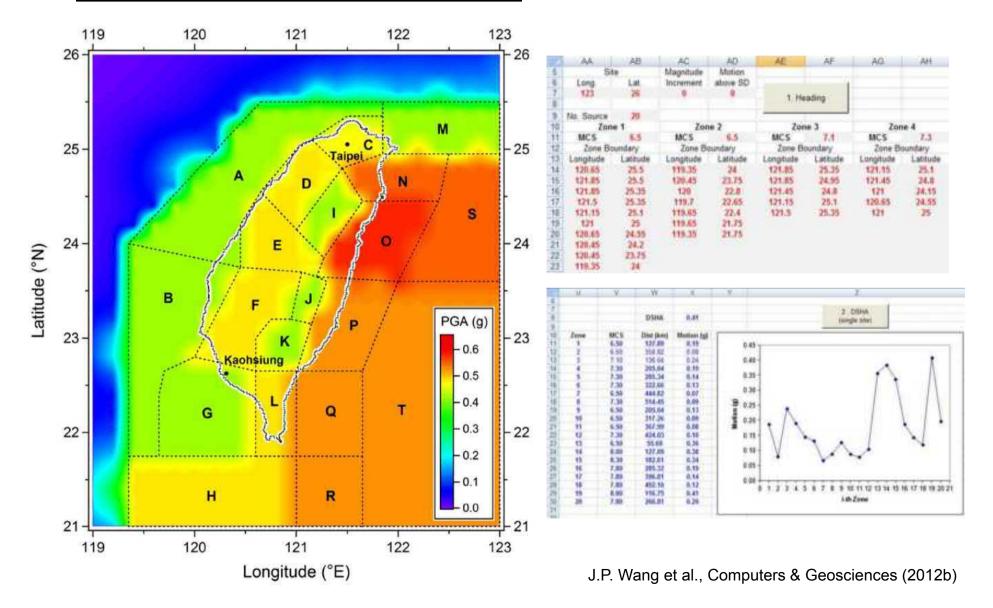
# Seismic hazard analysis

- To best estimate a design ground motion (e.g., PGA = 0.3 g), or the rate of motion of exceedance (e.g., PGA > 0.3 g = 0.01 per year)
- Two representative methods:
  - 1) Deterministic Seismic Hazard Analysis (DSHA)
  - => worse-case earthquake size and location, mean value from ground motion models
  - 2) Probabilistic Seismic Hazard Analysis (PSHA) => accounting for the uncertainties of size, location, ground motion models

#### **Overview of DSHA**

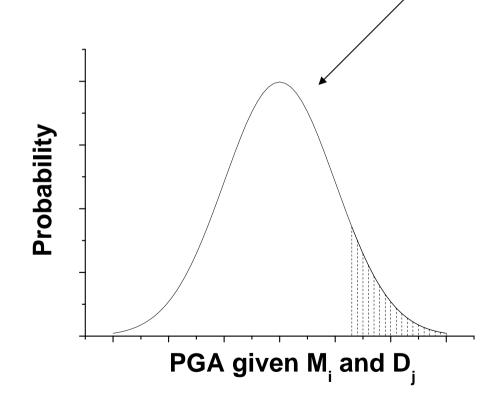


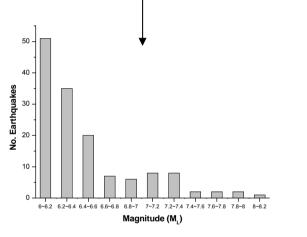
#### **DSHA** map for Taiwan

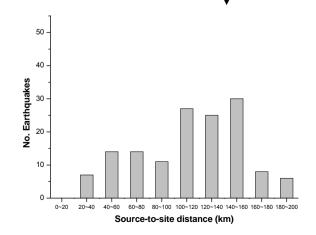


#### **Overview of PSHA**

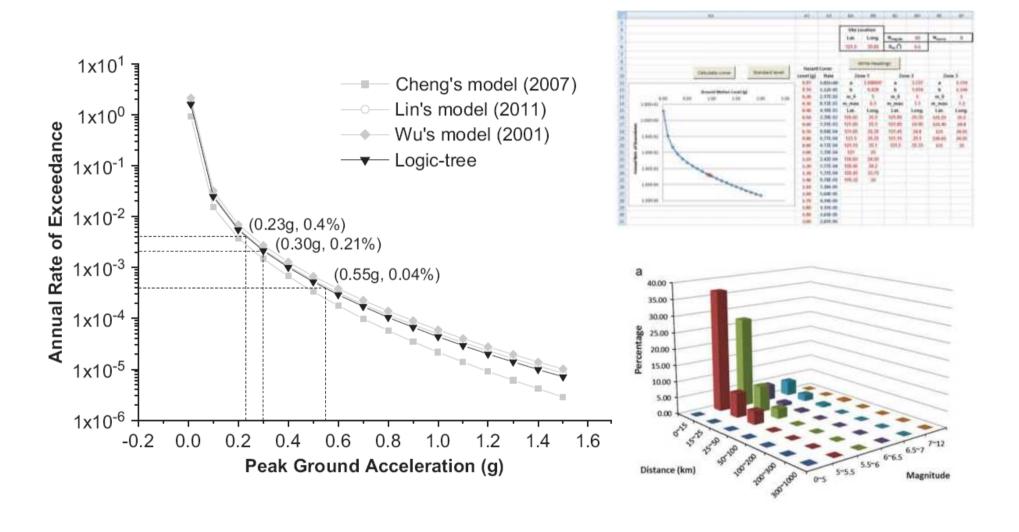
 $\lambda(Y > y^*) = \sum_{i=1}^{N_S} \nu_i \sum_{j=1}^{N_M} \sum_{k=1}^{N_D} \Pr[Y > y^* | m_j, d_k] \times \Pr[M = m_j] \times \Pr[D = d_k]$ 





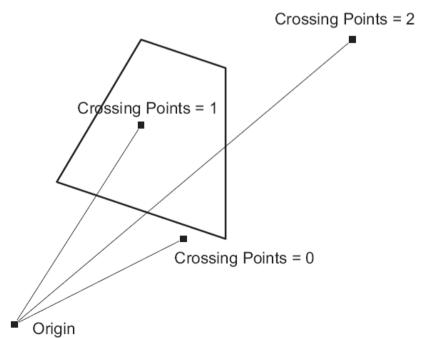


### **PSHA study for Taipei**



#### **Notes on DSHA and PSHA tools**

- The algorithms seem not that challenging
- One interesting and challenging algorithm, needed but not reflected on the governing equations, is to determine a point inside a given polygon or not



#### Excel is good for pre- and post-processing

- When you need to run a series of similar analyses with a FORTRAN program, such as SHAKE, SASSI,..., Excel can help by creating a gigantic input file
- Creatively using "TEXT functions" in Excel, such as "REPT"
- Excel can process a .txt file by
   DATA => TEXT TO COLUMN

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                                                         0.7245
                         0.0814
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Option 2 UAE Rev1 No. 1
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Option 4 – Assignment of Object Motion to a Specific Sublayer
Option 5 - Number of Iterations & Strain Ratio
5 0.65 10
Option 6 - Computation of Acceleration at Specified Sublayers Set
Option 9 - Response Spectrum
Option 1 - Dynamic Soil Properties
   0.00010.00031623
                          0.001 0.0031623
                                                0.01 0.031623
                                    0.9886
```

### **Excel and matrix computation**

- Matrix-based analyses, such as Markov chain, multiple regression analysis, factor analysis, principal-component analysis, etc..., are commonly used in engineering, but matrix operations are not as user-friendly as others in Excel
- Suggestions: using them in VBA is less hassle (although not as easy as using them on spreadsheets in the first place)
- Or create your own functionality from scratch

## $AE = \lambda E$ (Eigenvalues and Eigenvectors)

 But I have no idea how to create an in-house function solving eigenvalues λ of a matrix A

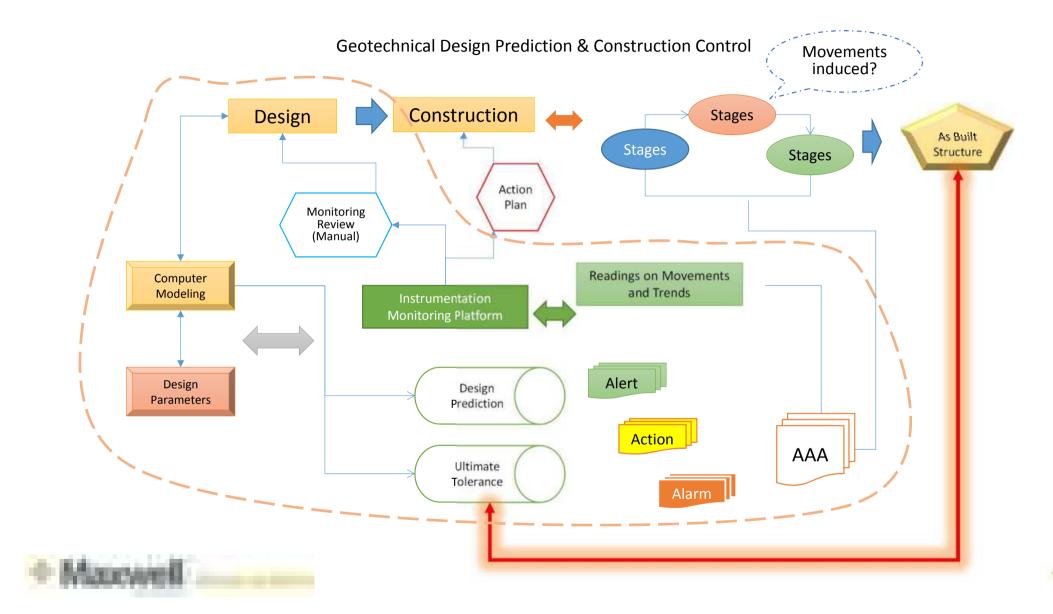
Suggestions:

http://digilander.libero.it/foxes

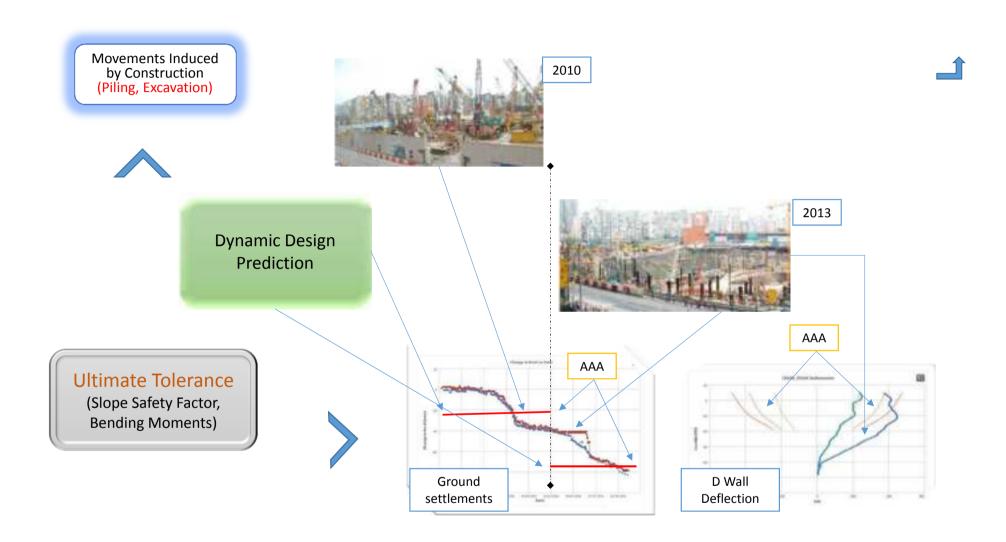
- There is an add-in about matrix calculation in Excel available from the link
- It is even open-sourced

### **Conclusions and Discussions**

- Probabilistic analysis accounts for the variability of the input variables
- It is relatively computational expensive, so that an efficient algorithm is preferred
- In most of our daily assignments, if MATLAB can do, EXCEL can do

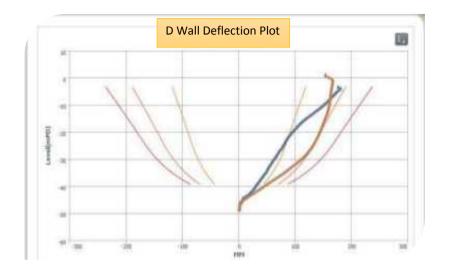


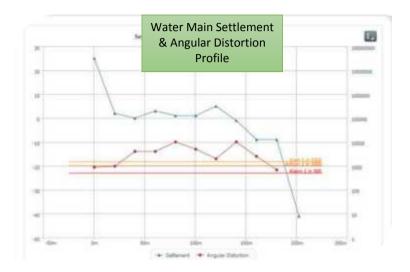


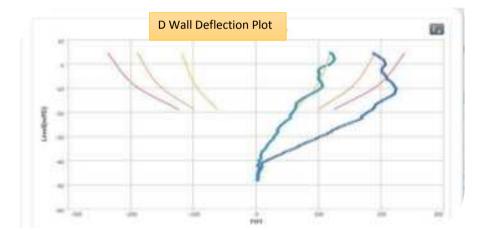


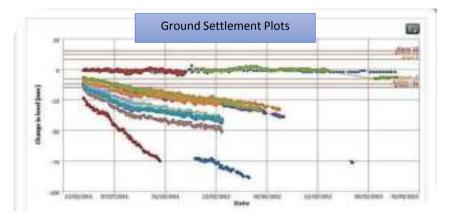










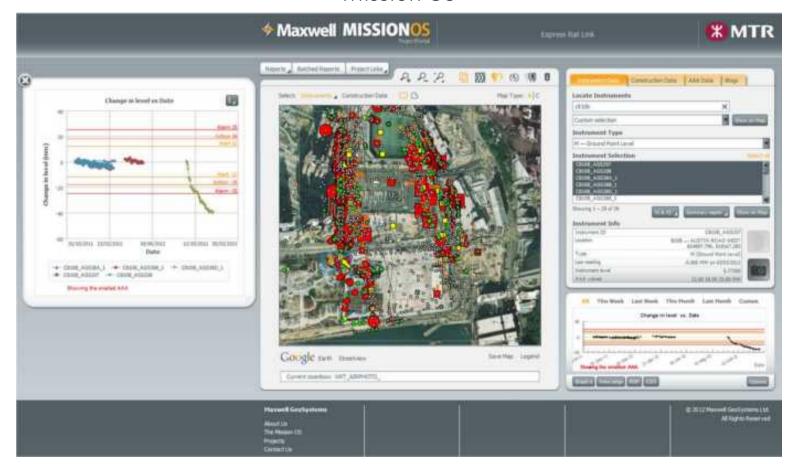






# Unified Web Based Mission OS

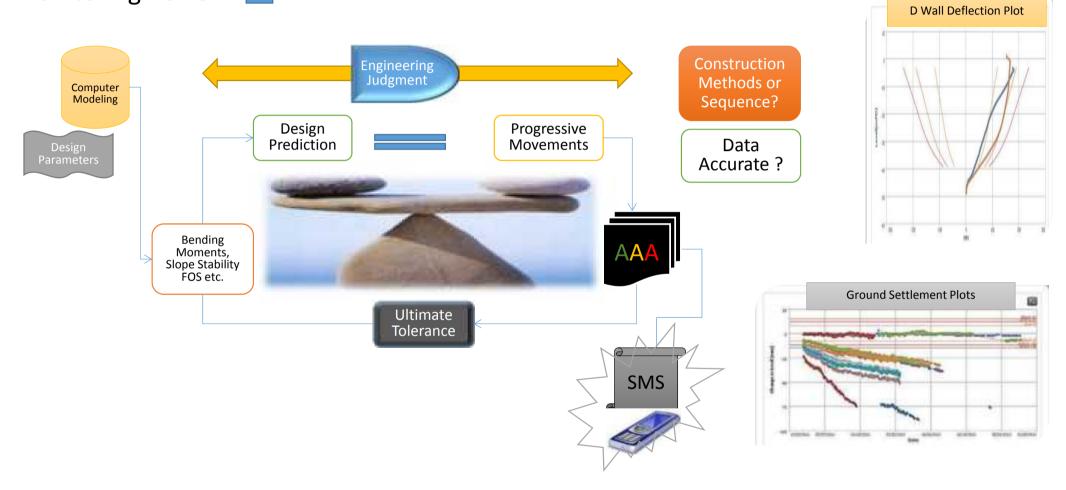








#### Monitoring Review 🔟





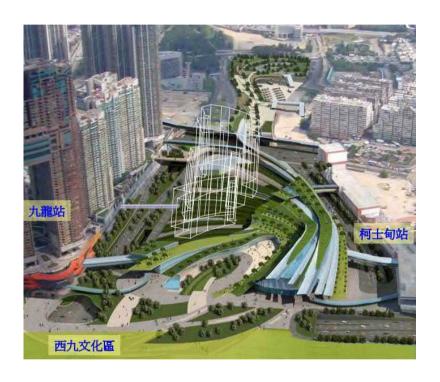


#### From Construction to Successful As-Built Structure







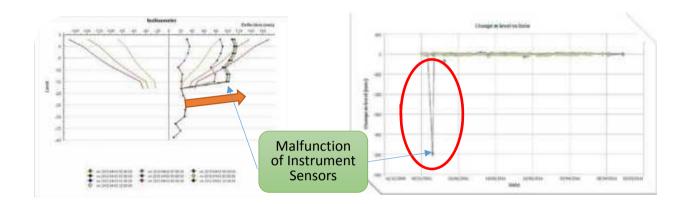






#### **Incorrect Data**

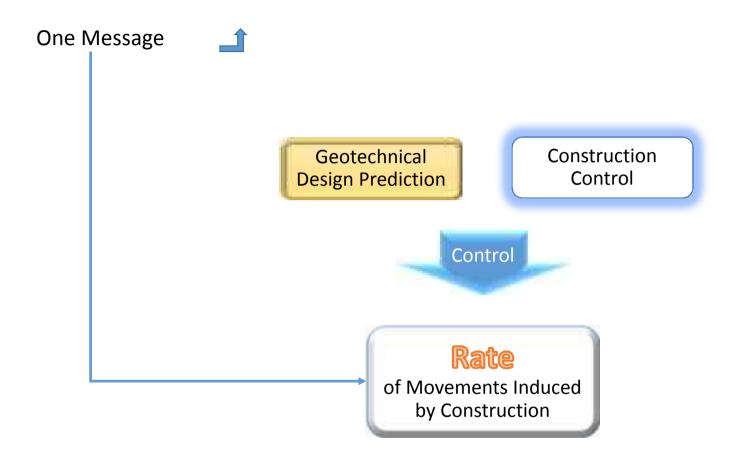
















Integrating Geotechnical Design Prediction into the Construction Process - Angus Maxwell

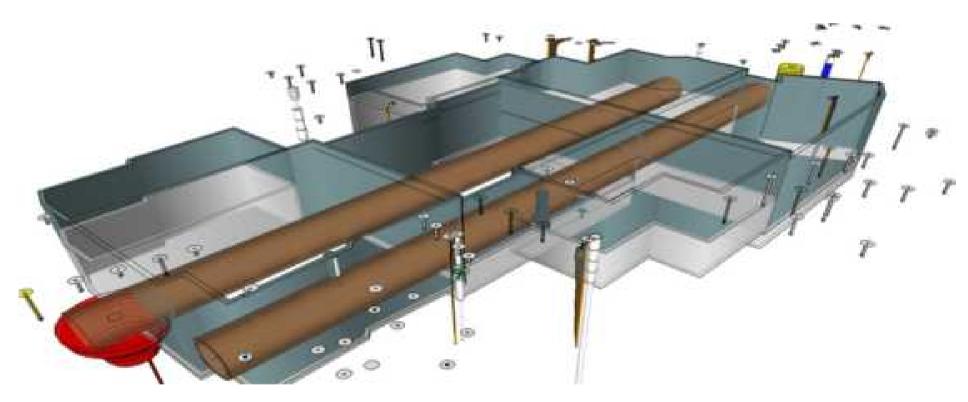




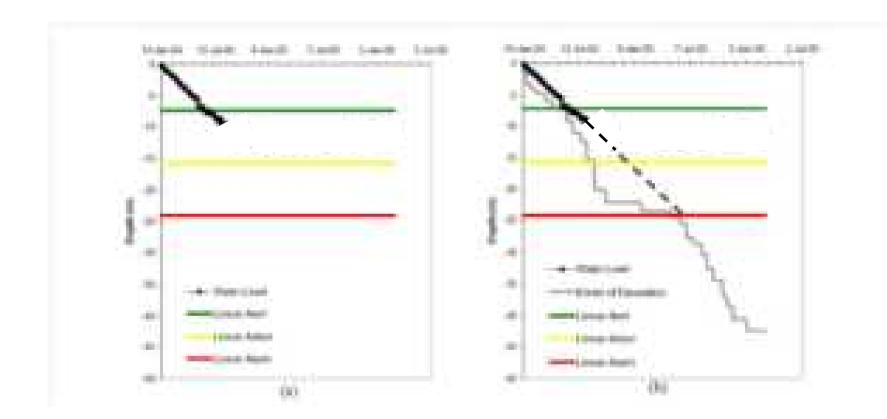
## **AAA Schemes**

- Hong Kong
- Singapore
- Thailand
- Australia
- Malaysia

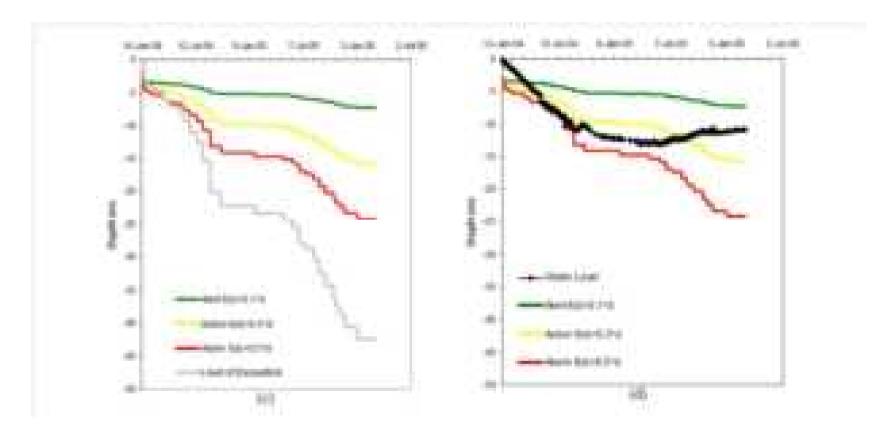




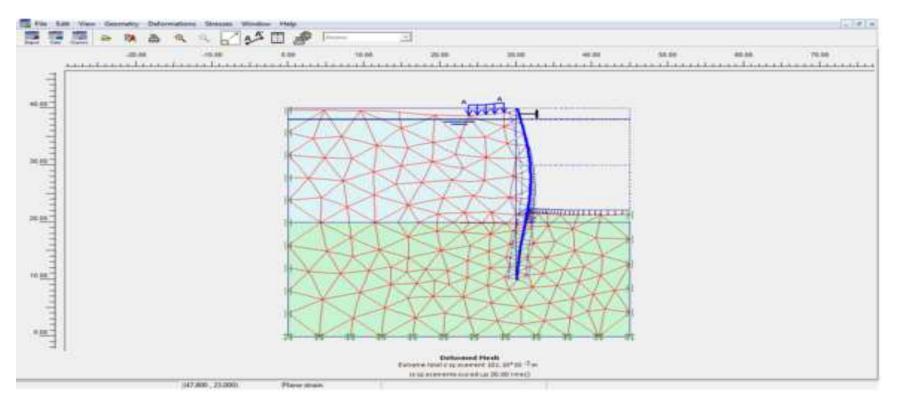






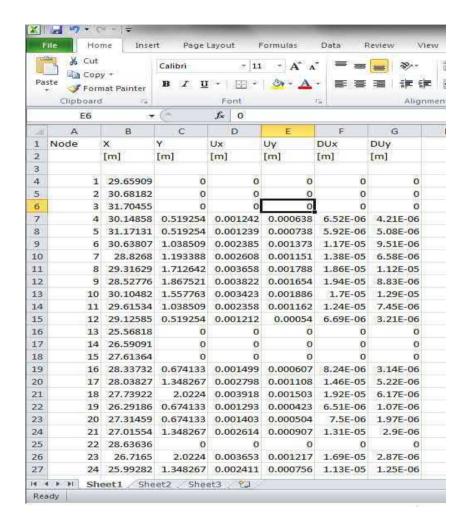


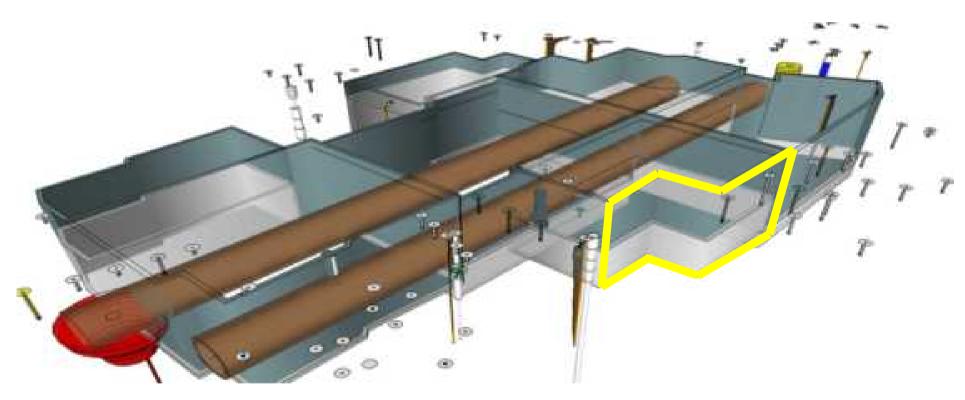




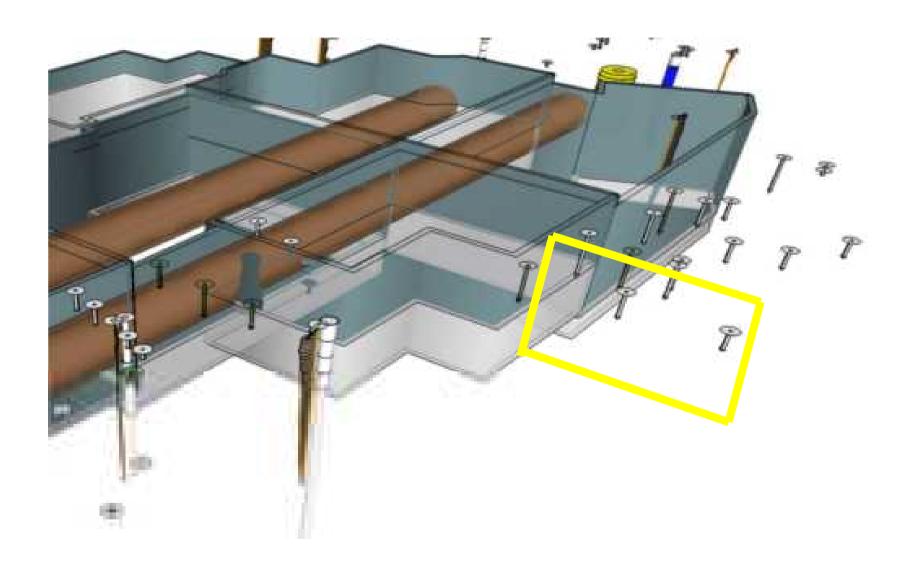


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1	29.659	0.000	0.000	0.000	0.000	0.000
2	30.682	0.000	0.000	0.000	0.000	0.000
3	31.705	0.000	0.000	0.000	0.000	0.000
4	30.149	0.519	1.242	0.638	0.007	0.004
5	31.171	0.519	1.239	0.738	0.006	0.005
6	30.638	1.039	2.385	1.373	0.012	0.010
7	28.827	1.193	2.608	1.151	0.014	0.007
8	29.316	1.713	3.658	1.788	0.019	0.011
9	28.528	1.868	3.822	1.654	0.019	0.009
10	30.105	1.558	3.423	1.886	0.017	0.013
11	29.615	1.039	2.358	1.162	0.012	0.007
12	29.126	0.519	1.212	0.540	0.007	0.003
13	25.568	0.000	0.000	0.000	0.000	0.000
14	26.591	0.000	0.000	0.000	0.000	0.000
15	27.614	0.000	0.000	0.000	0.000	0.000
16	28.337	0.674	1.499	0.607	0.008	0.003
17	28.038	1.348	2.798	1.108	0.015	0.005
18	27.739	2.022	3.918	1.503	0.019	0.006
19	26.292	0.674	1.293	0.423	0.007	0.001
20	27.315	0.674	1.403	0.504	0.008	0.002
21	27.016	1.348	2.614	0.907	0.013	0.003
22	28.636	0.000	0.000	0.000	0.000	0.000
23	26.716	2.022	3.653	1.217	0.017	0.003
24	25.993	1.348	2.411	0.756	0.011	0.001
25	25 269	0.674	1 181	0.362	0.005	0.000

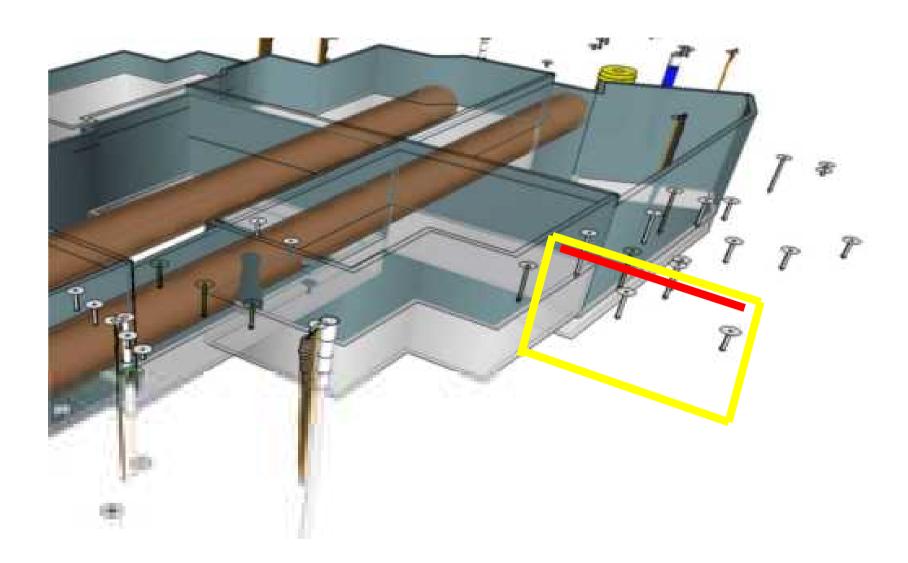




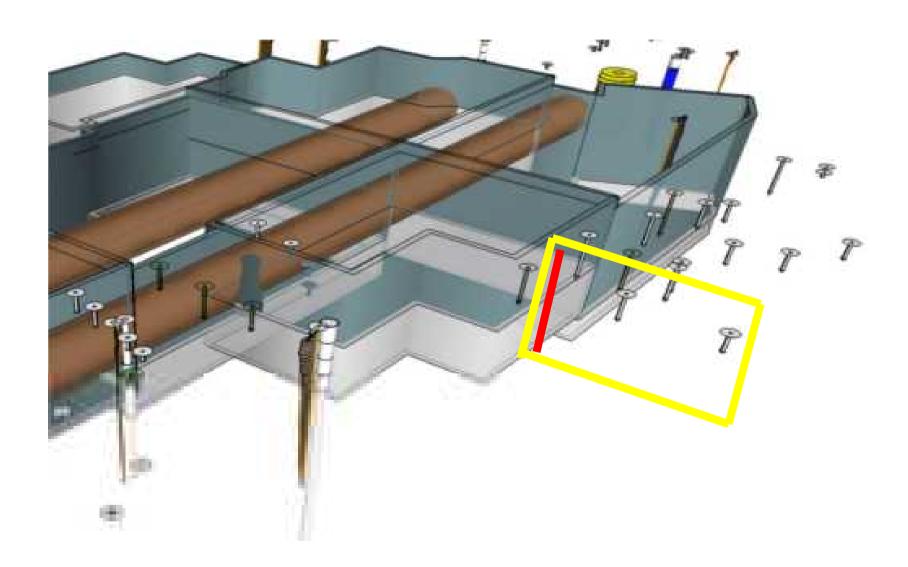




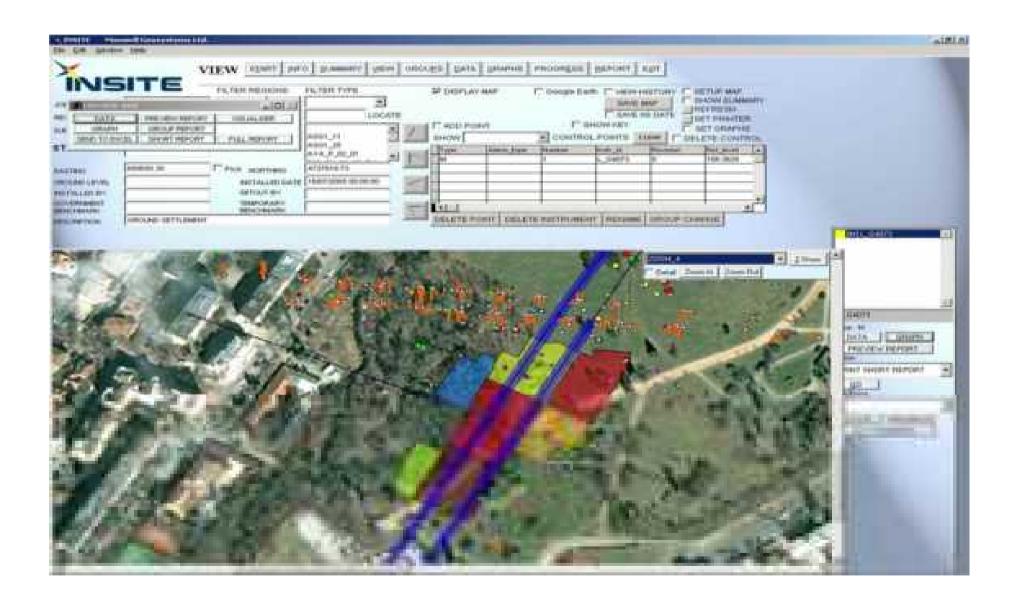


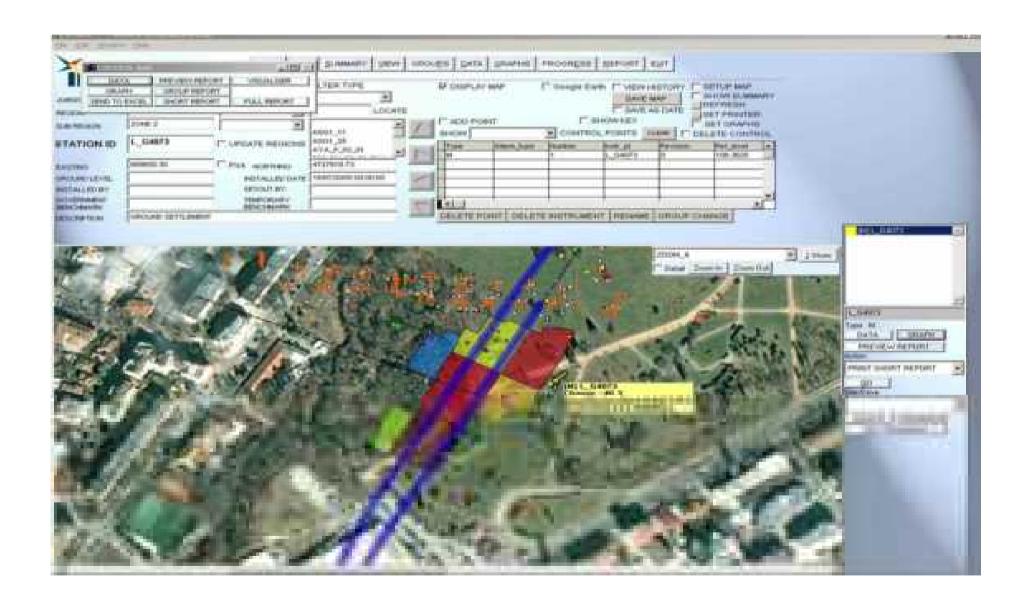


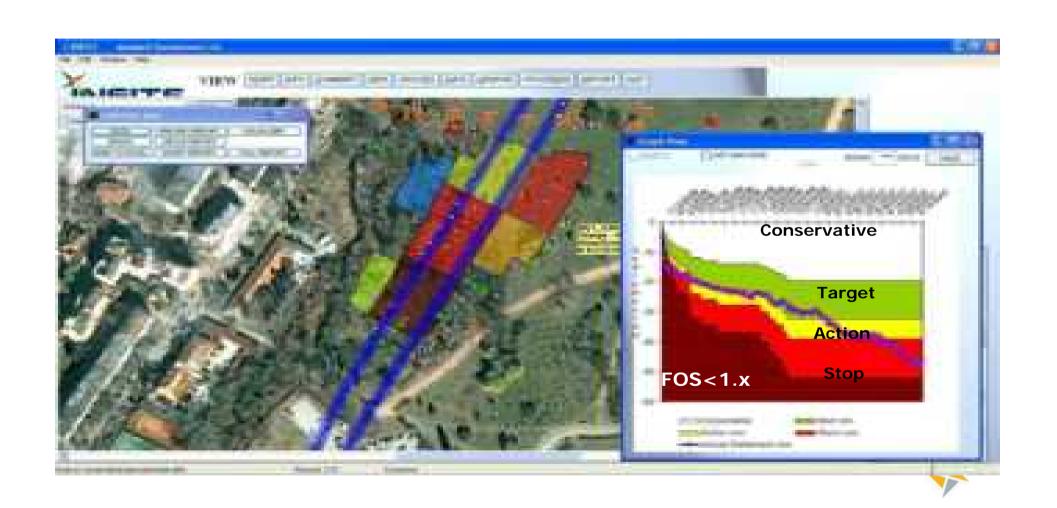


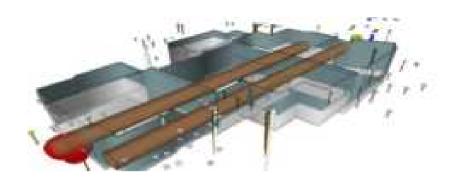








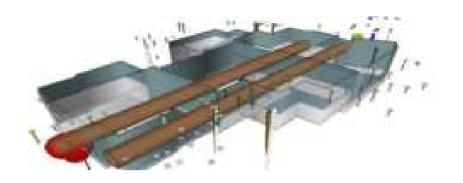




### **Discussions**

- Multiple components of movement
- Different types of design
- SLS and ULS controls





### Conclusions

- Automated revision can be done
- Feedback on design and building protection are possible within one AAA scheme



