SESSION 1 : Basic of Geotechnical Forensic Engineering : Myths and Common Problems in

Ir. Liew Shaw Shong

Content

- Introduction
  - *What is Forensic Engineering?.*
- Frameworks
  - *Approaches for Forensic Engineering.*
- Common Problems & Myths
  - *Issues related to Forensic Engineering.*
- Role of Geotechnical Engineer
  - *Methodology and Approaches*
- Conclusions
  - *Summary of messages to do quality Forensic Engineering*

Introduction

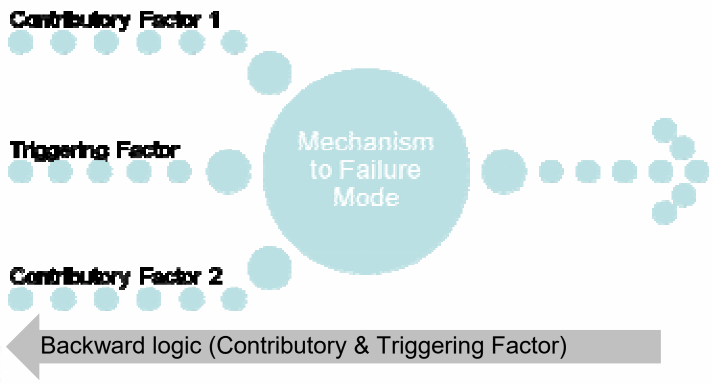
- What is forensic engineering?
- To find out reasons of non-compliance performance (SLS & ULS) of products and the causation (contributory and triggering factors) of undesired incident
- Purposes :
  - *To prevent recurrence and improve reliability & durability of product*
  - *To attribute responsibility and damage recovery (litigation)*
  - *To remedy failure/distress based on root cause*
- Locard's exchange principle : "Every contact leaves a trace"

Frameworks

- Desktop study
- Data collection (collecting evidences)
  - *Incident scene inspection*
  - *Interview with Eye-witness & Specimen collection*
  - *Measurements & Monitoring Data*
- Developing chronological events
- Examine cause-and-effect
- Developing model and failure analysis
  - *Fault Tree Analysis (FTA) – Deductive*
  - *Failure Mode and Effects Analysis (FMEA) & Criticality Analysis (CA) – Inductive*
- Experiments & laboratory tests

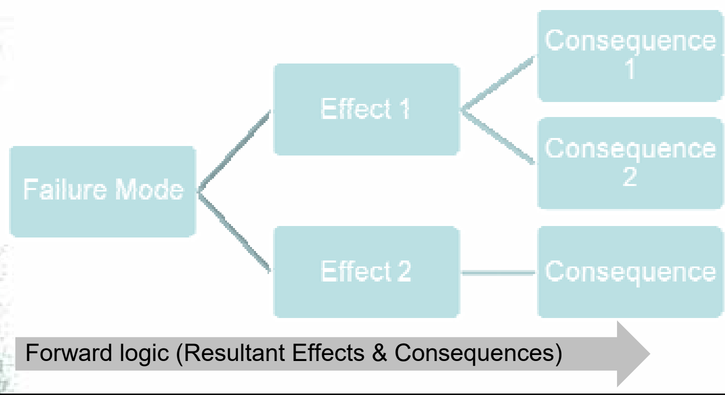
Failure Analysis

- Evolved from Reliability Engineering (military), Safety and QA/QC Engineering (but with perspective of post failure review. i.e. a re-run)
- FTA (Backward logic)



Failure Analysis

- FMEA (Forward logic)
  - *Functional (Design Requirements)*
  - *Design (ULS, SLS and Material Specifications)*
  - *Process (Method of Statement & Construction)*



Common Problems & Myths

Common Problems:

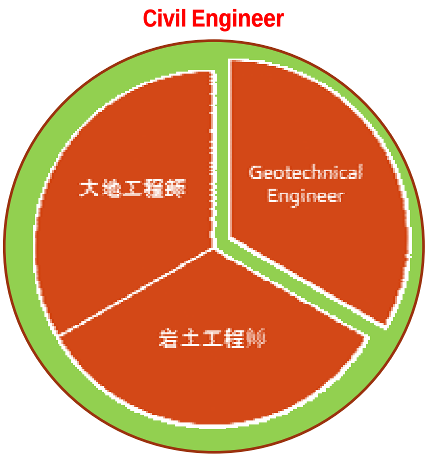
- *Inaccessibility to the incident site*
- *Timing between incident occurrence and commission of investigation (Destroy of Evidences)*
- *Incorporative altitudes of involving parties*
- *Release of critical information (information on design, construction records, monitoring results, maintenance and operation)*
- *Conflicting data and facts*
- *Representativeness of interpreted information*
- *Establishment of event sequences*

Common Problems & Myths

Myths:

- *Overly simple postulation of potential mechanisms*
- *Fundamentals of mechanics & kinematic movement traces*
- *Matching of performance data*
- *Cherry picking of facts to favourably suit perceptive failure scenarios*
- *Uniqueness of cause-and-effect relationship*
- *Soundness of evidences collected or implied*
- *Compliance of design codes, work statement & material specifications*

ROLE OF GEOTECHNICAL ENGINEER



- Geotechnical engineer in Malaysia is ambiguously regarded as "Geologist" in the public perception.
- Geotechnical engineer is a qualified civil engineer registered with Board of Engineers Malaysia as either graduate engineer or professional engineer having relevant and competent experience in geotechnical works
  - ability to plan ground investigation & characterise ground conditions for engineering processes
  - identify & assess the potential geo-hazards and the possible ground borne interaction to proposed structures
  - offer feasible engineering design solutions to ensure safety & satisfactory performance of the end product of the engineering works including its surrounding

WHY APPOINT GEOTECHNICAL ENGINEER?

Why Geotechnical Engineer?

Geotechnical engineer as an underwriter for risk assessment.

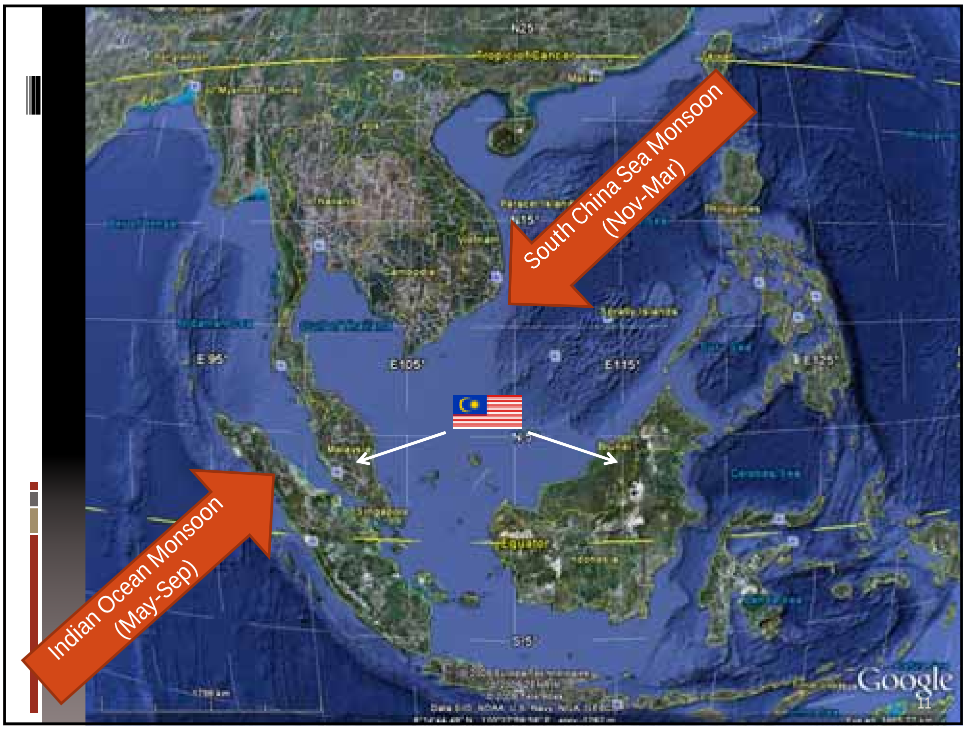
GI as tools for Geotechnical Engineer

It is regard as necessary, but not a rewarding expense. (Uncertainty, sufficiently accurate design options for Cost & Benefit study)

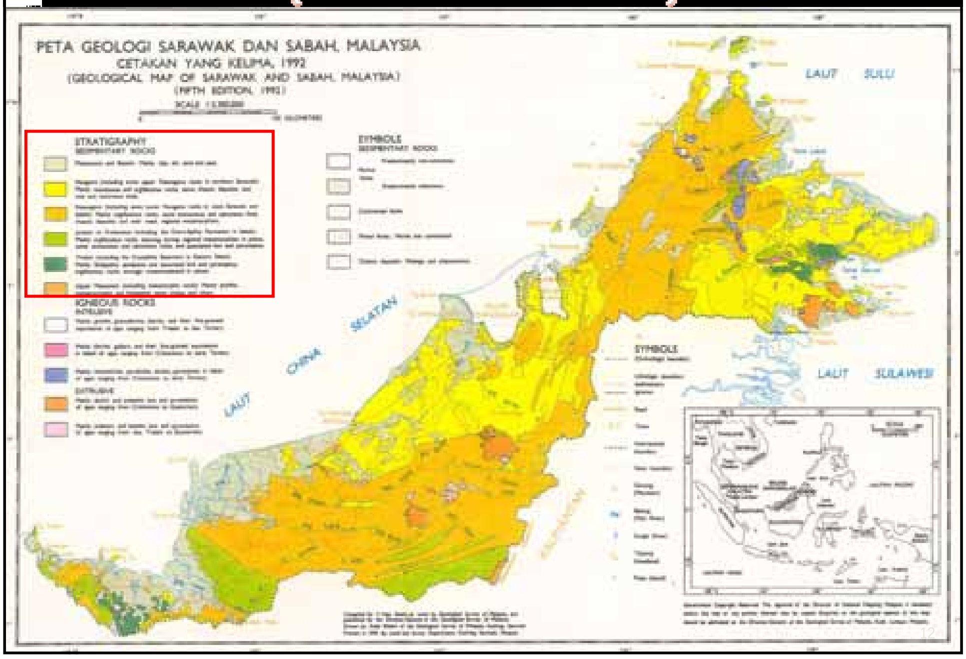
What Risk in Ground & its Consequence ?

Ground Variability & Geo-hazards.

Financial Viability & Cost Overrun (Construction & Operation).

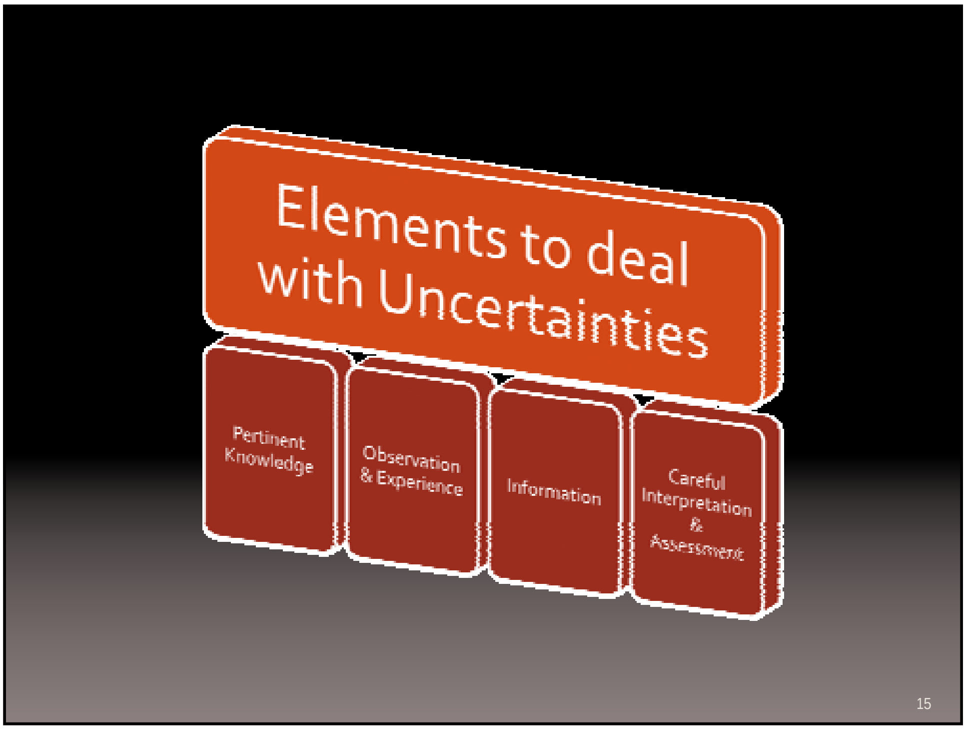


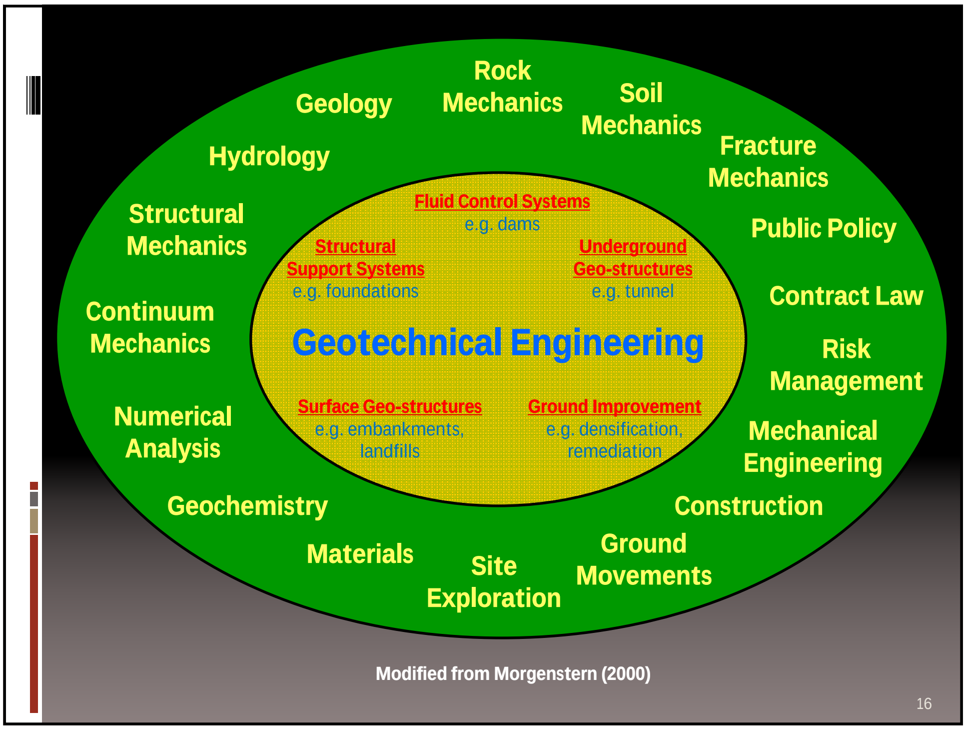
GEOLOGY (EAST MALAYSIA)

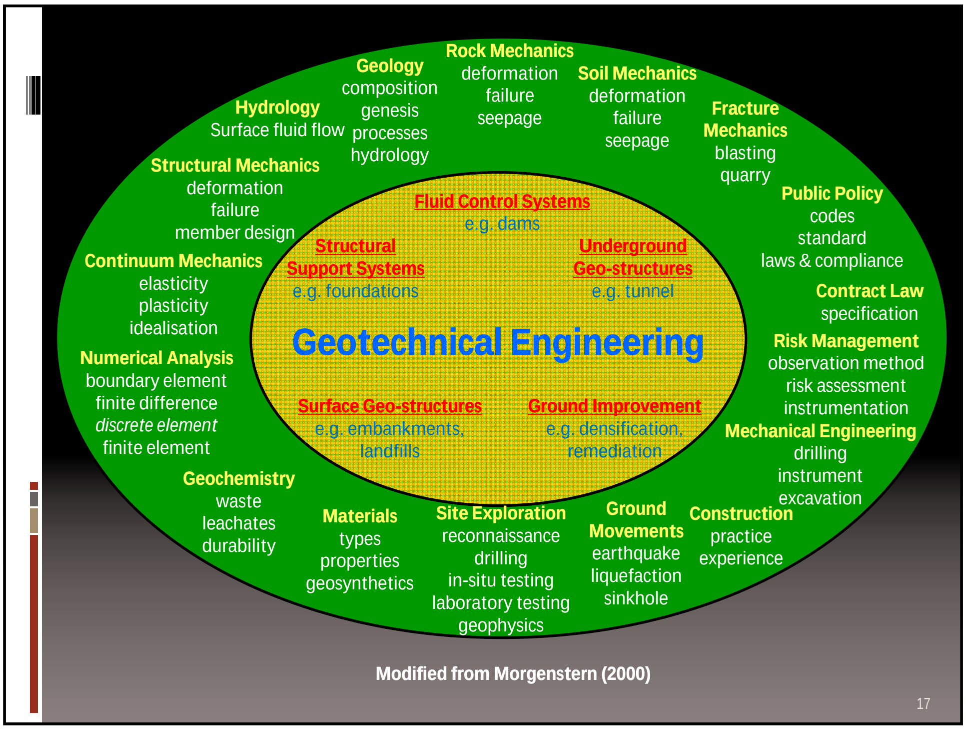


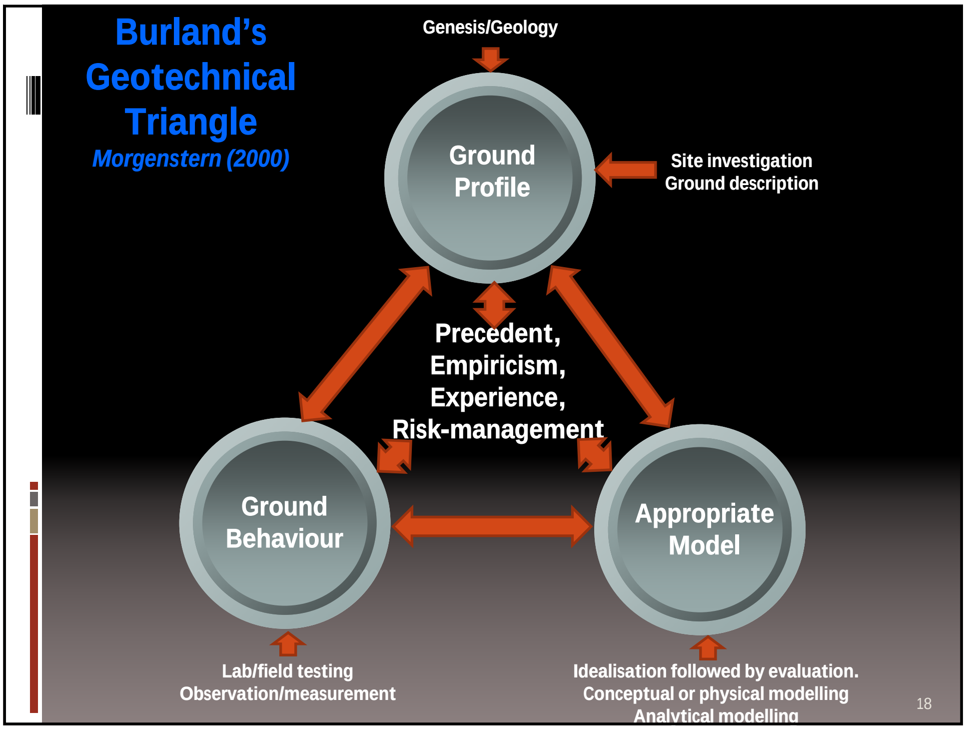
GEOLOGY (PENINSULAR MALAYSIA)

RISK ASSESSMENT


Elements to deal with Uncertainties
Pertinent Knowledge
Observation & Experience
Information
Careful Interpretation & Assessment
15


Rock Mechanics
Geology
Soil Mechanics
Hydrology
Fracture Mechanics
Structural Mechanics
Public Policy
Continuum Mechanics
Contract Law
Risk Management
Numerical Analysis
Mechanical Engineering
Geochemistry
Construction
Materials
Site Exploration
Ground Movements
Fluid Control Systems
e.g. dams
Structural Support Systems
e.g. foundations
Underground Geo-structures
e.g. tunnel
Geotechnical Engineering
Surface Geo-structures
e.g. embankments, landfills
Ground Improvement
e.g. densification, remediation
Modified from Morgenstern (2000)
16


Rock Mechanics
deformation
failure
seepage
Geology
composition
genesis
processes
hydrology
Soil Mechanics
deformation
failure
seepage
Hydrology
Surface fluid flow
Fracture
Mechanics
blasting
quarry
Structural Mechanics
deformation
failure
member design
Public Policy
codes
standard
laws & compliance
Fluid Control Systems
e.g. dams
Structural
Support Systems
e.g. foundations
Underground
Geo-structures
e.g. tunnel
Continuum Mechanics
elasticity
plasticity
idealisation
Contract Law
specification
Geotechnical Engineering
Numerical Analysis
boundary element
finite difference
discrete element
finite element
Risk Management
observation method
risk assessment
instrumentation
Surface Geo-structures
e.g. embankments,
landfills
Ground Improvement
e.g. densification,
remediation
Mechanical Engineering
drilling
instrument
excavation
Geochemistry
waste
leachates
durability
Materials
types
properties
geosynthetics
Site Exploration
reconnaissance
drilling
in-situ testing
laboratory testing
geophysics
Ground
Movements
earthquake
liquefaction
sinkhole
Construction
practice
experience
Modified from Morgenstern (2000)
17


Burland's
Geotechnical
Triangle
Morgenstern (2000)
Genesis/Geology
Ground
Profile
Site investigation
Ground description
Precedent,
Empiricism,
Experience,
Risk-management
Ground
Behaviour
Appropriate
Model
Lab/field testing
Observation/measurement
Idealisation followed by evaluation.
Conceptual or physical modelling
Analytical modelling
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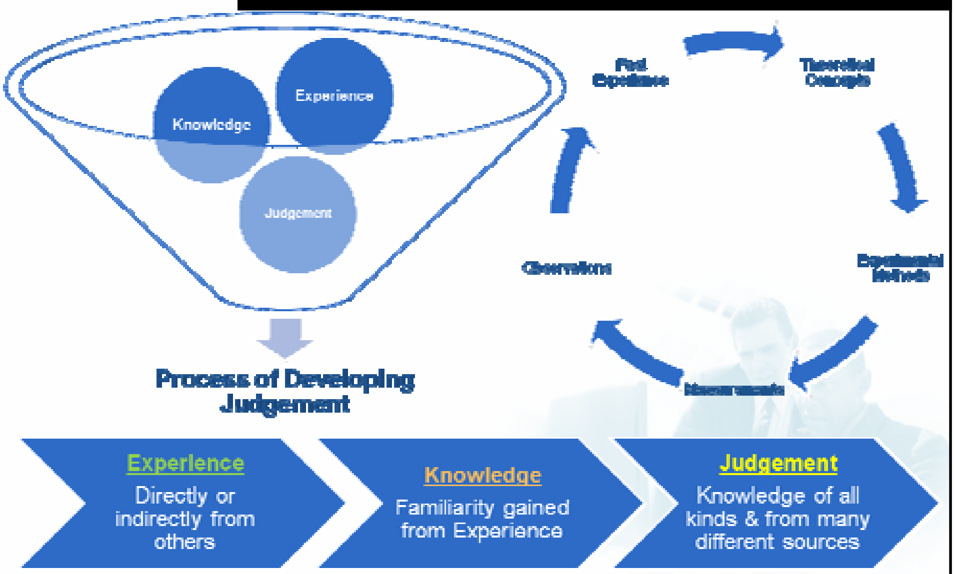
Engineering Judgement

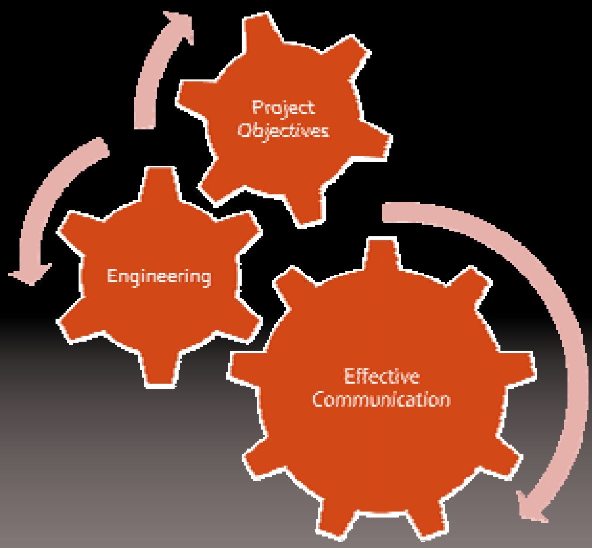
- **Definition** : The operation of the mind, involving "***comparison***" and "***discrimination***" by which knowledge of values and relations is mentally formulated. (*Webster's New Collegiate Dictionary*)

- **Recognition** : **Engineering judgement** as an acceptable engineering practice

Engineering Judgement

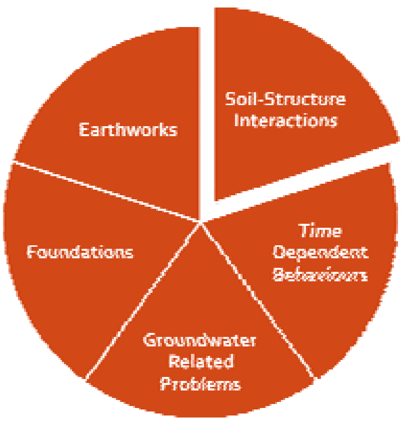


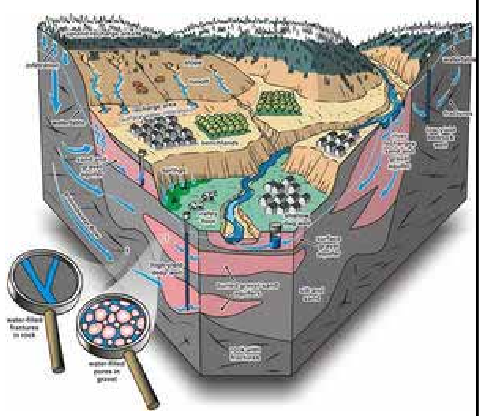
HOLISTIC APPROACH



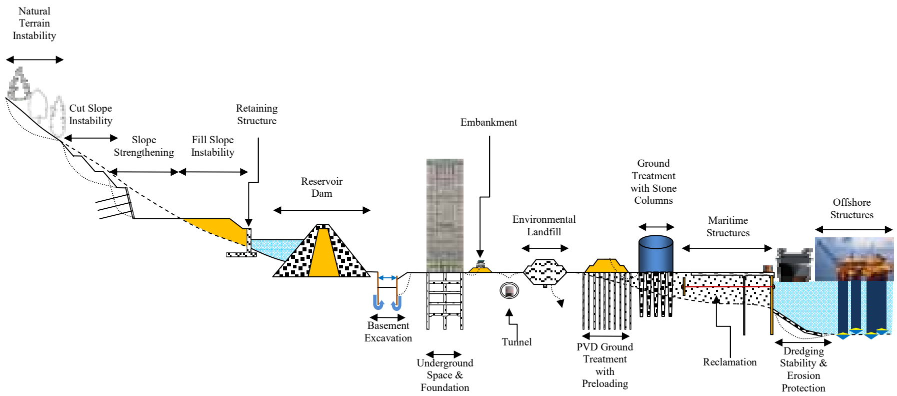
WORKSCOPE OF GEOTECHNICAL ENGINEERING

Scope



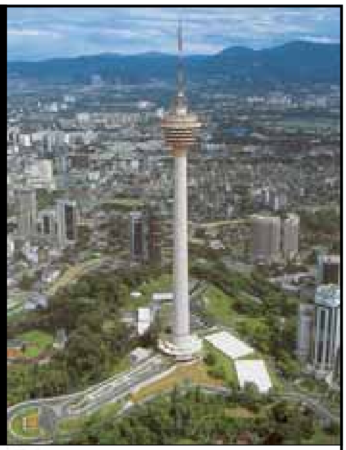


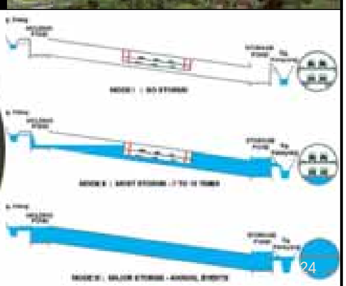
WORK SCOPE OF GEOTECHNICAL ENGINEERING



Potential Scope of Geotechnical Engineering (modified from Atkinson, 2006)

GEOTECHNICAL WORKS





GEOTECHNICAL WORKS

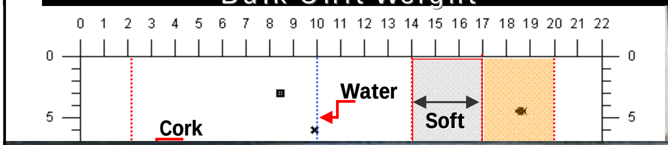
GEOTECHNICAL WORKS

GEO-ENVIRONMENT

UNCONTROLLED DUMP

MATERIALS AT CONSTRUCTION

Bulk Unit Weight



Weathering Profile

- Deviation of material classification between borehole and excavation

(Claim issue –

Soil or Rock ?)

GEOLOGICAL

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Difficulties in Identification of Complex Geological Settings

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Difficulties in Identification of Complex Geological Settings

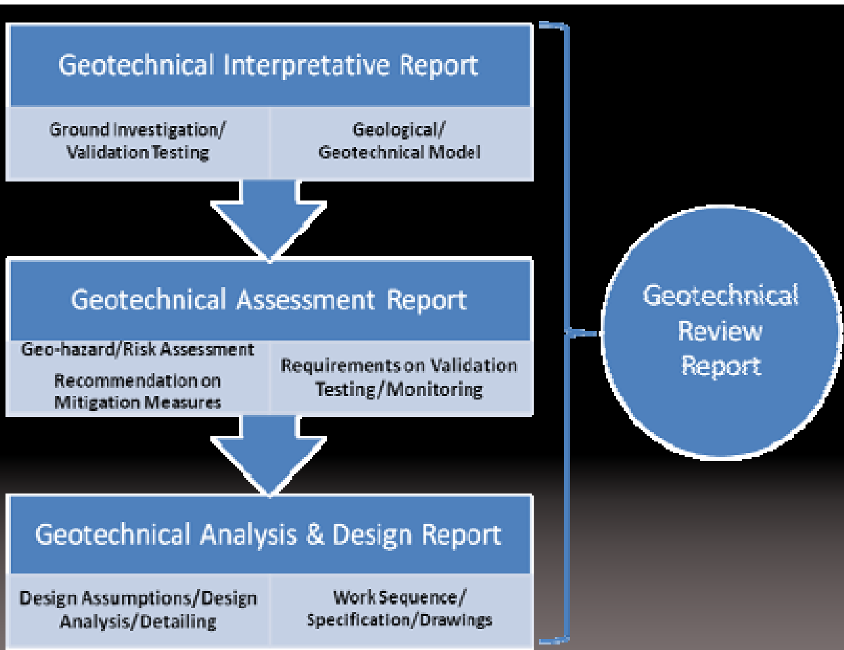



FAILURES





DELIVERABLES



Relationship of Deliverables of Typical Geotechnical Engineering Works

SUPERVISION

Babylonian King, Hammurabi (1792-1750BC) -"eye for an eye" method :

- If a builder builds a house for a man and does not make its construction firm and the house which he has built collapses and causes the death of the owner of house – the builder shall be put to death
- If it causes the death of the son of the owner of the house – the son of that builder shall be put to death
- If it causes the death of a slave of the owner of the house – he shall give to the owner of the house a slave of equal value
- If it destroys a property, he shall restore whatever it destroyed, and because he did not make the house which he built firm and it collapsed, he shall rebuild the house which collapsed at his own expense
- If a builder builds a house for a man and does not make its construction meet the requirements and a wall fall in, that builder shall strengthen the wall at his own expense

- Translated by R.F. Harper

SUPERVISION

CODE CIVIL

DES FRANÇAIS.

TITRE PRÉLIMINAIRE.

DE LA PUBLICATION, DES EFFETS ET DE L'APPLICATION DES LOIS EN GÉNÉRAL.

ARTICLE 1.er

LES lois sont exécutoires dans tout le territoire français, en vertu de la promulgation qui en est faite par le PREMIER CONSUL.

Elles seront exécutées dans chaque partie de la République, du moment où la promulgation en pourra être connue.

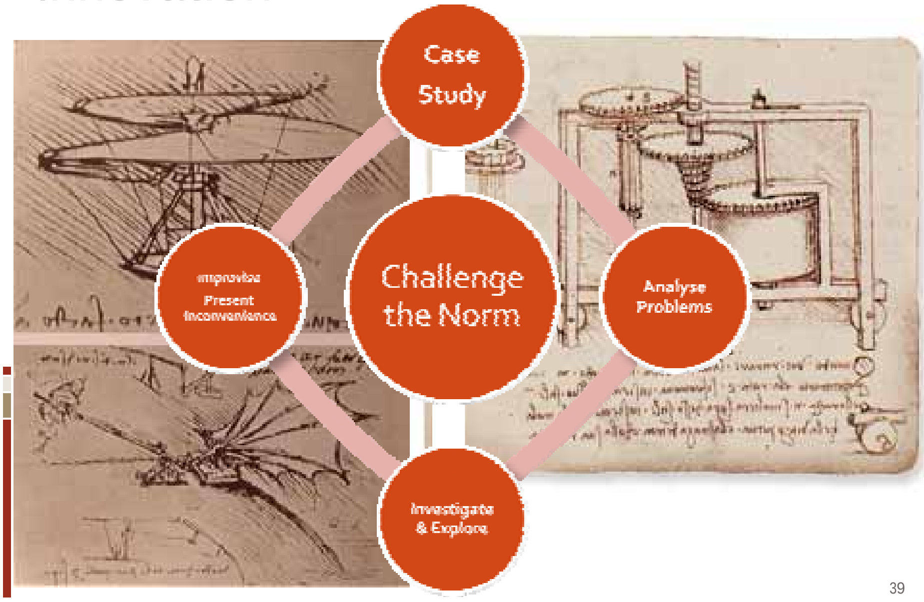
La promulgation faite par le PREMIER CONSUL sera réputée connue dans le département où siégera le Gouvernement, un jour après celui de la promulgation; et dans chacun des autres départemens, après l'expiration du même délai, augmenté d'autant de jours qu'il y aura de fois dix myriamètres [environ vingt lieues anciennes] entre la ville où la

A

Napoleonic Code (1804) :

- If a structure had a loss of serviceability within 10 years of its completion, due to poor workmanship or foundation failure, then the builder would be sent to prison.

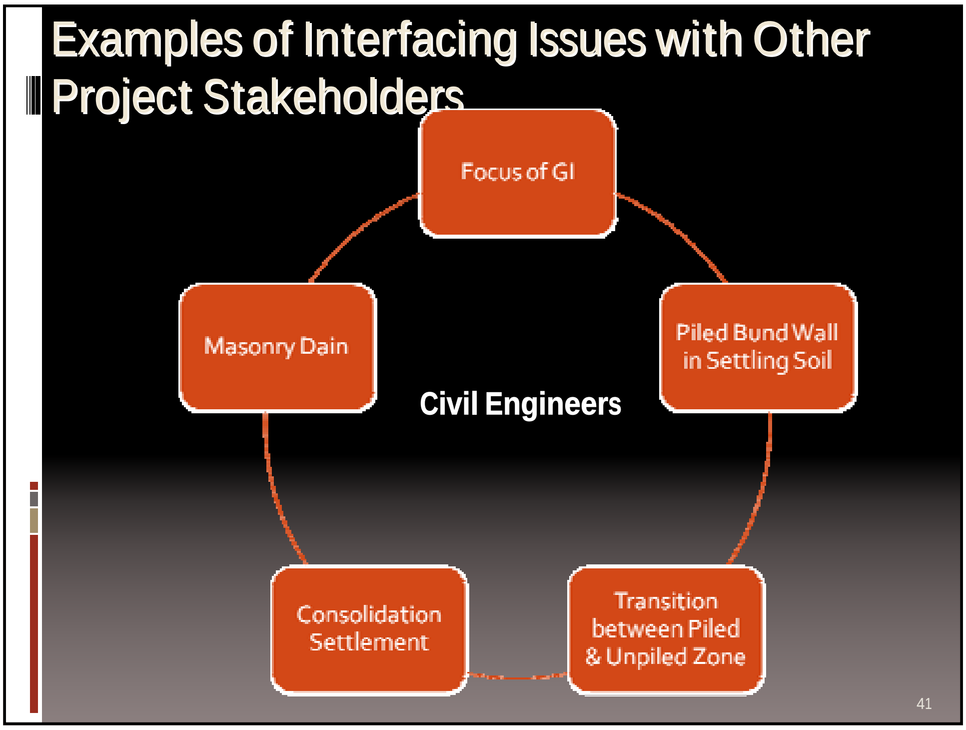
Innovation

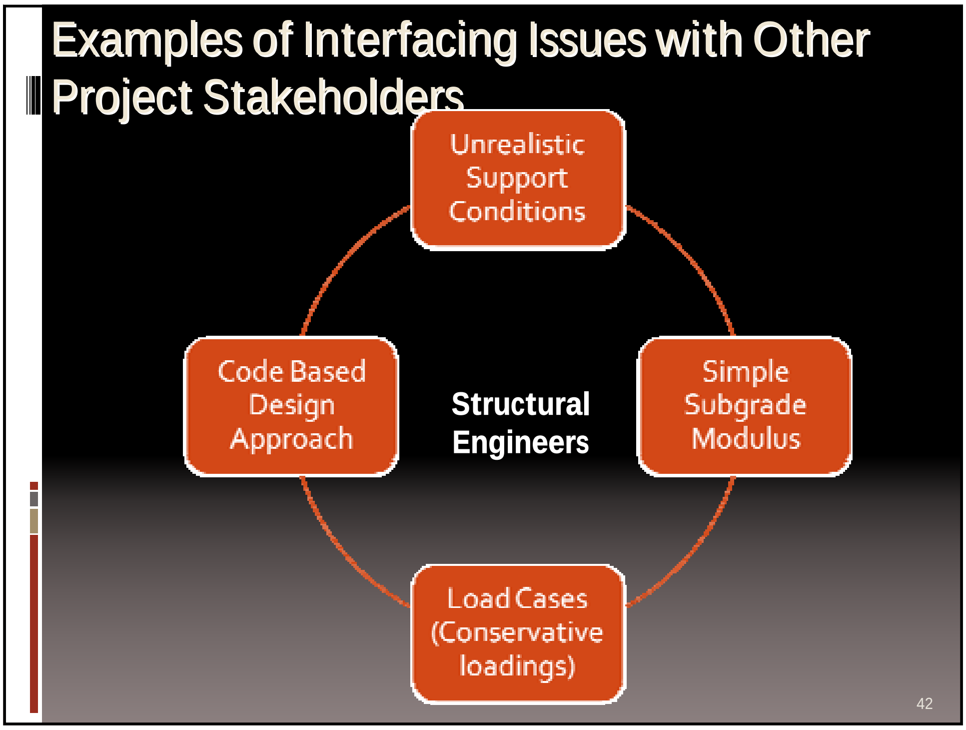


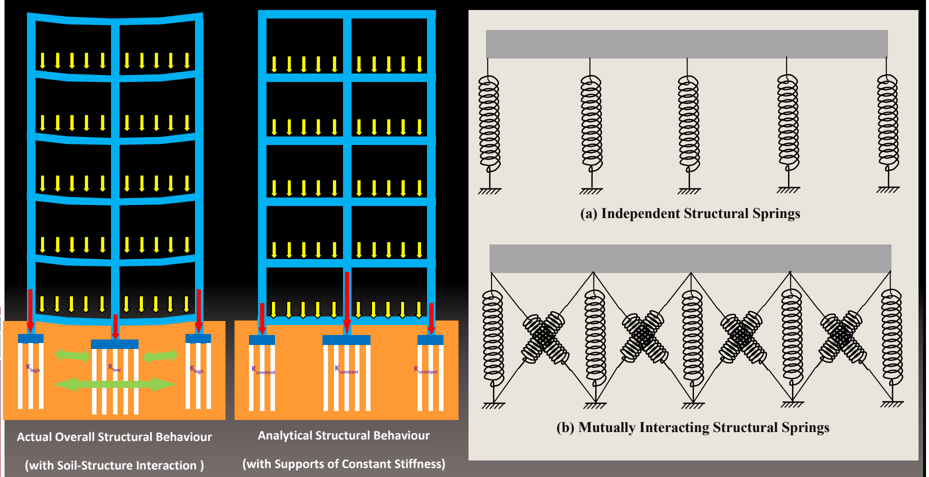
Forensic Engineering

- To learn the consequence of ignorance, design overlooks or overconfidence of an engineering works.
- A complete investigative cycle looking for factual evidences and rational reasoning of the causation out of the probable possibilities and sequence of the failure events.
- Very valuable lesson learnt & unforgettable experience to prevent similar recurrence.
- Common problems faced in forensic investigation : overwhelming of either irrelevant or conflicting information; untimely access to the scene for gathering first hand information.
- For problems with complex action-soil-structure interaction, it is essential to figure out the moment of which certain components in the system reach their corresponding ultimate limit state condition leading to the unacceptable performance.
- Forensic investigation is often tied up with legal proceeding to recover and apportion the damage and responsibility to the parties at fault. For complicated cases, the loss adjuster will recommend engagement of geotechnical specialist consultant to investigate the causation and determine reasonableness of the proposed remedial solution by the insured.
- Common findings in geotechnical forensic investigation by the author are as follow:
  - Poor understanding of ground conditions due to inadequate ground investigation and la boratory testing,
  - Technical deficiencies, likes design errors, mistakes in specification or construction/sho p drawings,
  - Non-compliance on materials, approved method statement due to lack of supervision,
  - Lack of maintenance,
  - Improper usage of structure during construction stage by builder or operation stage by owner,
  - Vibration and erosion.

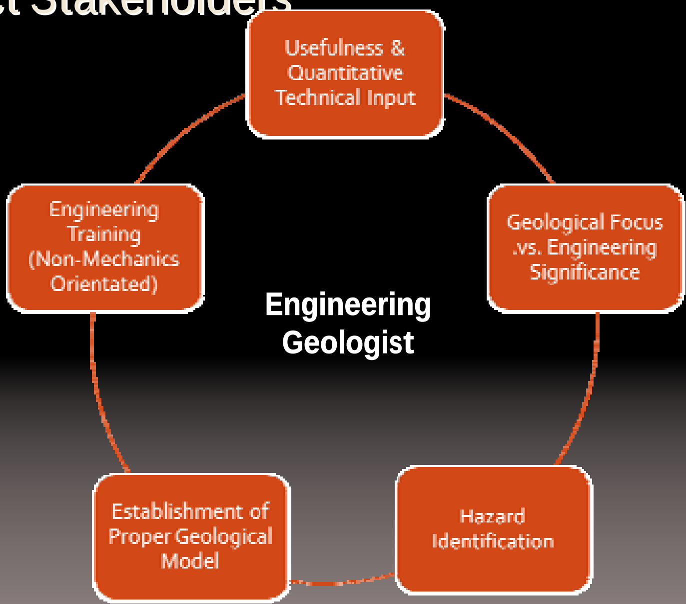
  In most cases, the first three factors account for the failures.


Examples of Interfacing Issues with Other Project Stakeholders
Focus of GI
Masonry Dain
Piled Bund Wall in Settling Soil
Civil Engineers
Consolidation Settlement
Transition between Piled & Unpiled Zone
41


Examples of Interfacing Issues with Other Project Stakeholders
Unrealistic Support Conditions
Code Based Design Approach
Structural Engineers
Simple Subgrade Modulus
Load Cases (Conservative loadings)
42



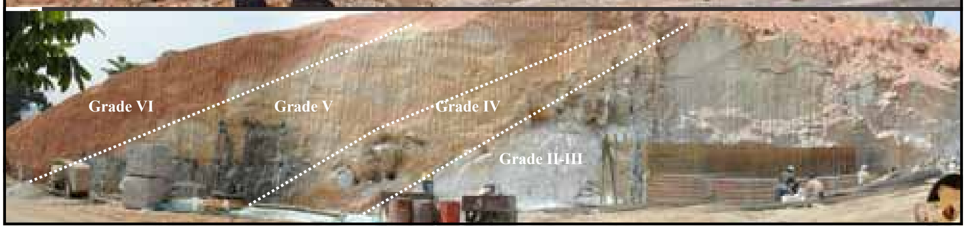
Examples of Interfacing Issues with Other Project Stakeholders



Roles of Engineers and Geologists

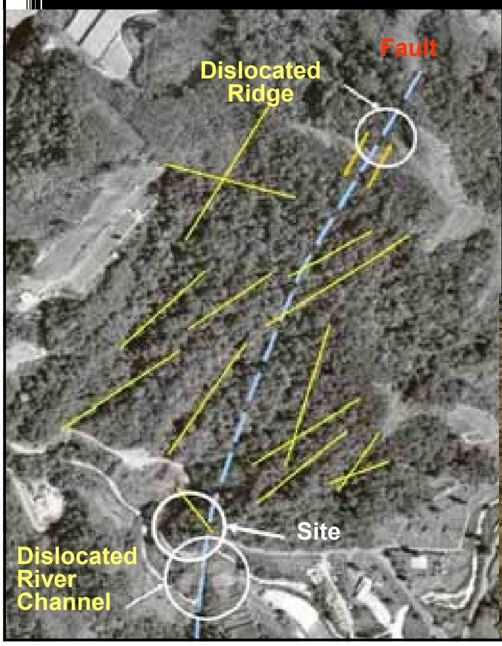
	Engineering Geologists	Geotechnical Engineers
1	Provide regional geological setting & potential geohazards	Covers all geotechnical aspects of a project
2	Detailed study of site geology and produce specific geological models and maps	Planning and implementing site investigations to obtain design parameters for engineering analysis
3	Engineering geology such as geological formations, slope conditions, highlight potential geological constrains and problematic areas and materials	Carrying out detailed engineering analysis for possible failure mechanism, suitable engineering solutions
4	Engineering geological assessments provide to engineer, including during construction, if required	Undertaking detailed engineering designs of all geotechnical components, supervision and advising on monitoring and maintenance

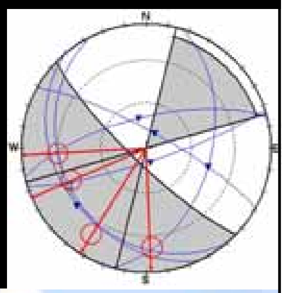
Example 1: Slope Strengthening Design



Example 1: Slope Strengthening Design

Example 2: Slope Failure Investigation





Example 2: Slope Failure Investigation

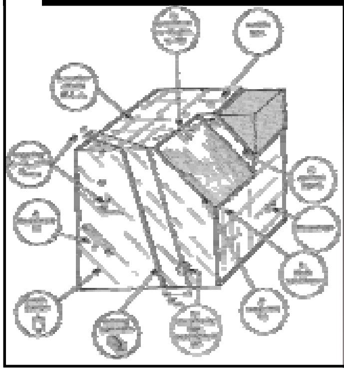
Summary

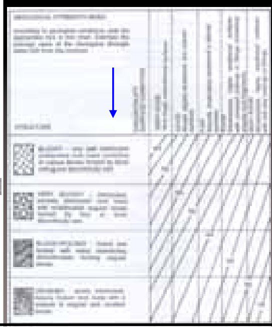
- Geologists identify geological constraints and forewarn the Engineers of such constraints.
- The Engineers would then decide on the proper course of actions to be taken to counter such constraints with engineering solution to ensure public safety.

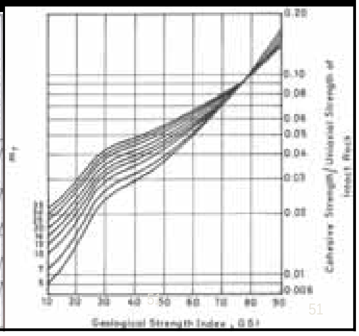
Complexity of Rock Mass Properties

- Complicated rock mass strength (slope & excavation design)
- Empiricism requiring judgement (involving subjectivity)
- Information normally only available during construction, not design stage

$$\sigma_1' = \sigma_3' + \sigma_u \left[m_b \left(\frac{\sigma_3'}{\sigma_u} \right) + s \right]^a$$







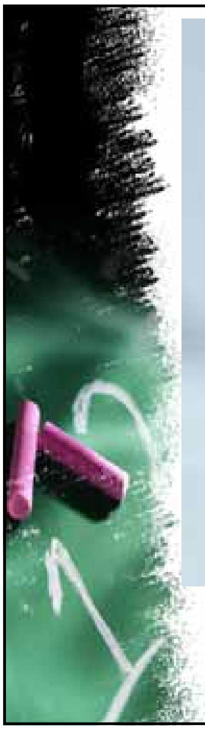
Communication Problem

Summary of Geotechnical Engineer's Role

- Define the role of geotechnical engineering at various project cycles (project inception, investigation, assessment, design, construction stage till maintenance after completion),
- Highlight potential value adding process by geotechnical engineer,
- Lesson learnt from forensic investigation minimize serious mistakes & avoid recurrence,
- Problems encountered, solution exploration & innovation achieved in some of the projects,
- Interfacing problems with other project stakeholders & highlights for future improvements with better mutual understanding,
- Case histories demonstrate the important role and value of geotechnical engineer in dealing with the uncertainties in the ground.

Conclusions

- Application of forensic principles in geotechnical investigation
- Difficulties encountered and ways to overcome
- Role of Geotechnical Engineer & Geologist
- Professional responsibility to reveal truth of the causation factors, failure mechanism, effects and consequences for lessons learnt



Thank You

SESSION 2 : ROLES OF GEOTECHNICAL INVESTIGATION

Ir. Liew Shaw Shong

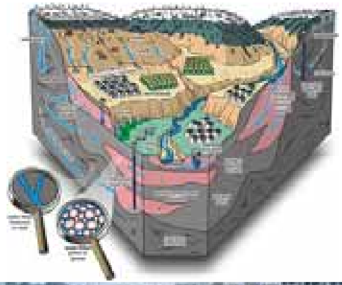
Introduction

Scope

- **Site Investigation**
  - Information on Hydrology, Meteorology, Environment, Natural Resources, Activities & Topography
- **Ground Investigation**
  - Information on Ground & Groundwater conditions
- **Monitoring**
  - Time dependent changes in ground movements, groundwater fluctuation & movements

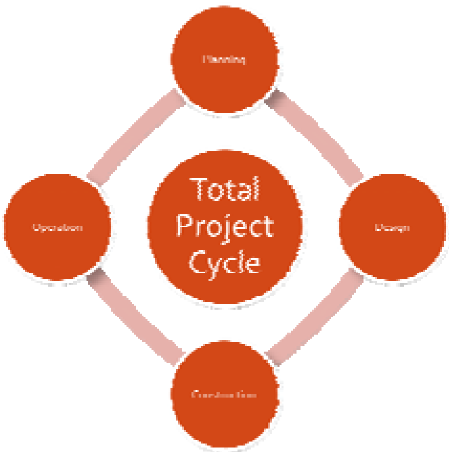
Introduction

Purpose



Introduction

- Project Cycle
- Ground Investigation
- Common Problems & Trend
- Conclusion



Why doing GI? Why Geotechnical Engineer? What Risk & Consequence

Why doing GI?

It is regard as necessary, but not a rewarding expense. (Uncertainty, sufficiently accurate design options for Cost & Benefit study)

Why Geotechnical Engineer?

Geotechnical engineer as an underwriter for risk assessment.

What Risk in Ground & its Consequence ?

Ground Variability & Geo-hazards.

Financial Viability & Cost Overrun (Construction & Operation).

WITHOUT SI, GROUND IS AN HAZARD

Sink hole triggers dramatic Florida viaduct collapse

SITE INVESTIGATIONS failed to pick up a sink hole which caused a motorway viaduct to collapse in Tampa, Florida, last month.

Ground investigations involved borehole probes to 3.5m below the base of the 19.5m foundations for each of the viaduct's 212 piers.

Project client Tampa-Hillborough Expressway Authority said this was double normal requirements.

A 6m high pier for the 10km long highway sank suddenly into the ground on 13 April during construction of a glued segmental deck span.

The reinforced concrete pier almost completely disappeared.

The collapse was slow enough for workers to get clear, although two were taken to hospital. The busy Lee Roy Selman Crosstown Expressway which runs beneath the viaduct was closed until traffic could be redirected.

Cause of the collapse is thought to be a limestone sink hole, more than 30m below the site. A spokeswoman for the Authority said Florida was largely underlain by limestone and sink holes were prevalent. It was impossible to determine the location of every one.

Ground investigation was by Dames & Moore, subcontractor to the Authority's general engineering consultant URS. Additional input was made by Williams Earth Science.

Ground radar and seismic probing may now be used to check the remaining pier locations for the highway. The existing 160 piers should be okay said the Authority spokeswoman.

"The pier sank when the launching truss for assembling the 16 segment precast span was fully loaded which means it had half a 700,000lb (320t) load on it," she said. Existing piers have already received this de facto load test.

The $310M project, due for completion next year, will create an additional three lanes, 6m above a busy existing commuter route. Traffic flow will reverse between morning and night.

Designer for the elevated structure is the Figg Engineering Group and contractor PCL Civil Constructors from Canada.

Source :http://www.sptimes.com/2004/04/16/Tampabay/At_site_of_collapse__.shtml

WITHOUT SI, GROUND IS AN HAZARD

Light saves man in sinkhole scare

IPOH: When Lee Pek Sang, 84, got up to answer nature's call at 5am yesterday, he realised something was amiss.

The toilet at his home in Bukit Mertah New Village, was missing — lost to a sinkhole.

The sinkhole, measuring 2.44m by 4.57m, was the 21st that had occurred in the area since last October, according to Geological Survey Department officers.

Lee said he would have fallen into the sinkhole if not for the light outside the toilet which was always switched on.

He also said he cannot leave his home because he had nowhere else to go.

The last sinkhole which appeared at the new village next to a cobbler's house on May 16 measured 2m by 8m.

MP for Batu Gajah Yeong Chee Wah will ask to make public the findings on the frequent appearance of sinkholes at the Bukit Merah new village during the Dewan Rakyat sitting in July.

Yeong said the affected villagers have been living in fear since October, adding that some form of remedial action should be taken.

At present, the sinkholes are a threat to 50 houses located side-by-side in three rows in the village.

The village elders when questioned about the occurrence of sinkholes there, said water from a nearby mining pool was drained away underground below the affected houses and could be the main reason for the sinkholes.

The Lahat mines about 500m away from the Bukit Merah New Village is a large and very deep dry mine which has existed for years and has been dubbed the "Grand Canyon of Malaysia" since it could be seen when travelling on the new Ipoh-Lumut outer ring road.

DEEP TROUBLE ... Yeong (standing, left) peering into the sinkhole at what used to be Lee's toilet yesterday. The MP pledges to follow up on the matter at the Dewan Rakyat in July.

WITH SI, GROUND CAN BE A HAZARD

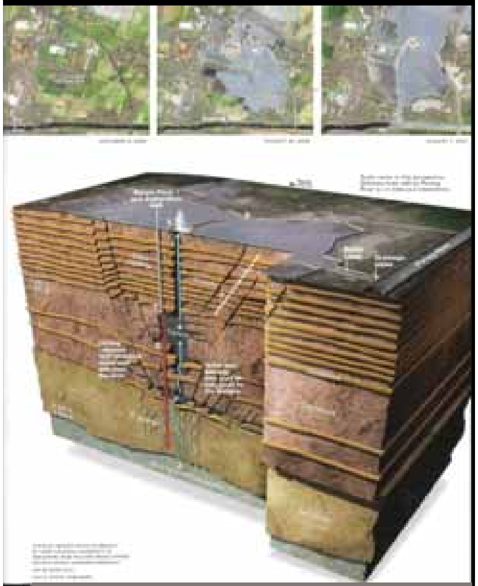
Source :National Geographic (Jan 2008)

WITH SI, GROUND CAN BE A HAZARD

UNDER THE MUD VOLCANO

It began with a burst of steam and a splurt of mud. But the gloopy surge that locals call Lusi soon became a sprawling nightmare. Satellite images (top) show Lusi swallowing more than two square miles in the Porong District. A cross section (right) illustrates what geologist Richard Davies believes caused the disaster.

1. Drillers exploring for gas bored 3,580 feet down, then inserted a steel casing to strengthen the hole.
2. Drilling went deeper without the steel casing. Water and gas filled the hole, and the resulting pressure fractured unprotected rock strata.
3. Hot, high-pressure water was released, probably from the Kujung aquifer.
4. The water raced upward and liquefied masses of mudstone.
5. Mud surged through layers of mudstone and sandstone and broke through the surface.
6. Engineers built dikes in an attempt to contain the mud.
7. Underground, caverns formed and collapsed, causing faults.



Source :National Geographic (Jan 2008)

Unexpected Blowout of Underground Gas

- Gas pockets at 32m bgl
- Flushing out of sand

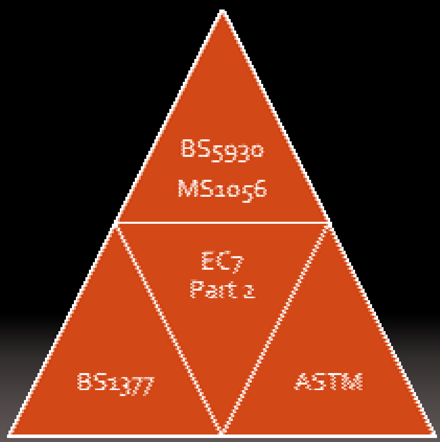
GOD CREATION & HUMAN CREATION

- How GI cost

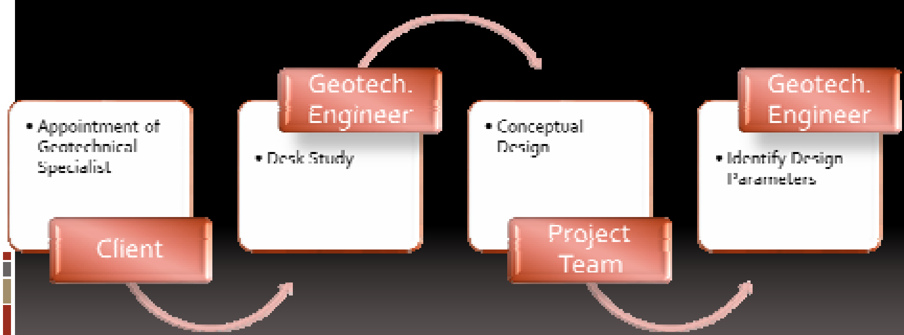
Consequence

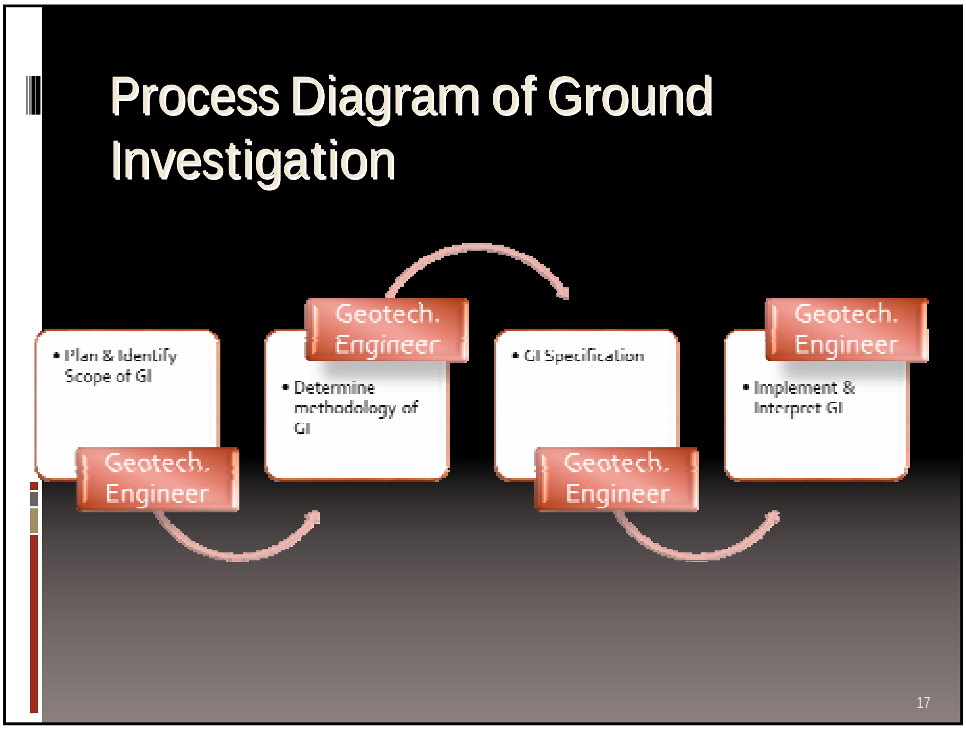
How GI shall be done ?

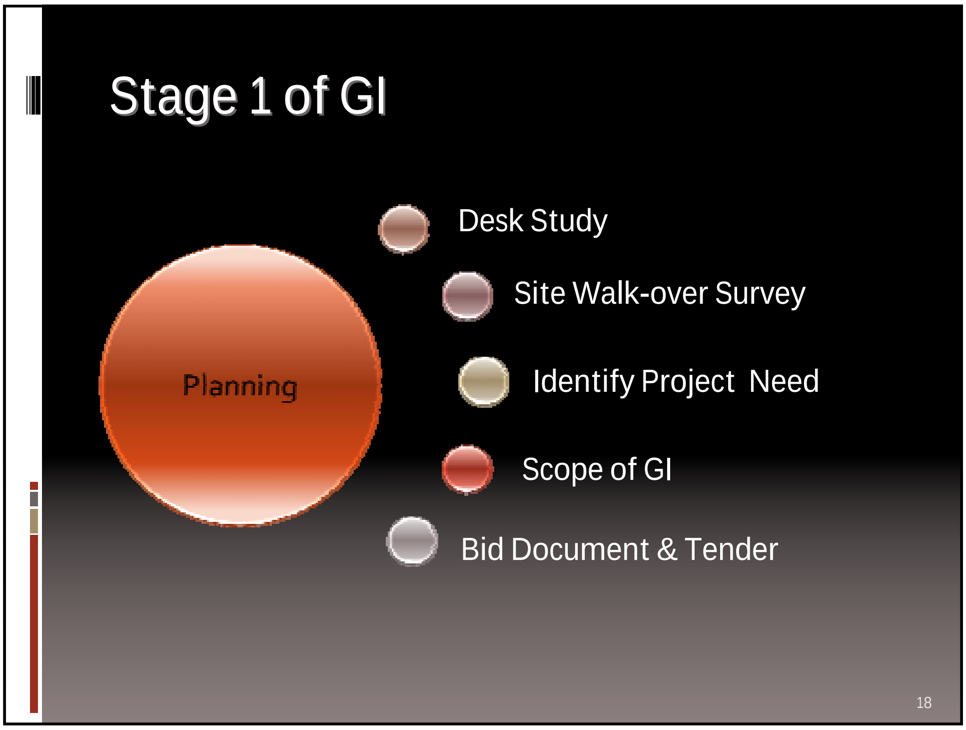
Codes & Standards

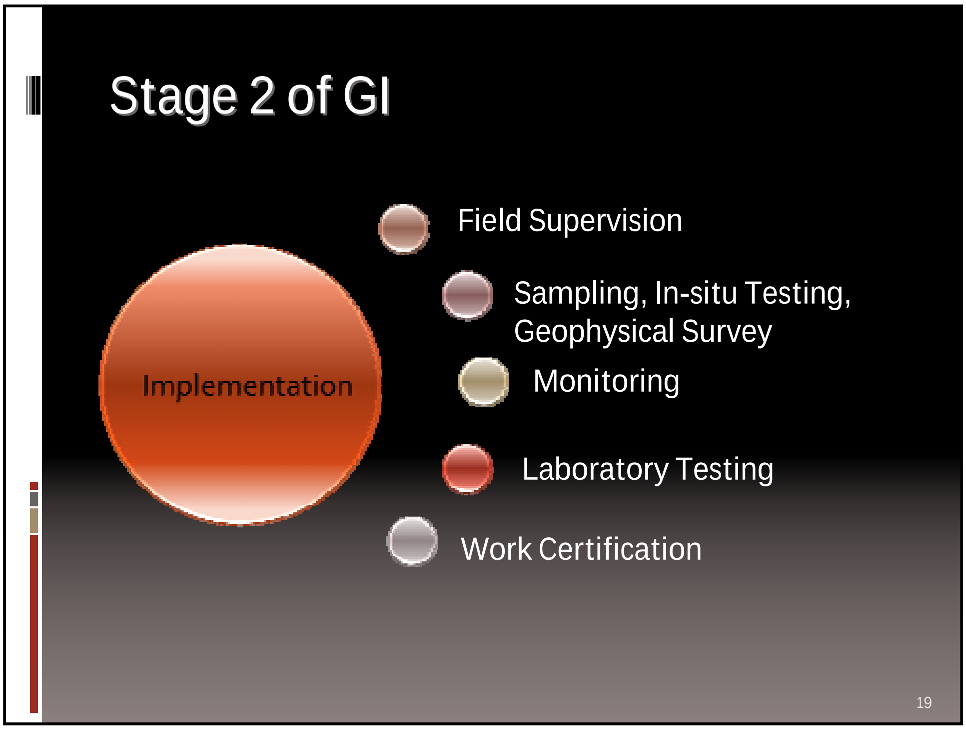


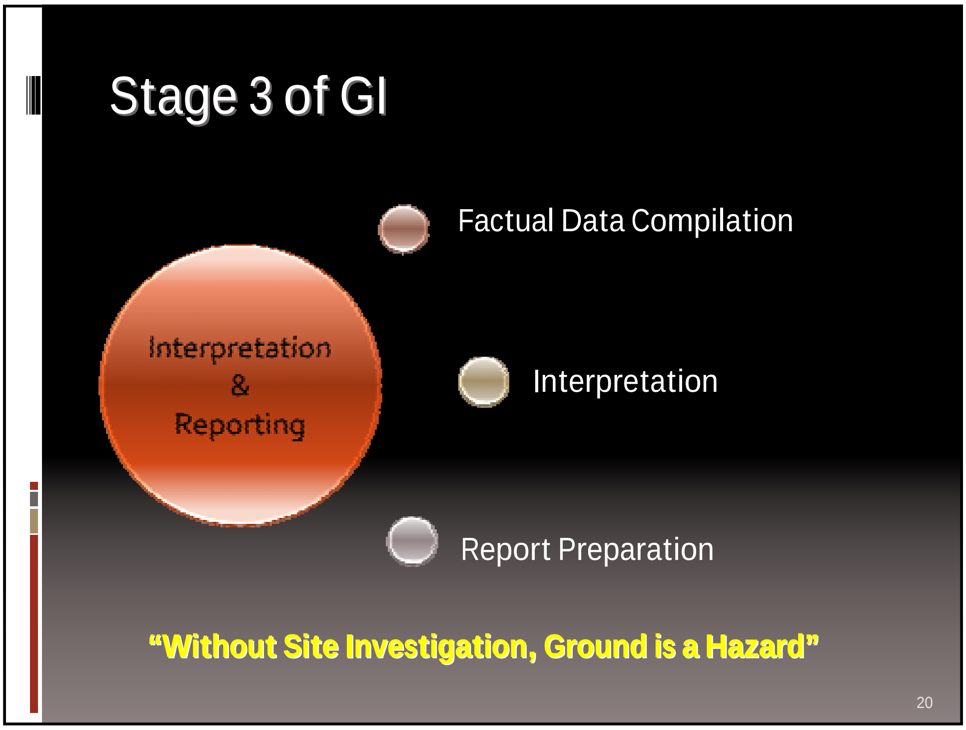
Process Diagram of Ground Investigation




Process Diagram of Ground Investigation
Plan & Identify Scope of GI
Geotech. Engineer
Determine methodology of GI
Geotech. Engineer
GI Specification
Geotech. Engineer
Implement & Interpret GI
Geotech. Engineer
17


Stage 1 of GI
Planning
Desk Study
Site Walk-over Survey
Identify Project Need
Scope of GI
Bid Document & Tender
18

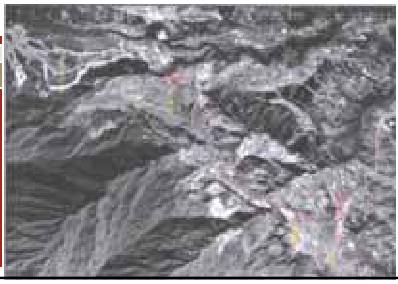

Stage 2 of GI
Implementation
Field Supervision
Sampling, In-situ Testing, Geophysical Survey
Monitoring
Laboratory Testing
Work Certification
19


Stage 3 of GI
Interpretation & Reporting
Factual Data Compilation
Interpretation
Report Preparation
"Without Site Investigation, Ground is a Hazard"
20

Desk Study

Information for Desk Study :

- Topographic Maps
- Geological Maps & Memoirs
- Site Histories & Land Use
- Aerial Photographs
- Details of Adjacent Structures & Foundation
- Adjacent & Nearby Ground Investigation



Site Walkover Survey

- Confirm the findings from Desk Study
- Identify additional features & information not captured by Desk Study

Site Reconnaissance

GI Planning

Layout

- Direct influence beneath the proposed structure/works
- Distant Impact from the proposed structure/works

Frequency

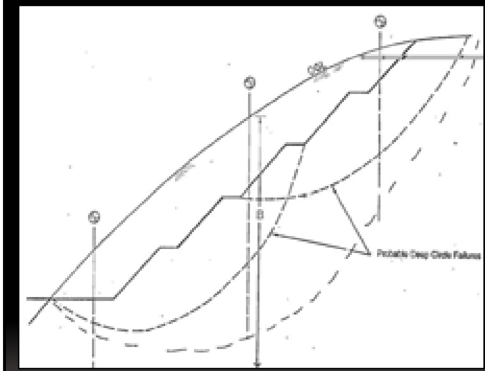
- Light structure
- Compact structure (3 ~ 5 points)
- Linear infrastructure (Representation of each geological unit)
- Slope : 3 probing per critical section

Vertical Extent

- Foundation : 10% stress bulb or to competent founding strata
- Slope : Hard strata or bedrock, not less than overall slope height

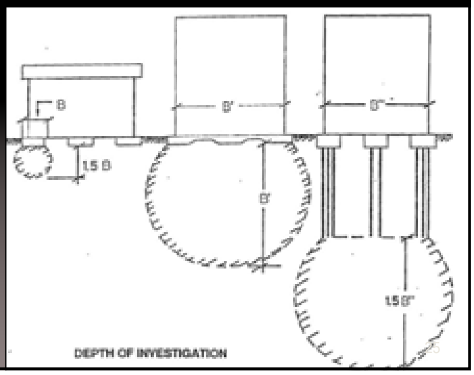
Watch out for boulder, cavity, hard pan, necessary depth for weathering profile

Depth of Investigation



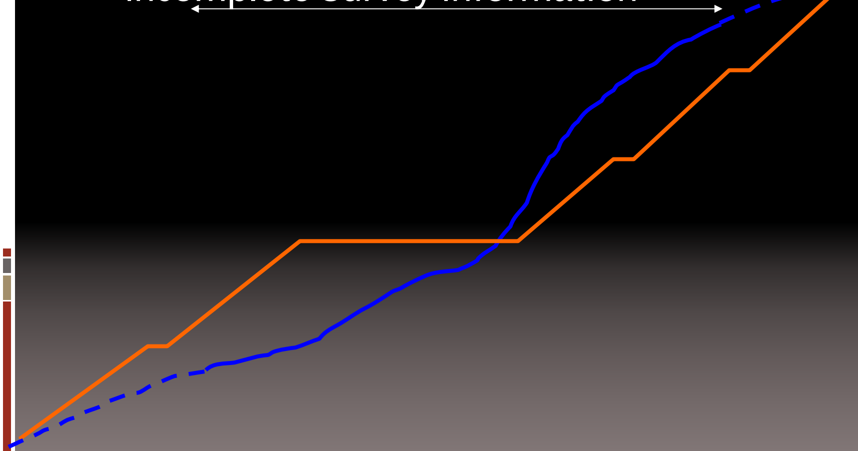
Stability Analysis

Foundation Design



Common Problems

- Incomplete Survey Information



GI Planning

Sampling
- Reasonable samples in each soil strata and bedrock
- Groundwater samples

In-situ Test
- Advance indication on strength, stiffness, permeability
- Direct testing
- Less sample size effect
- In-situ stress

Laboratory Test
- Sample quality & disturbance
- Late availability of result
- Stress path controlled & effective strength are possible under controlled environment

GI Planning

Monitoring
- Ground movement (sliding surface, settlement/compression)
- Groundwater Fluctuation
- Appropriate timing & monitoring duration
- Identify potential failure mechanism

Stage of Investigation
- Preferably in three stages (strategically)
  - Preliminary GI with contingency provision – Broad overview of ground conditions
  - Detailed GI – At critical areas for more information
  - GI in Construction Verification - Areas not covered in previous GI/design modification

Flexibility
- Allow for flexibility of information coverage catering for option exploration

Specification

- Objectives (study, design, forensic, construction)
- Type of investigation, mapping & field survey
- Vertical & lateral extent (termination depth)
- Sampling requirements (types, sampling locations & techniques)
- In-situ and laboratory testing requirements (standards)
- Measurement/monitoring requirements (instrument types & frequency)
- Skill level requirements in specialist works & interpretation
- Report format & data presentation

Specification

- Work schedule & GI resources planning
- Payments for services, liability, indemnity, insurance cover

Boring/Drilling

Recover Sample
- Subsurface stratification/profile
- Material classification & variability
- Laboratory tests

In-situ Testing
- Allow in-situ tests down hole (profiling)
- Direct measurement of ground behaviours

Monitoring
- Allow monitoring instruments installed down hole

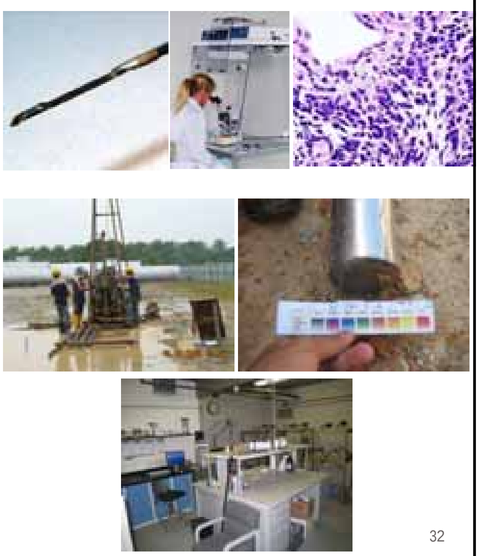
Direct Method – Boring, Sampling, In-situ & Laboratory Testing

Medical Applications

- Biopsy sampling

Geotechnical Applications

- Boring, Trial Pitting & Sampling
  - Thin-walled, Piston Sampler
  - Mazier Sampler
  - Block Sample
- In-situ Testing
  - SPT, MP, CPTu, VST, PMT, DMT, PLT,
  - Permeability Test
  - Field Density Test
- Laboratory Testing
  - Classification Test
  - Compressibility Test (Oedometer/Swell)
  - Strength Test (UU/UCT/CIU/DS)
  - Permeability Test
  - Compaction Test
  - Chemical Test (pH, Cl, SO4, Organic Content, Redox, etc)
  - Petrography & XRD



Indirect Method – Geophysical Survey

Medical Applications

- X-ray, Computer Tomography & MRI
- Ultra-sound

Geotechnical Applications

Geophysical Survey

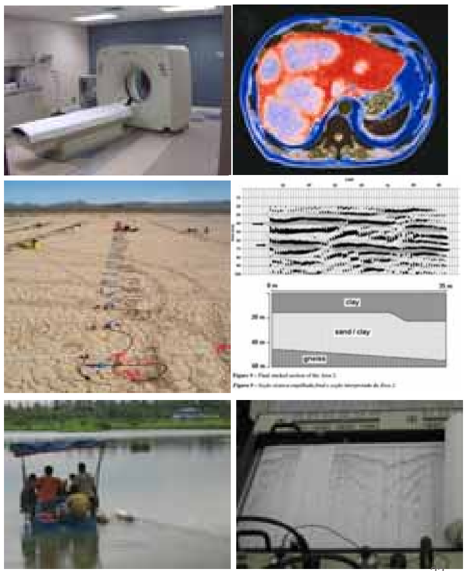
- Electromagnetic Waves

(***Permeability, Conductivity & Permittivity***)

- Mechanical Wave

(Attenuation, S-waves & P-waves)

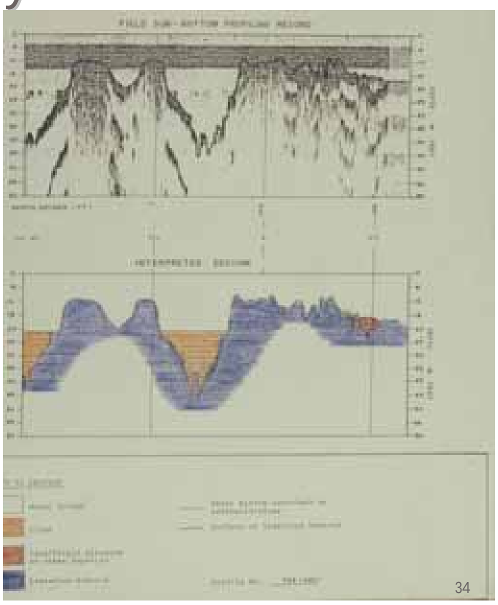
- Resistivity Method
- Microgravity Method
- Transient Electro-Magnetic Method
- Ground Penetration Radar
- Seismic Method



Santamarina, J. C. (2008) - http://www.elitepco.com.tw/ISC3/images/Keynote-03-Santamarina.pdf

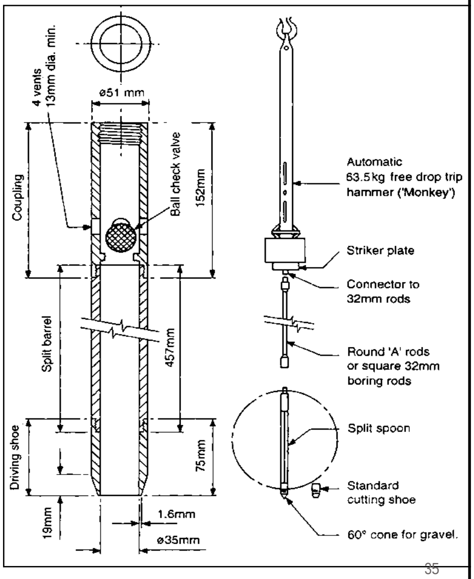
Geophysical Survey

- Merits
  - Lateral variability (probing location)
  - Profiling (sampling & testing)
  - Sectioning (void detection)
  - Material classification
  - Engineering parameters (G_0 & $G_{dynamic}$)
- Problems
  - Over sale/expectation
  - Misunderstanding between engineers, engineering geologists & geophysicists
  - Lack of communication
  - Wrong geophysical technique used
  - Interference/noise



Sampler

Split Spoon
Thin-Walled
Piston Sampler
Mazier Sampler
Core Barrel
Wire-line



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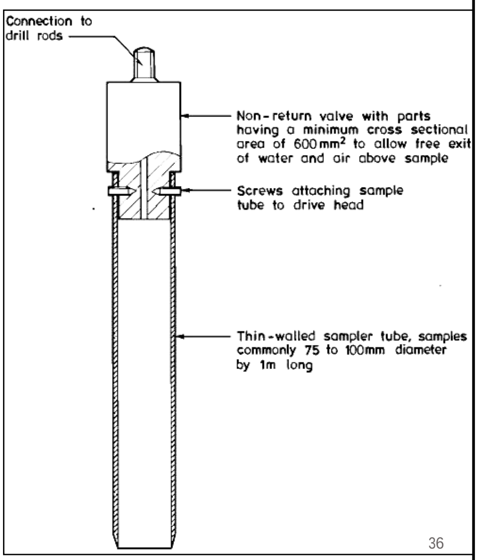

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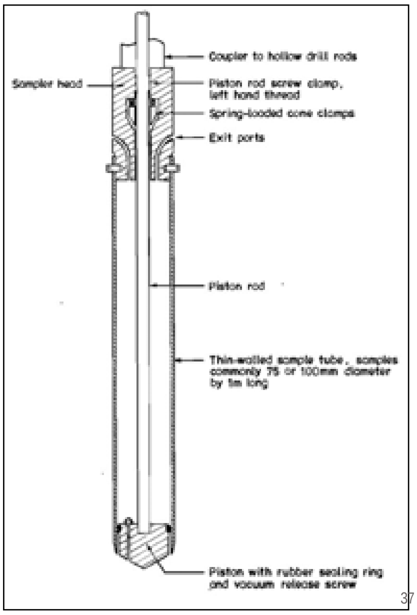

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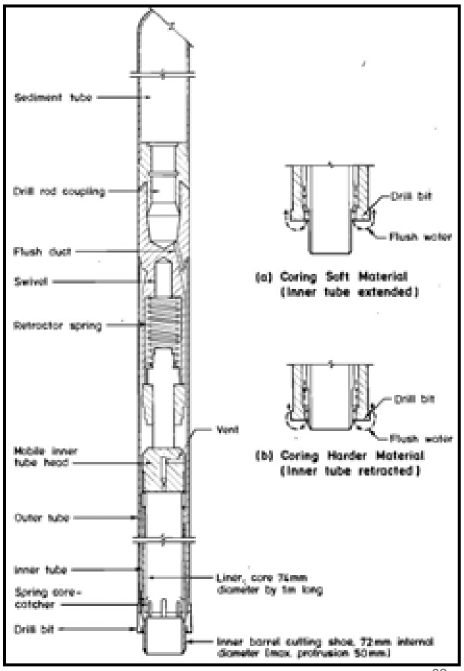

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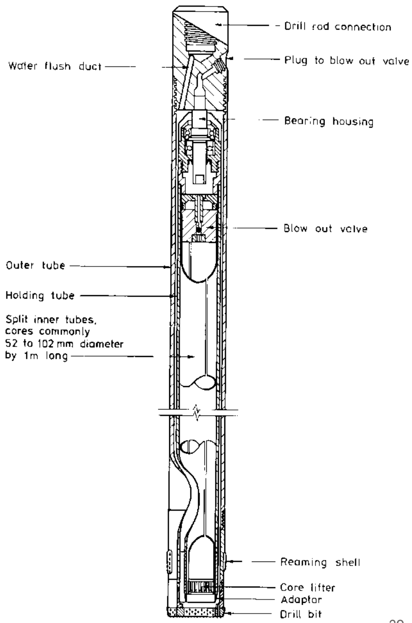

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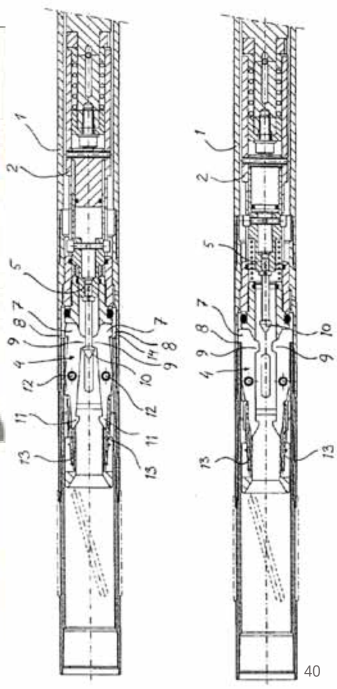


Sample Storage, Handling, Transportation

Sample Preparation

Sampling

- Sample Sizes
  - Representative mass (particle sizes, fabric, fissures, joints)
  - Adequate quantity for testing
- Sample Disturbance
  - Stress conditions
  - Deformation behaviours
  - Moisture content & void
  - Chemical characteristics

At Different Stages of SI		
Before	**During**	**After**
Stress relief	Stress relief	Stress relief
Swelling	Remoulding	Moisture migration
Compaction	Displacement	Extrusion
Displacement	Shattering	Moisture loss
Base heave	Stone at cutting shoe	Heating
Piping	Mixing or segregation	Vibration
Caving	Poor recovery	Contamination

Clayton et al (1982)

Sample Disturbance

- Poor recovery
  - Longer rest period for sample swelling
  - Slight over-sampling
  - Use of sample retainer
- Sample contamination

Sample Quality Classification

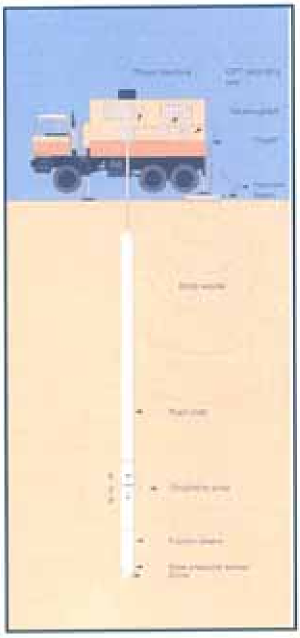
Sample Quality	Soil Properties					
	Classification	Moisture Content	Density	Strength	Deformation	Consolidation
Class 1	✓	✓	✓	✓	✓	✓
Class 2	✓	✓	✓	✗	✗	✗
Class 3	✓	✓	✗	✗	✗	✗
Class 4	✓	✗	✗	✗	✗	✗
Class 5	✗	✗	✗	✗	✗	✗

BS 5930 (1981)

In-situ Tests

Piezocone (CPTu)

CPT Equipment



- The Seismic Cone Penetration Test (SCPT) is a reliable, cost effective technique to determine the insitu seismic wave velocity.
- Seismic wave velocities give an indication of ground characteristics such as low strain shear modulus and Poisson's ratio.
- Data from the cone penetrometer is used in delineating the strata changes identified by the seismic results.

In-Situ Tests

- BS1377 : Part 9
- Suitable for materials with difficulty in sampling
  - Very soft & sensitive clay
  - Sandy & Gravelly soils
  - Weak & Fissured soils
  - Fractured rocks
- Interpretation
  - Empirical
  - Semi-empirical
  - Analytical

Applicability of In-situ Tests

Test	Stress	Strength			Stiffness			Permeability
	K_0	ϕ'	C_u	σ_c	E'/G	E_u	G_{max}	k
SPT		G	C	R	G	C	G	
CPT/CPTu		G	C		G			
DMT	G, C				G			
Borehole PMT			C		G, R	C		
PLT			C		G, R	C		
VST			C					
Seismic							G, C, R	
SBPMT	G, C	G	C		G, C			
Falling/ Rising Head Test								G
Constant Head								C
Packer Test								R

Clayton , et al (1995)   G = granular, C = cohesive, R = Rock

Applicability of In-situ Tests

SUMMARY ON THE COMMON TYPES OF GROUND INVESTIGATION, FIELD TESTS, SAMPLING & LABORATORY TESTS

Description	Types of Ground Investigation						Field Test					Laboratory Test							
	JP	HA	TP	BH	PZ	GS	SPT	PM	PLT	VS	PW	C	M/C	γ	Con	UU	UCT	CIU	Chem
1) Soft ground treatment	m	m	m	y	y	m	-	-	-	y	m	y	y	y	y	y	y	m	m
2) Shallow foundation																			
cohesive soil	y	m	m	y	-	-	y	m	y	m	-	y	y	y	y	y	y	m	m
non cohesive soil	y	m	m	y	m	-	y	-	y	-	-	y	y	y	-	-	-	-	m
3) Pile Foundation																			
Fill ground	m	m	m	y	m	m	y	m	-	m	-	y	y	y	y	y	y	-	m
Cut ground	-	-	m	y	-	m	y	-	-	-	-	y	y	y	-	-	-	-	m
4) Slope																			
Cut	-	-	m	y	-	y	y	-	-	-	y	y	y	y	-	y	y	y	-
Fill	m	m	m	y	m	m	y	-	-	y	m	y	y	y	y	y	y	y	m

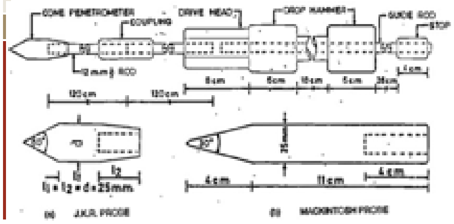
Legend:

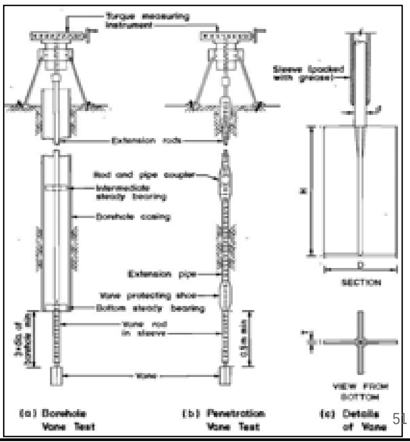
JP : JKR Probe
HA : Hand Auger
TP : Trial Pit
BH : Borehole
PZ : Piezocone
GS : Geophysical Survey

SPT : Standard Penetration Test
PM : Pressuremeter
PLT : Plated Bearing Test
VS : Vane Shear Test
K : Permeability Test
Y : Yes should be done
M : May be added
- : Not relevant/necessary

C : Classification
M/C : Moisture Content
γ : Unit Weight
Con : Consolidation
UU : Unconsolidated Undrained
UCT : Unconfined Compression
CIU : Triaxial with Pore Water Pressure
Chem : Chemical Test

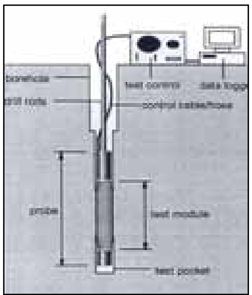
In-situ Tests





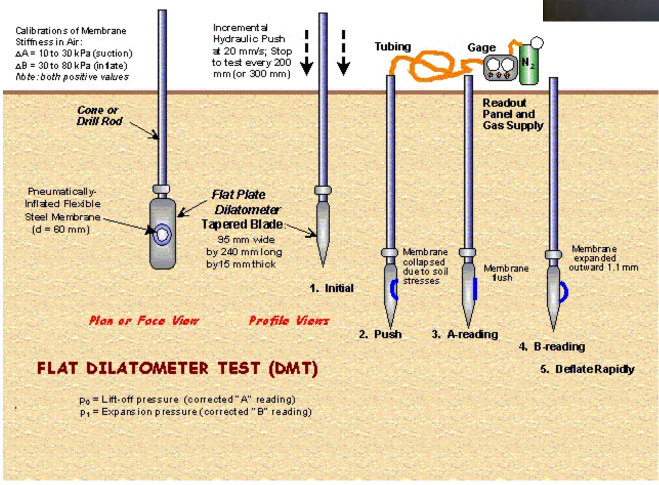
In-situ Tests

Pressuremeter (PMT)

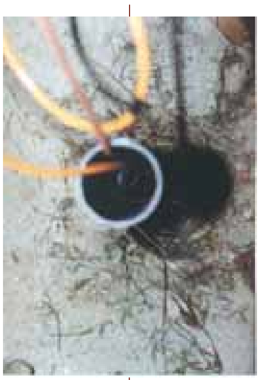


In-situ Tests

Dilatometer (DMT)

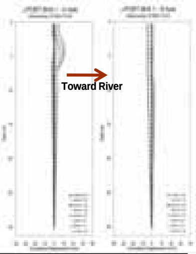


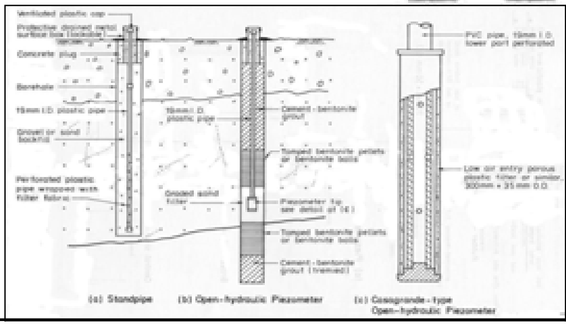
Geophysics Methods



Instrumentation Monitoring

- Inclinometer
- Extensometer
- Rod Settlement Gauge/Marker
- Piezometer
- Observation Well





Laboratory Tests

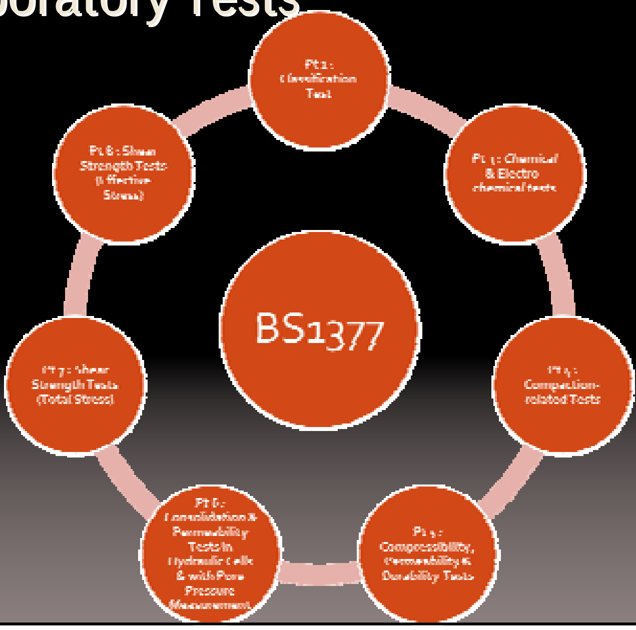
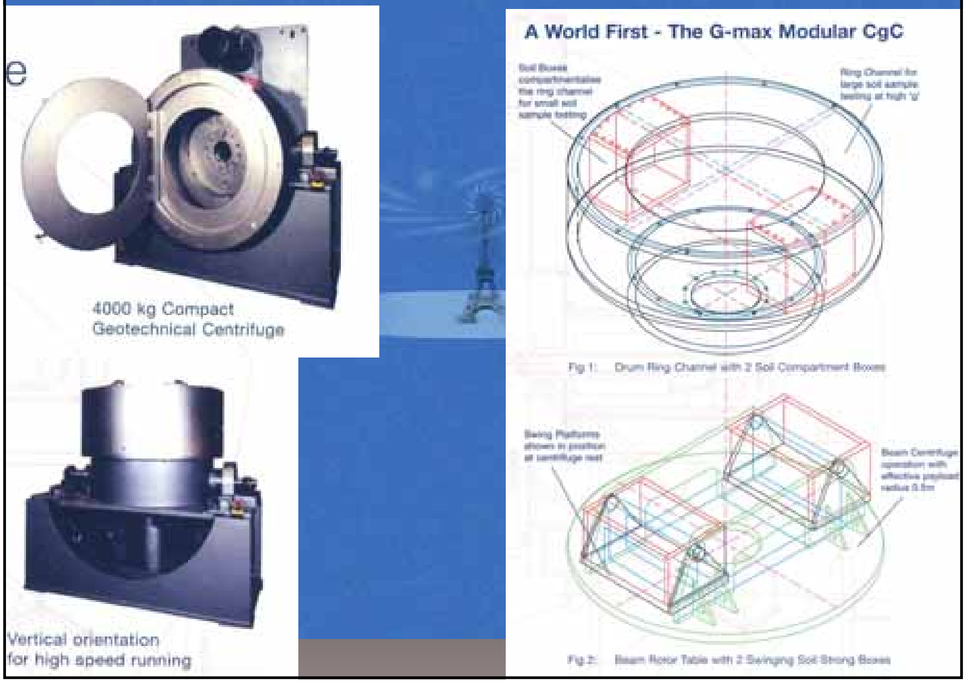
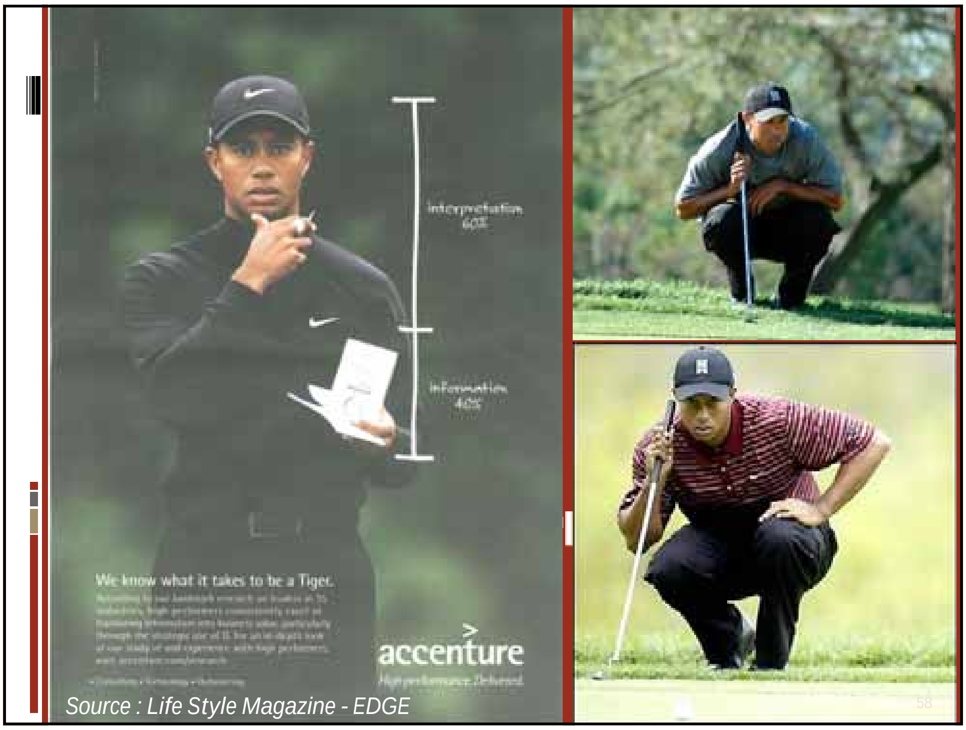


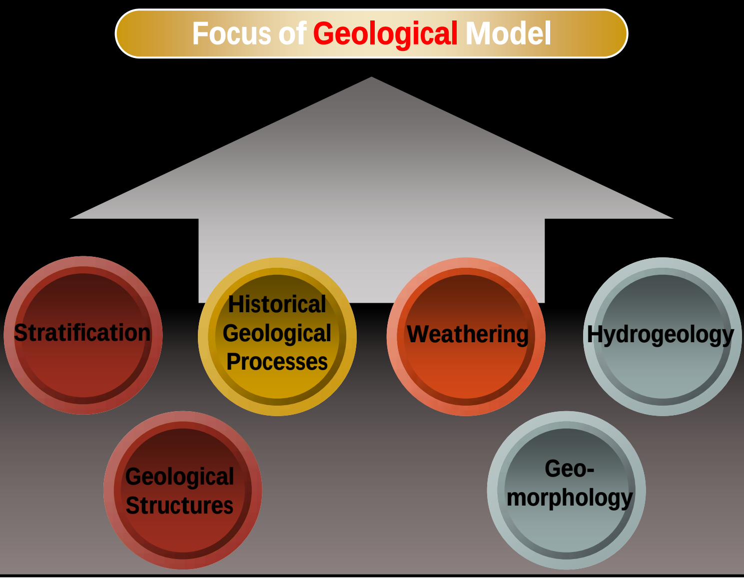
Table Top Geotechnicial Centrifuge





Source : Life Style Magazine - EDGE

Ground Characterisation

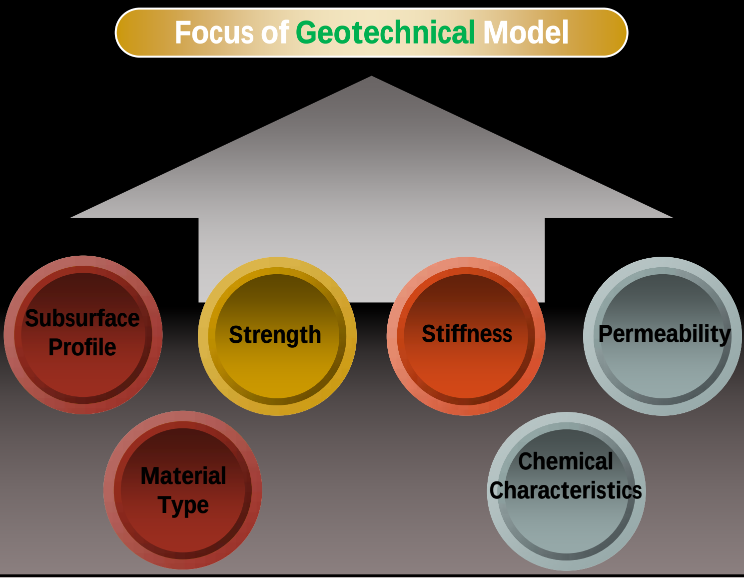


Geological Mapping

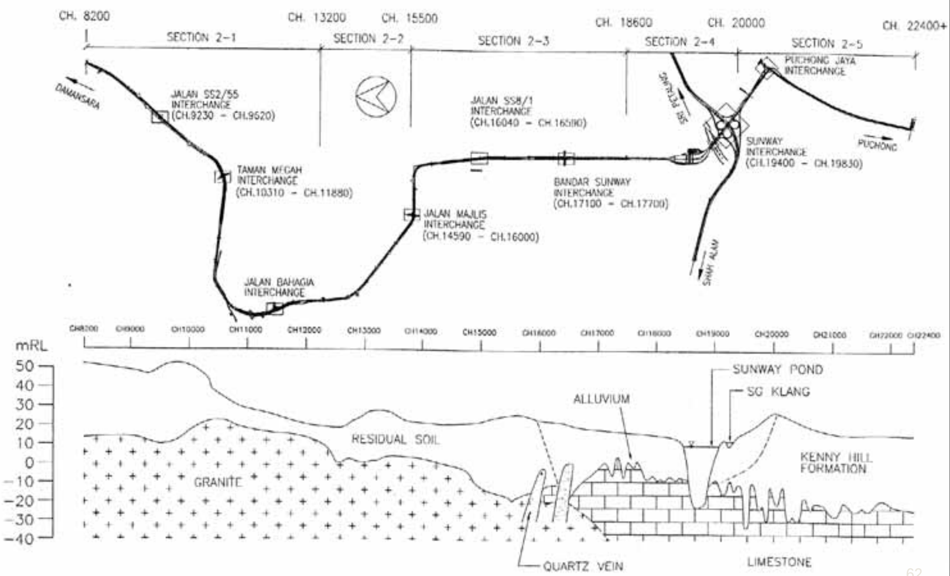
Mapping of :

- Geological features (Structural settings)
- Weathering profile
- Outcrop exposure
- Seepage conditions
- Geomorphology
- Lithology
- Stratification
- Sequence of geological actions & history

Ground Characterisation



GEOTECHNICAL MODEL



COMMON PROBLEMS & TREND

General Dilemma of GI Industry

- Lack of pride & appreciation from consultant/client in GI industry.
- Actions done is considered work done!
  Poor professionalism.

- Financial survival problem due to competitive rates in uncontrolled environment (cutting corner)
- No appropriate time frame for proper work procedures (shoddy works)
- Shifting of skilled expert to Oil & Gas or other attractive industries

Poor Planning & Interpretation

- Inadequate investigation coverage vertically & horizontally
- Wrong investigating tools
- No/wrong interpretation
- Poor investigating sequence

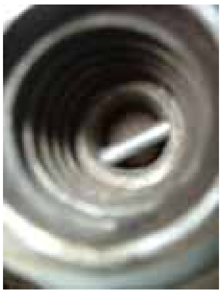
Poor Site Implementation

- Lack of level & coordinates of probing location
- Sample storage, handling, transportation
- Inappropriate equilibrium state in Observation Well & Piezometer

Poor In-situ & Laboratory Results

- Lack of equipment calibration
- Wear & Tear Errors
- Equipment systematic error (rod friction, electronic signal drift, unsaturated porous tip)
- Defective sensor
- Inappropriate testing procedures
- Equipment calibration (Variation of pH Values)
- Improper sample preparation
- Inadequate saturation
- Inappropriate testing rate
- Inadequate QA/QC in testing processes
- Inherent sample disturbance before testing

Poorly Maintained Tools





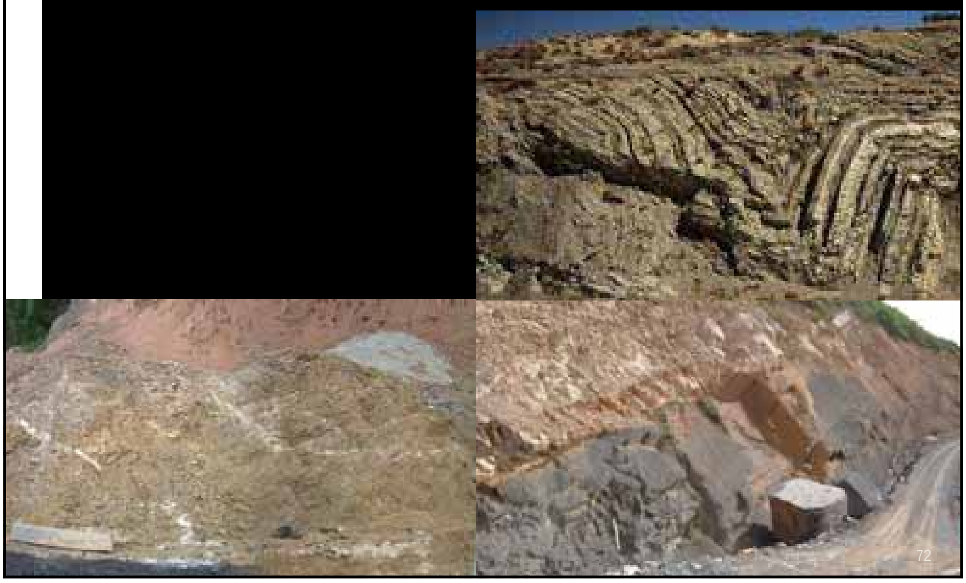
Over-confidence in Geophysics

- We detect everything in geophysical data, but indentify almost nothing (**Rich** but **Complex**).
-Not a unique solution in tomographic reconstruction (Indirect method)
- Poor remuneration to land geophysicist as compared to O&G
- Poor investigation specification
- Lack of good interpretative skill (human capital)
- High capital costs in equipment & software investment

Communication Problem

Difficulties in Identification of Complex Geological Settings

Difficulties in Identification of Complex Geological Settings



Weathering Profile

- Deviation of material classification between borehole and excavation

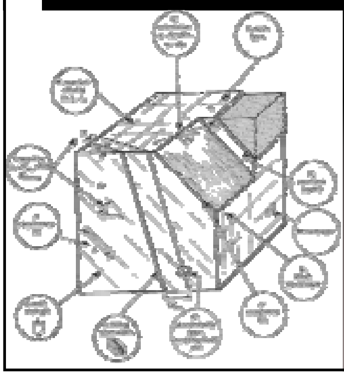
(Claim issue –

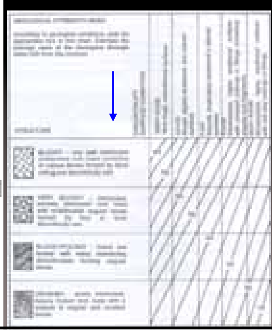
Soil or Rock ?)

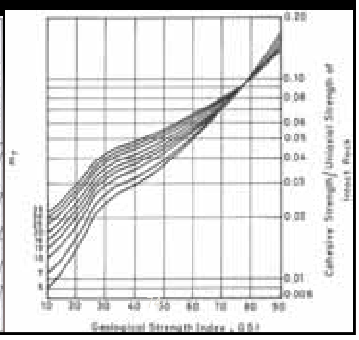
Complexity of Rock Mass Properties

- Complicated rock mass strength (slope & excavation design)
- Empiricism requiring judgement (involving subjectivity)
- Information normally only available during construction, not design stage

$$\sigma_1' = \sigma_3' + \sigma_u \left[m_b \left(\frac{\sigma_3'}{\sigma_u} \right) + s \right]^a$$







Unexpected Blowout of Underground Gas

- Gas pockets at 32m bgl
- Flushing out of sand

Supervision

- Work compliance & certification
- Document critical information
- Timely on-course instruction (sampling, in-situ testing & termination)
- Checking between field records and reported information

Future Trend - Electronic Data Collection, Transfer & Management

- AGS data transfer format & AGS-M format (monitoring data)
  - First Edition in 1992, AGS(1992)
  - Second Edition in 1994, AGS(1994)
  - Third Edition in 1999
- Advantages :
  - Efficient & Simplicity
  - Minimised human error
  - GI & Monitoring Data Management System
  - Record keeping
  - Spatial data analysis

http://www.ags.org.uk/site/datatransfer/intro.cfm

Conclusions

- Nature of GI works & Geotechnical design (Uncertainties)
- Role of Geotechnical Engineer, Engineering Geologist & Geophysicist
- Stages of GI works (Planning, Implementation, Interpretation & Report)
- Specifications
- Methodology of GI (Merits & Demerits)
  - Fieldworks (Direct/Indirect) + Geological Mapping
  - Laboratory tests
- Common Problems & Future Trend

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THANKYOU

SESSION 2: GEOTECHNICAL INSTRUMENTATION

By Ir. Liew Shaw Shong

Course Outline

1. Planning, Specification & Contractual Arrangement
2. Site Monitoring
3. Data Processing / Analysis, Interpretation & Actions
4. Common Problems, Applications & Lesson Leant from Case Study

Why Instrumentation?

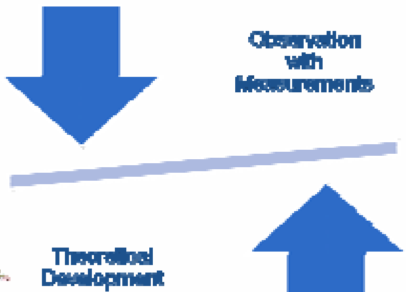
WHY DO WE NEED INSTRUMENTATION?

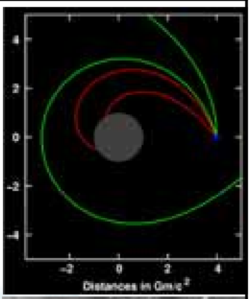
It is a useful tool to supplement what we can not identify trend of behaviours & quantify the changes of the crucial parameters affecting the bahaviours in the observation.

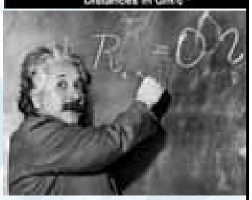
7 | Texas

COASTAL FURY *Hurricane Ike slammed into Galveston (above), and ensuing winds and rainfall drifted up through Texas and north into the Midwest, killing at least 51 people in 10 states and leaving millions without power. Heavy rains caused flooding along the banks of the Mississippi and Missouri rivers. In Texas, thousands crowded into shelters and hotels paid for by the Federal Government, many expecting to stay for weeks. Throughout the region, evacuees waited in long lines for food, water and gas.*

Theory .vs. Observation



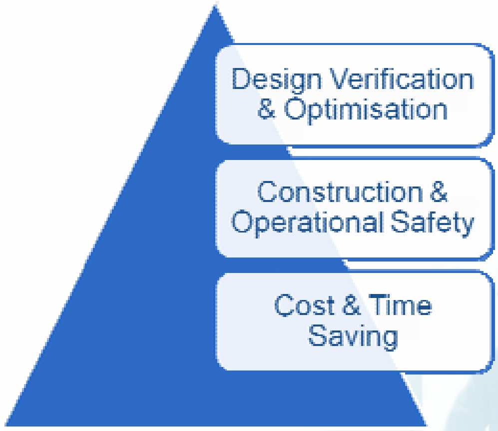




Sir Isaac Newton – Law of Gravity by observation

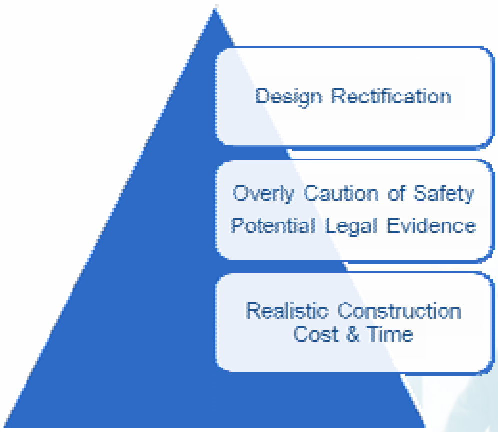
Albert Einstein - General relativity's predictions have been confirmed in all observations and experiments to date.

Benefits of Instrumentation

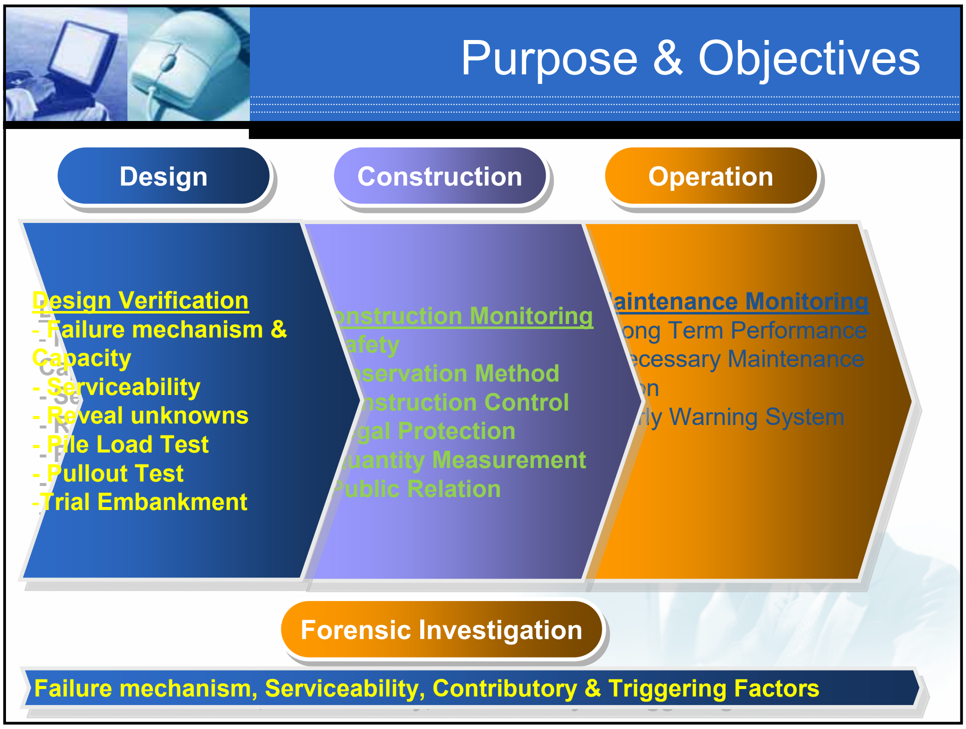


If you can not get high quality and reliable data, then better don't initiate any instrumentation scheme because it will create more problems than being advantageous.

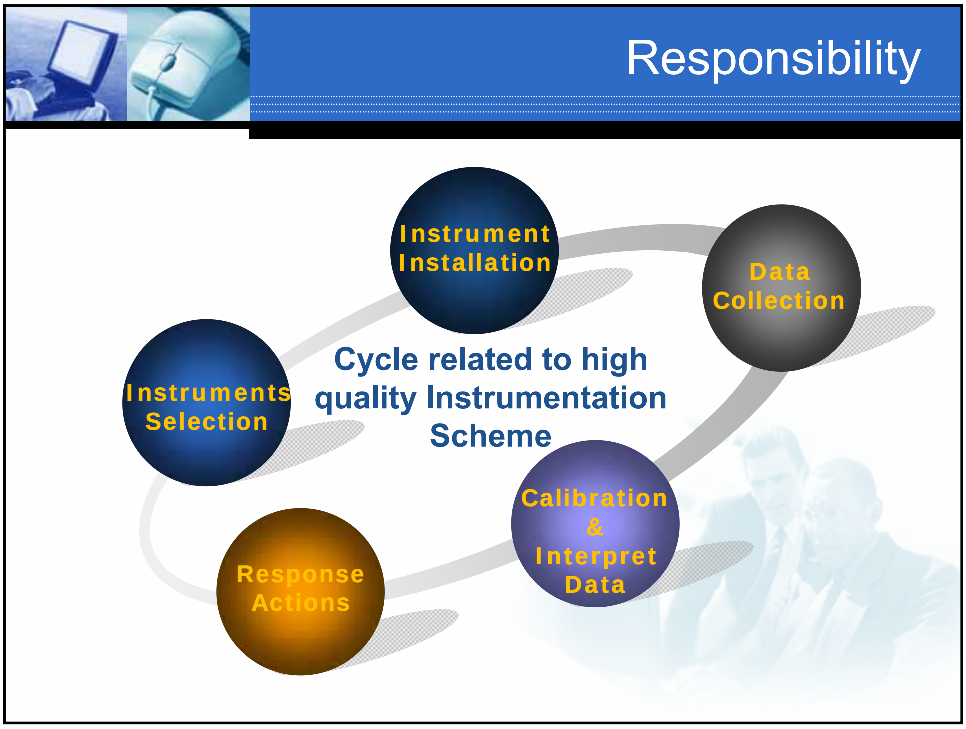
Pitfalls of Instrumentation



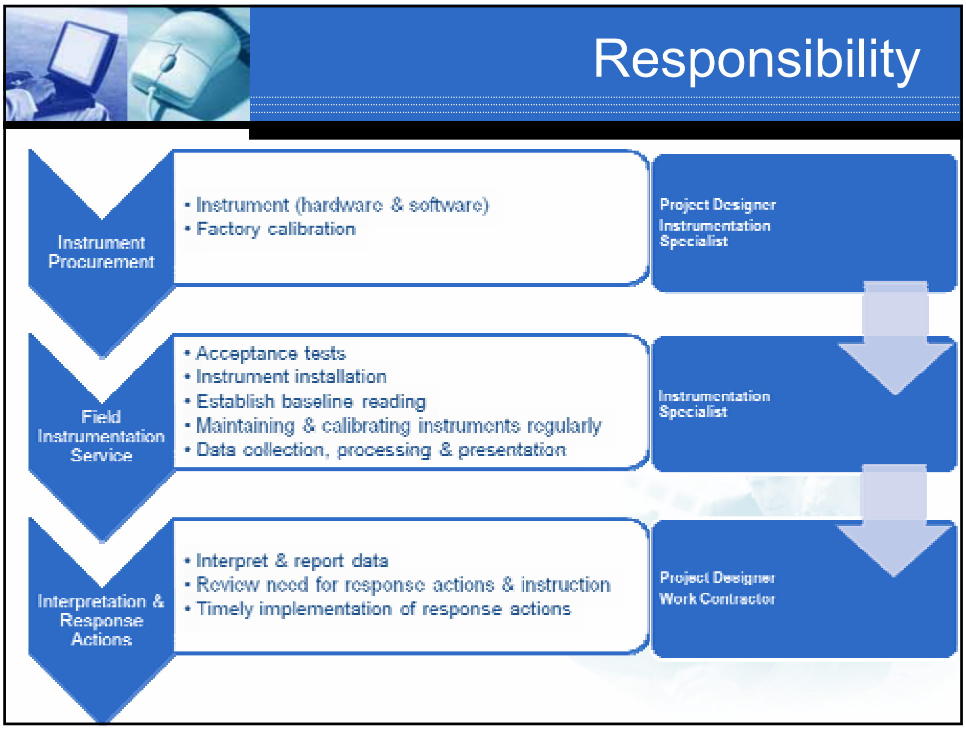
In some cases, instrumentation results may reveal the shortcomings or negligence in the design of the project designer and also those by the work contractor.


Purpose & Objectives
Design
Construction
Operation
Design Verification
- Failure mechanism & Capacity
- Serviceability
- Reveal unknowns
- Pile Load Test
- Pullout Test
-Trial Embankment
onstruction Monitoring
afety
servation Method
nstruction Control
gal Protection
uantity Measurement
ublic Relation
aintenance Monitoring
ong Term Performance
ecessary Maintenance
rly Warning System
Forensic Investigation
Failure mechanism, Serviceability, Contributory & Triggering Factors


Stakeholders
Project Objectives
Project Owner
Design Consultant
Instrument Specialist
Construction Contractor
Insurance Company

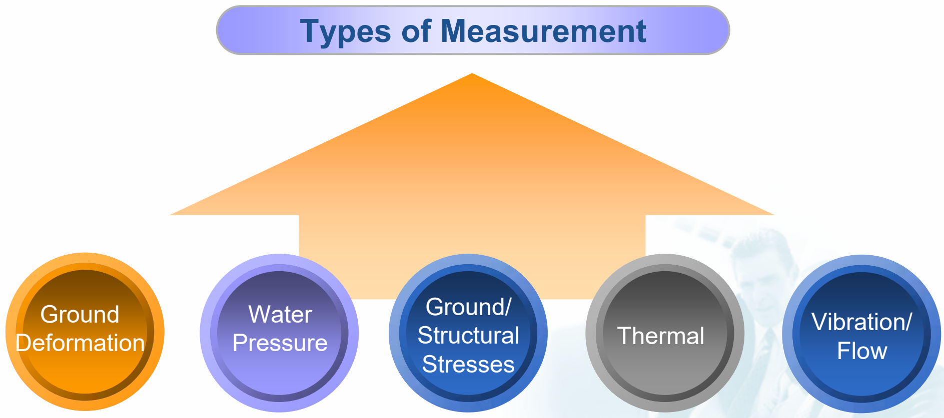


Responsibility
Instrument Installation
Data Collection
Instruments Selection
Cycle related to high quality Instrumentation Scheme
Calibration & Interpret Data
Response Actions

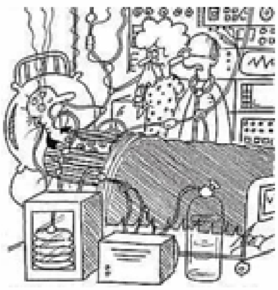


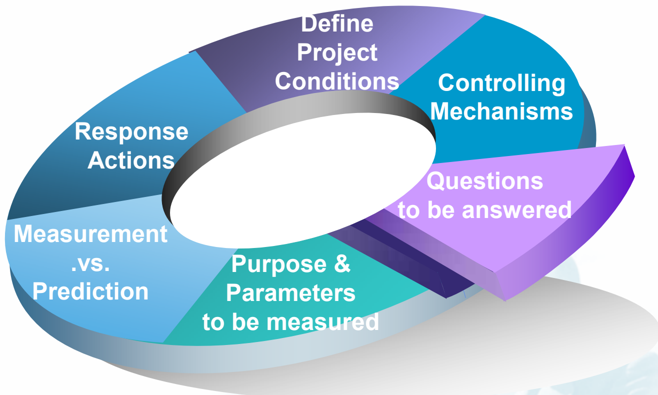
Responsibility
Instrument Procurement
• Instrument (hardware & software)
• Factory calibration
Project Designer
Instrumentation Specialist
Field Instrumentation Service
• Acceptance tests
• Instrument installation
• Establish baseline reading
• Maintaining & calibrating instruments regularly
• Data collection, processing & presentation
Instrumentation Specialist
Interpretation & Response Actions
• Interpret & report data
• Review need for response actions & instruction
• Timely implementation of response actions
Project Designer
Work Contractor

Parameters to be Monitored



Planning Cycle





Every instrument shall be placed at the site to answer specific question. If no question, then no instrument.

Project Conditions

- **Construction Control** : modify or improve the initial construction sequence or/and method.
- **Remedy** : strengthen the stability, reduce the negative impacts, repair the damage or distresses
- **Notice** : serving notice to project owner, insurance, neighbouring owners, local authorities

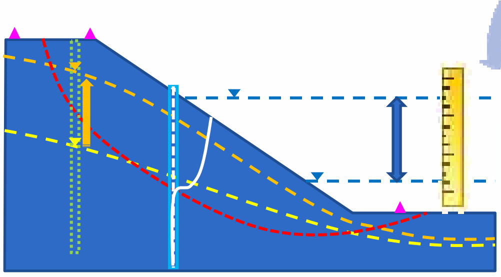
Questions to be answered

- **Any Questions related to Performance of the Concerned System**
  - **Deformation of Ground or Structures**
  - **Stress or Strain in Ground or Structure**
  - **Water Pressure Distribution, Flow and Changes**
  - **Thermal, Vibration, Tidal Effects**
  - **Location and magnitude of changes**

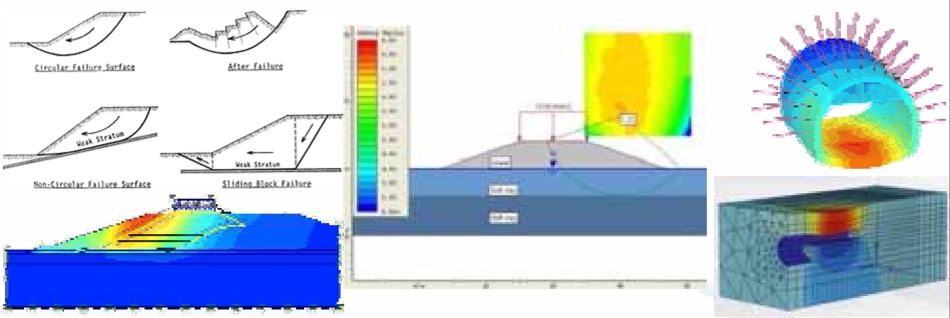
What does instrument measure & response?

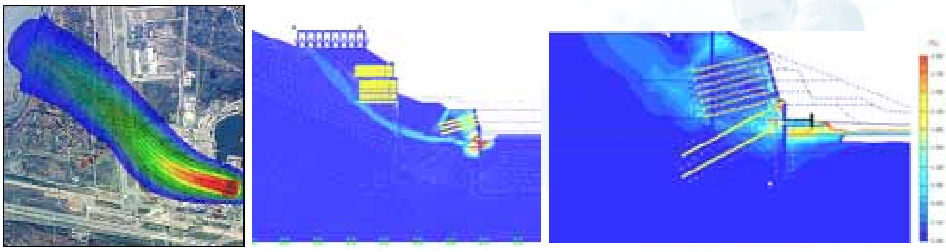
• Measurement can be either performed on the changes of **CAUSES** (difficult to pick up the changes) or **EFFECTS** (usually too late for response actions).

• Most instruments provide point measurement with dependence on localised characteristics, hence may not represent the problem in larger scale, unless large number of point measurement instruments are installed.

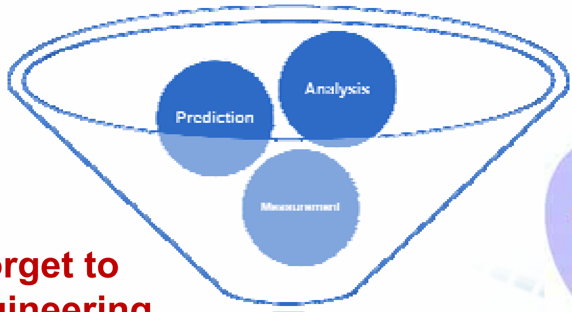


Controlling Mechanisms





Measurement .vs. Prediction



Don't forget to apply Engineering Judgement

Hazard Warning Level

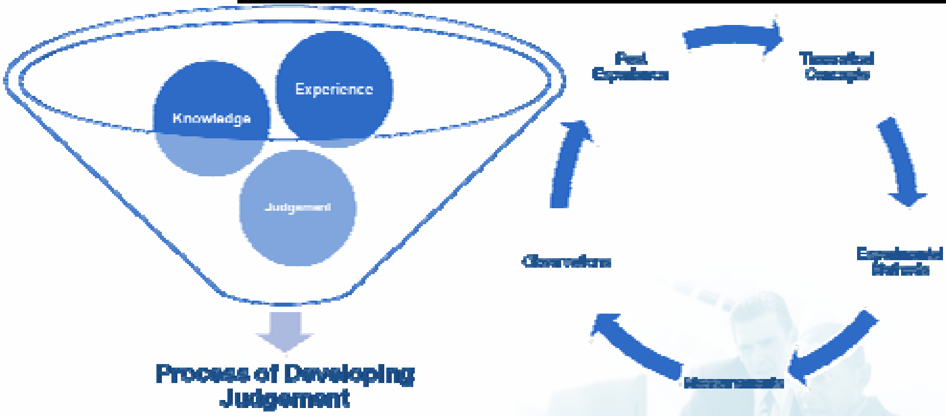
- Green: No action
- Amber: Cautionary Measures
- Red: Timely Contingency Action

Engineering Judgement

- **Definition** : The operation of the mind, involving "***comparison***" and "***discrimination***" by which knowledge of values and relations is mentally formulated. (*Webster's New Collegiate Dictionary*)

- **Recognition** : **Engineering judgement** as an acceptable engineering practice

Engineering Judgement



Experience
Directly or indirectly from others

Knowledge
Familiarity gained from Experience

Judgement
Knowledge of all kinds & from many different sources

Response Actions

- **Construction Control** : modify or improve the initial construction sequence or/and method.
- **Remedy** : strengthen the stability, reduce the negative impacts, repair the damage or distresses
- **Notice** : serving notice to project owner, insurance, neighbouring owners, local authorities

Dilemma of Instrumentation

2 : Well, do you want me to open up everything, big or small one, to check for fixing.

1 : Doc, can you guarantee I have 100% fix of all my problems?

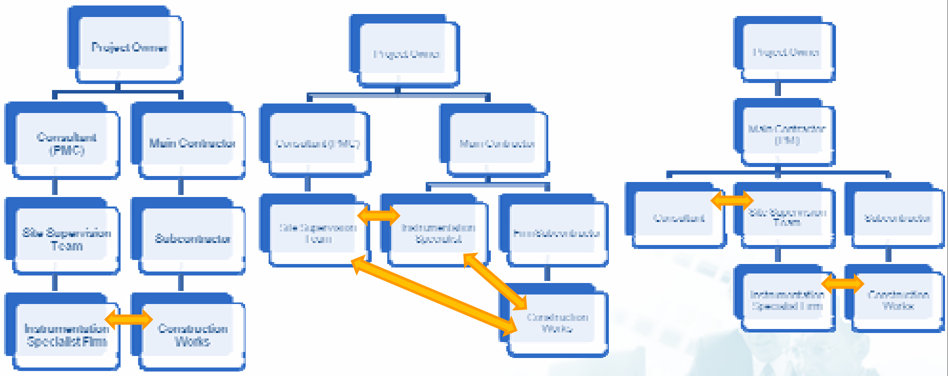
3 : Doc, his credit card limit is up to RM50,000 only.

Specification

Clear – **Concise** – **Complete** – **Correct**

Clear	Concise	Complete	Correct
Over-specified -High price -Inadequate budget with expectation of omission of requirements -Inexperienced site staffing	Project-specific -Measurement range -Duration of service	Under Owner -Sufficient baseline data -Avoid price slaughter in subcontracting	-Prescriptive Owner accept liability, but better control -Performance Innovation, no bias, clear liability, competitive, but difficult to evaluate

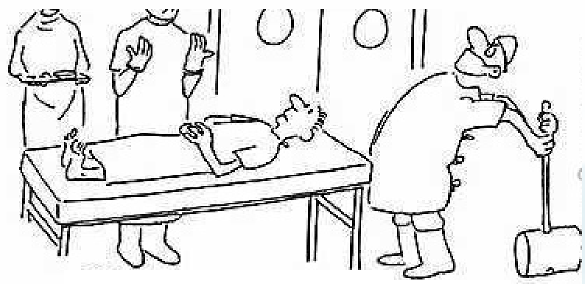
Contractual Arrangement



Independence : Good Data Quality : Good Problem : No liability for Contractor	Independence : Fair Data Quality : Possibly Fair Problem : Low bid tender Advice : Nominate Specialist	Independence : Poor Data Quality : Possibly Poor Problem : Low bid tender Advice : Nominate Specialist

Procurement Approach

- **Professional Service**
- **Lowest Bid Tender**
- **Independence**



We're underfunded, but we manage!

Good Practices

- **Instrument Life-Cycle Costs** : Calibration, installation, taking readings, maintenance, data management & interpretation, and decommissioning.

- **Partnership to Instrument Manufacturers/Suppliers**

Good Practices

- **Good QA/QC of Personnel Training, Equipments, Data Management**

- **Dedicated Team & Equipment for Project**

- **Measures of Instrument Protection**

- **Duplicate Instruments for Data Redundancy**

Course Outline

1. Planning, Specification & Contractual Arrangement
2. **Site Monitoring**
3. Data Processing / Analysis, Interpretation & Actions
4. Common Problems, Applications & Lesson Leant from Case Study

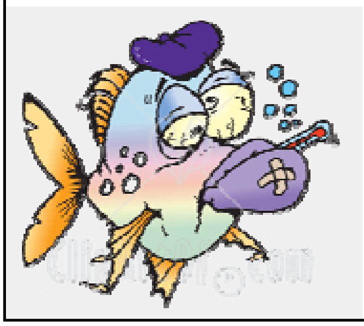
Measurement Uncertainty & Reliability

- Accuracy
- Precision
- Conformance
- Sensitivity
- Resolution

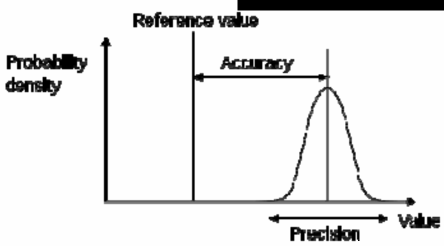
- Linearity
- Hysteresis
- Error
- Noise

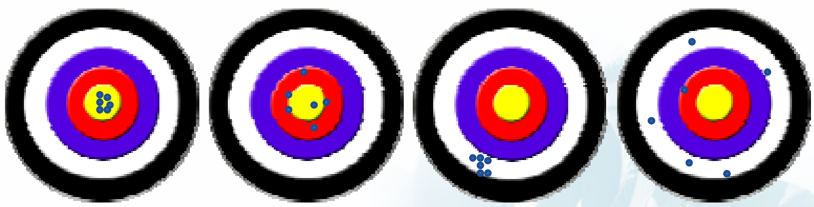
Conformance

• Good conformance of instrument and installation procedures are necessary for measurement of good accuracy.
• Beware of any changes of properties related to parameters to be measured due to presence of instrument



Accuracy & Precision



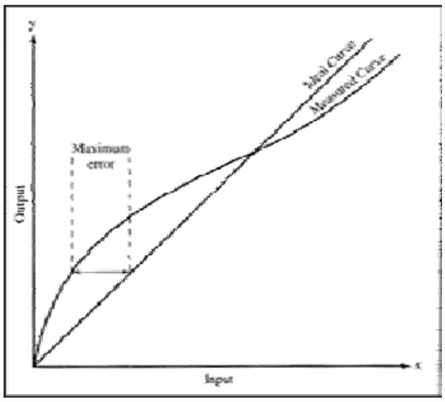


Accuracy	High	High	Low	Low
Precision	**High**	**Low**	**High**	**Low**
Acceptance	Good	Fair	Systematic Error	Bad

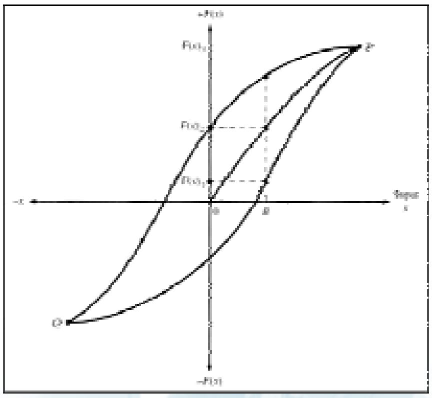
Measurement Deviation

- **Resolution** : the degree to which the smallest change it can detect in the quantity that it is measuring.
- **Sensitivity** : the smallest absolute amount of change that can be detected by a measurement, usually defined as the ratio between output signal and measured property
- **Linearity** : The amount of error change throughout an instrument's measurement range. Linearity is also the amount of deviation from an instrument's ideal straight-line performance.
- **Hysteresis** : an error caused by when the measured property reverses direction, but there is some finite lag in time for the sensor to respond, creating a different offset error in one direction than in the other
- **Noise** : Random measurement variations by external factors

Linearity & Hysteresis



Non Linearity



Hysteresis

Types of Errors & Corrective Measures

Type of Error	Sources	Corrective Actions
Gross Error	Human mistakes	Care, checking & training
Systematic Error	Calibration, hysteresis & non-linearity	Periodic recalibration
Conformance Error	Instrument design & installation	Appropriate instrument, improve installation procedures
Environmental Error	Weather, temperature, vibration & corrosion	Apply correction with recorded environmental changes & conditioning instrument to ambient environment
Observation Error	Variation between observers	Training & automised data acquisition
Sampling Error	Inherent variability & sampling technique	Sufficient instruments
Random Error	Noise, friction & environmental effect	Statistical analysis on multiple readings

Course Outline

1. Planning, Specification & Contractual Arrangement
2. Site Monitoring
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Parameters to be Measured

- **Deformation/Movement**
  - Inclinometer
  - Extensometer
  - Ground Movement Marker
  - Tiltmeter
  - Crackmeter
- **Water/Earth Pressure**
  - Piezometer, Observation Well
  - Earth Pressure Cell

Parameters & Measurement

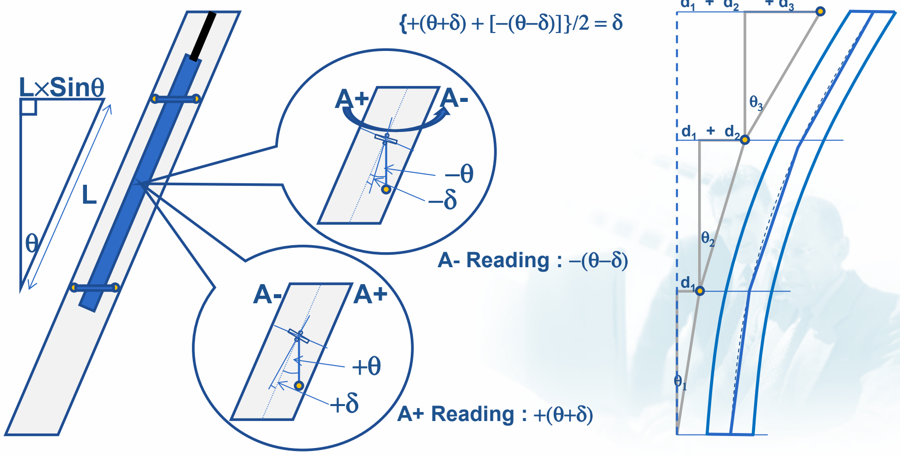
- **Load/Stress/Strain**
  - Strain Gauges
  - Load Cell
- **Thermal**
  - Thermal Coupler
- **Flow**
  - V-Notch Gauge
- **Vibration**
  - Accelerometer

Inclinometer

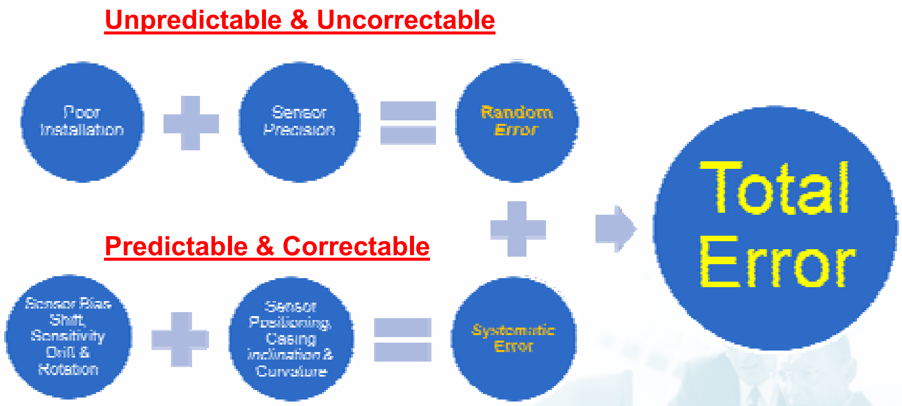
- **Inclinometer**

Reading :
$\{+(\theta+\delta) - [-(\theta-\delta)]\}/2 = \theta$

Checksum Review :
$\{+(\theta+\delta) + [-(\theta-\delta)]\}/2 = \delta$



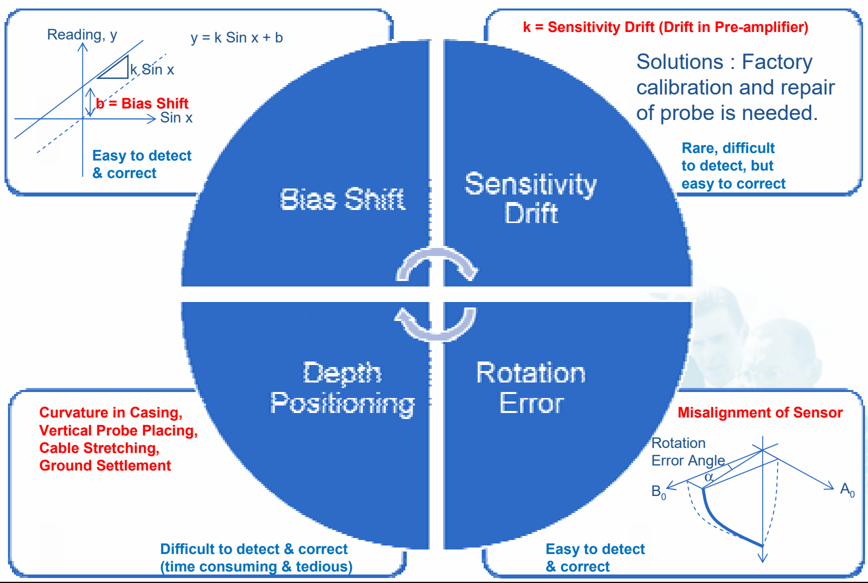
Inclinometer



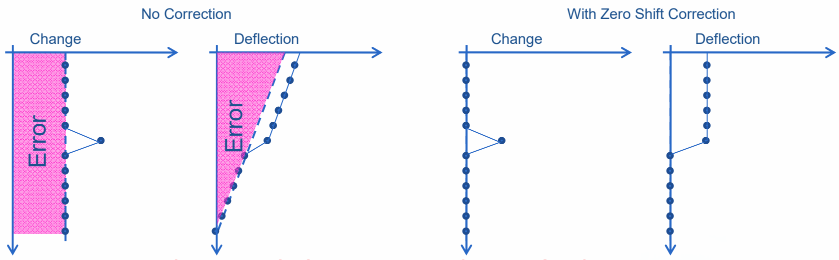
Systematic errors can accumulate upward in the cumulative displacement at ground surface (**apparent cumulative displacement**).

Total Error = $\varepsilon_{Random} \times \sqrt{\text{No. of Readings}} + \varepsilon_{Systematic} \times (\text{No. of Readings})$

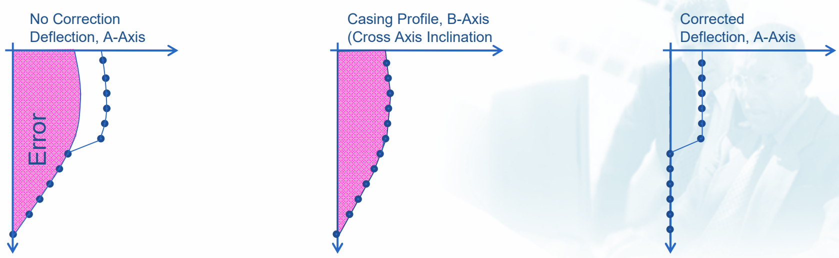
Inclinometer



Inclinometer



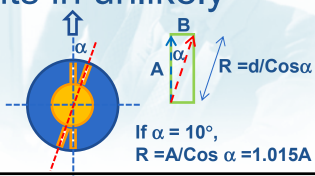
Identification & Correction of Bias Shift Error



Identification & Correction of Rotation Error

Inclinometer

- **Spiral Probe**
- Twisted casings lead to incorrect magnitude of movement in the A and B directions.
- Application :
  - To check orientation of the inclinometer grooves for necessary correction for direction of resultant movement.
  - Readings show movements in unlikely direction
  - Check installation quality
  - Deep casing installation



Inclinometer

- **Error Detection & Correction :**
  - Double data redundancy with readings taken in diametrical direction
  - 3 to 6m bottom of casing into firm strata for good fixity to provide calibration data
  - Deeper readings have highest potential systematic errors : (a) Sensor warming up, (b) Steepest borehole inclination, (c) Further distance from top reference

Inclinometer

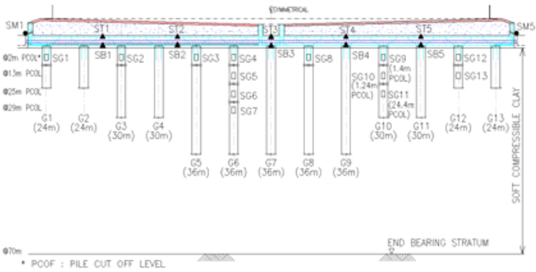
- **Tolerance :** Variation of Checksum < 5 to 10 units of Mean Checksum
- **Correction :**
  - If the large variation is localised to one depth, correction can be performed based on mean of other checksum.
  - If the large variation spreads over the entire dataset, it is better to retake the readings.

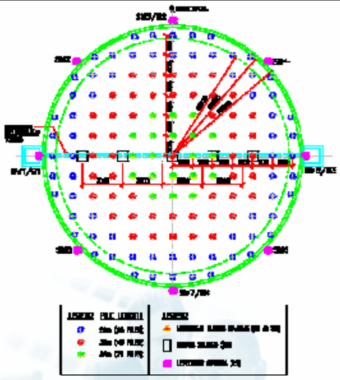
Inclinometer

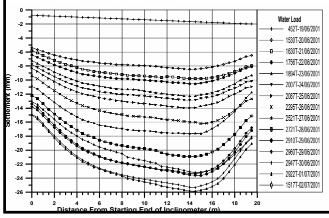
- **Inclinometer (Vertical)**

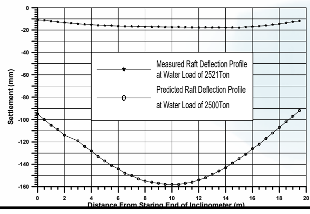
Inclinometer

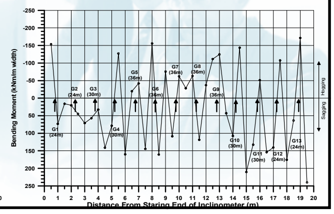
- **Horizontal Profiler**









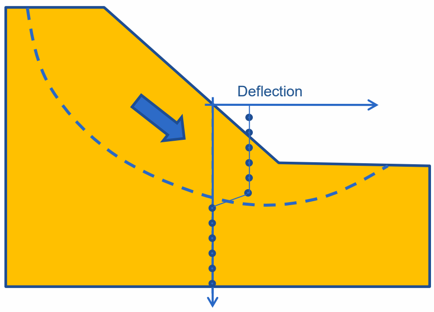


Inclinometer

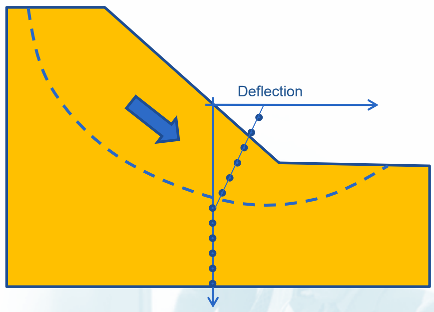
- **Horizontal Profiler**

Data Evaluation

- **Type of Ground Movement**



Developed Shear Zone with Drastic Movement Profile



Creeping Slope with Continuous Movement Profile

Data Presentation

- **Good Practice :**
  - Use of exaggerated horizontal scale shall be avoided because “errors” are magnified & could be misinterpreted.
  - Change plot (incremental deformation) is useful to emphasize the location of deformation zone.

Course Outline

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4. Common Problems, Applications & Lesson Leant from Case Study

Myths in Instrumentation

- **Myth No.1** : Instrumentation can prevent bad thing from occurring.
- **Myth No. 2** : Maintenance free instruments are possible.
- **Myth No. 3** : Geotechnical engineer is not needed to review the instrumentation results if threshold and action plan are available (traffic light system).
- **Myth No. 4** : Instrumentation does not require the input from instrumentation specialist.

Myths in Instrumentation

- **Myth No. 5** : Instrumentation can replace engineering judgement. Everything is fine if instrumentation is in place.
- **Myth No.6** : More instruments and data are better.
- **Myth No. 7** : Instrumentation is costly investment, hence is unnecessary if the design is good.

Common Problems

- **Instrument** : Selection of appropriate instrument fit for the purpose.
- **Contract Arrangement** : Interest party for high quality instrumentation data.
- **Data Quality** : Poor quality data will neither reveal the truth of engineering behaviours nor give correct warning.
- **Data Management** : Keeping raw data is essential for future data reprocessing with new interpretative objectives

Common Problems

- **Data Interpretation** : Screening & filtering of problematic data or uninvited events/factors for a distilled content are deliberately needed.
- **Data Presentation** : Data presentation without connection to records of activities at site is a discounted information for decision making.

Common Problems

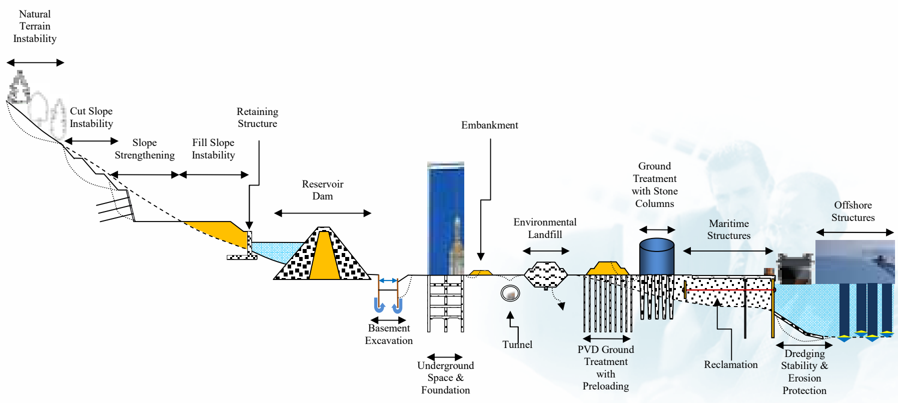
- **Review** : Timely review is important to capture indication of distress development & need for instrument maintenance/checking for proper functioning.
- **Loss of Feel** : Sometimes readings given to person who is not taking care of the instruments has no clue to slight variation of the readings, but possible an important indication of adverse effect. (You will not know your baby if you did not take care of him/her.)
- **Threshold Limits** : It is not easy to set a accurate set of threshold limits for multiple parameters controlling the behaviours.
- **Action** : Timely implementation of actions as identified from interpreting instrumentation results.

Advices

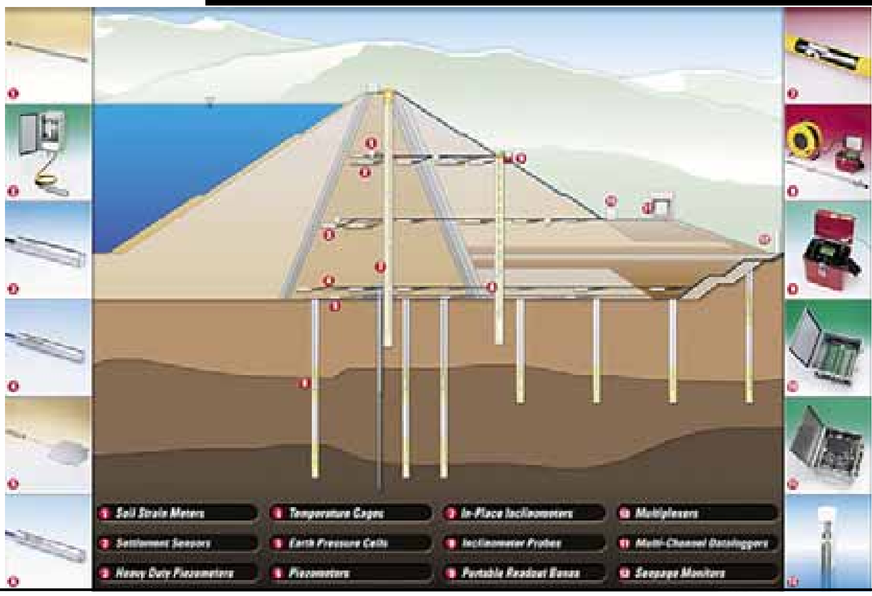
- **Paradox :**
  - Appearance of apparently unmotivated change are often the first sign of distress
  - Observations of overall phenomenon become more relevant than “spot” occurrence.

Applications

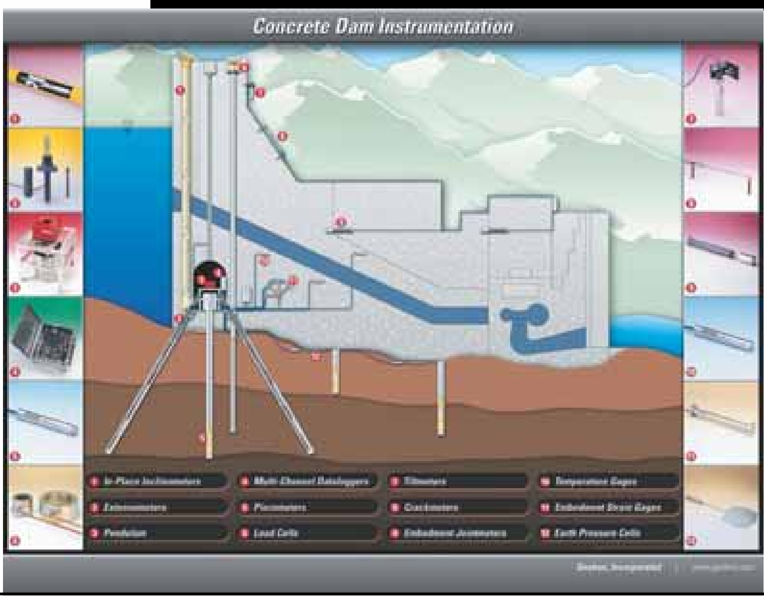
- **Observation Method** (e.g. **NATM** in Tunnel)



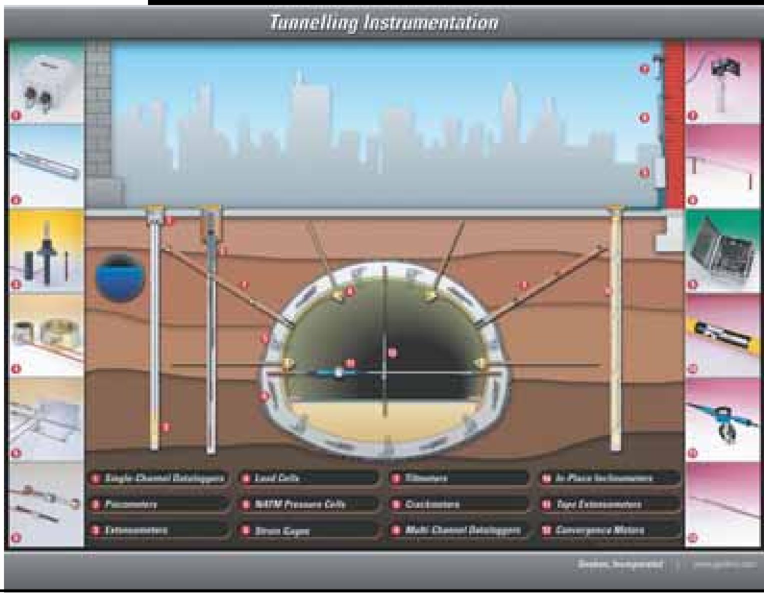
Earthfill/Clay Core Rockfill Dam



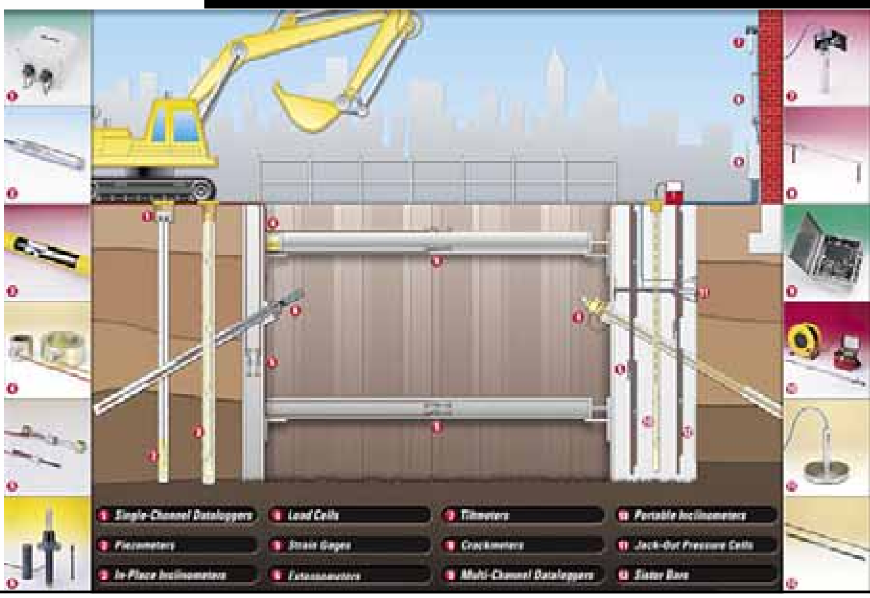
Concrete Dam



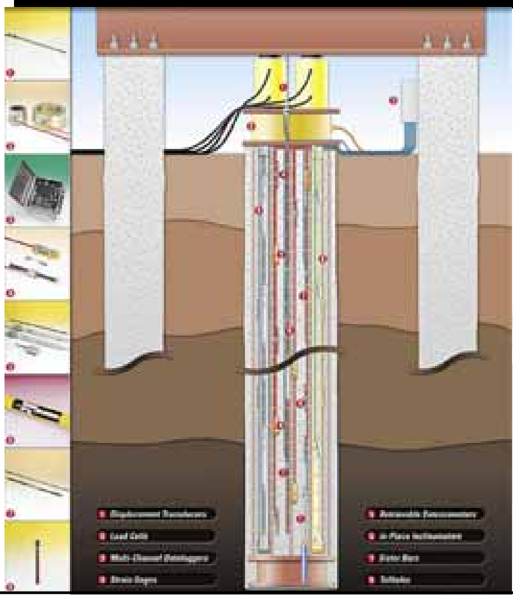
Tunnel & Underground Excavation



Strutting & Excavation



Design Verification Testing



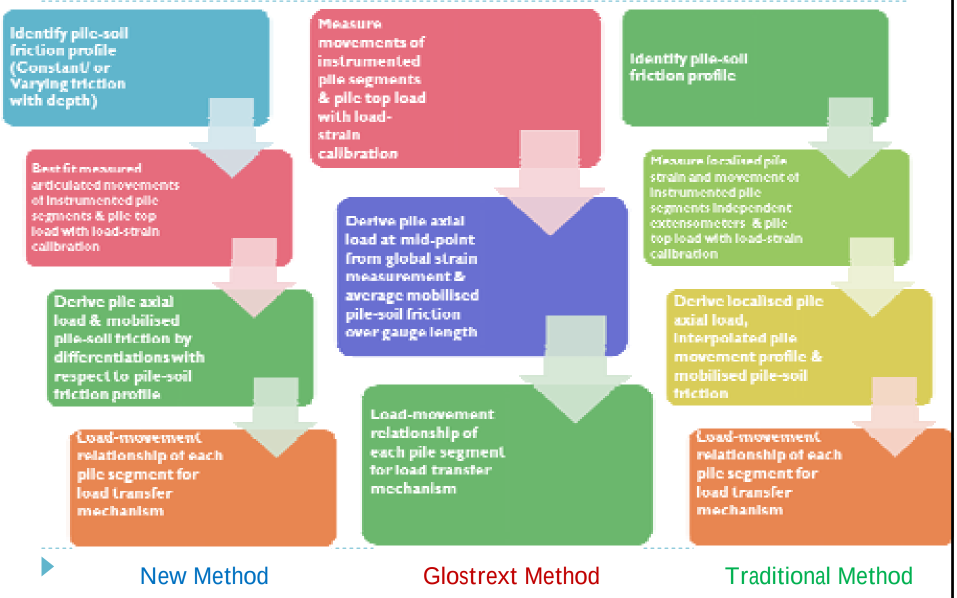
Pile Test Interpretation
(using Global Strain Measurement)

- Facts on Axially Tested Pile :
  - Free standing portion – No friction interference
  - Embedded portion – Constant or linearly varying shaft friction with depth
  - Tensile cracking in tensile loading affecting axial stiffness of composite pile section

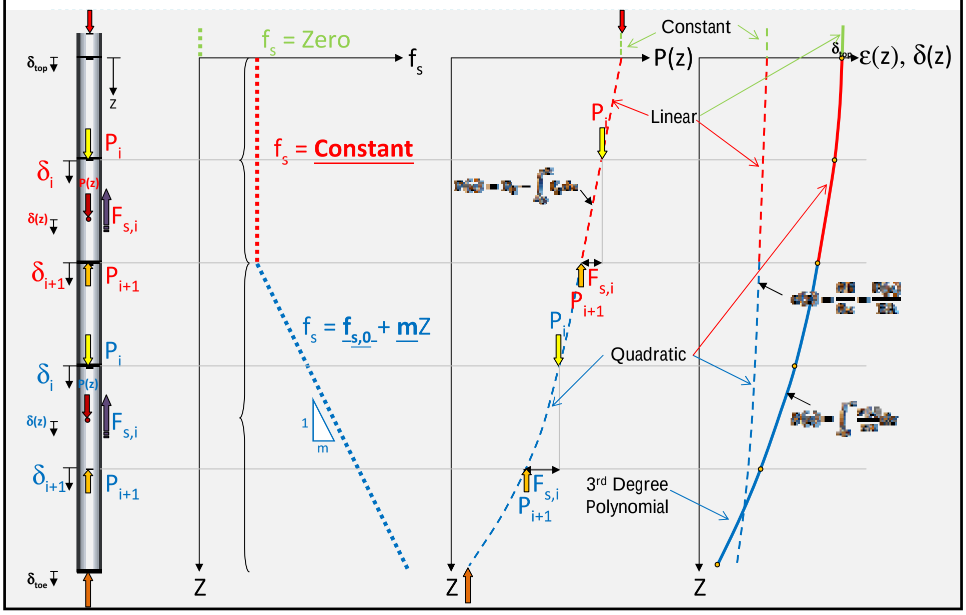
  - Factors affecting accuracy of pile instrumentation
  - Linearity of load-strain calibration
  - Pile shaft resistance profile assumed
  - Instrument locations for pile axial load measurement
  - Numbers of pile segment movement measurement
  - Gauge length of strain measurement (global / local strain measurement)

- Consequences :
  - Interpreted pile axial load at location assigned within the gauge length can be unjustified (unless no interference of shaft friction)

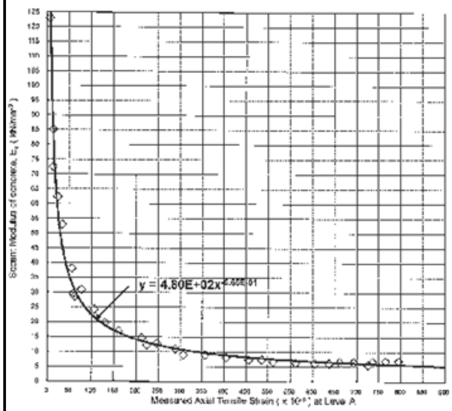
Pile Instrumentation & Interpretation Approaches

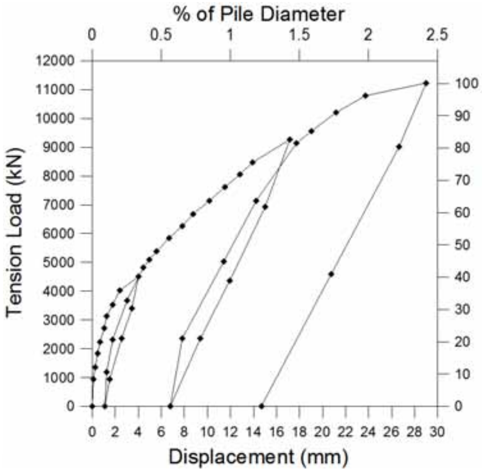


Load Transfer of Test Pile



Tensile Pile Test





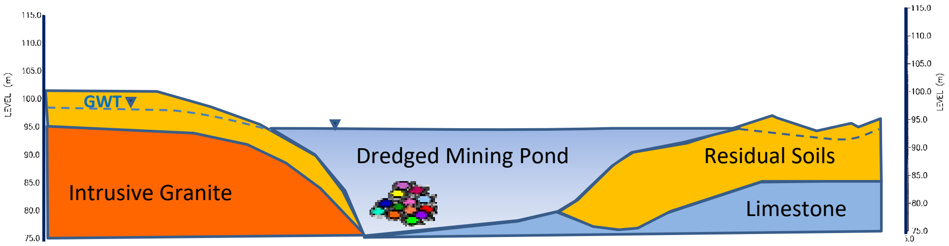
Case Studies for Dewatering & Seepage Problems

Dewatering

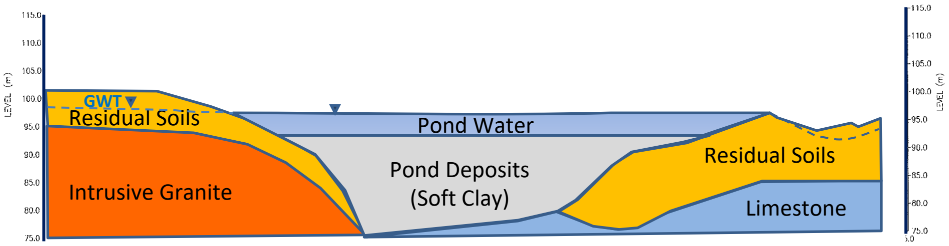
- Case 1 : Investigation of Distress Structure due to Construction Dewatering
- Case 2 : Excavation Stability by Construction Dewatering & Recharge
- Case 3 : Revetment Design Under Seepage

Case 1 - Initial Site Conditions

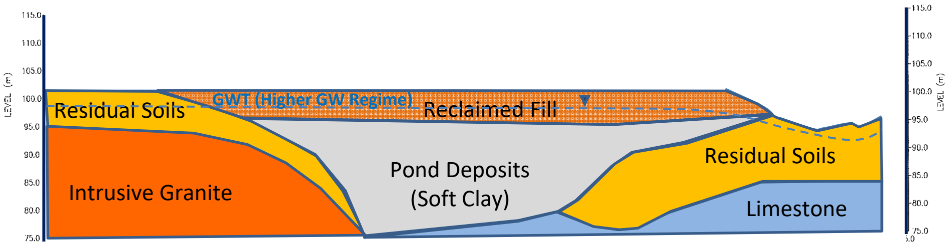
Case 1 : Dredged Pond in Mining Activities



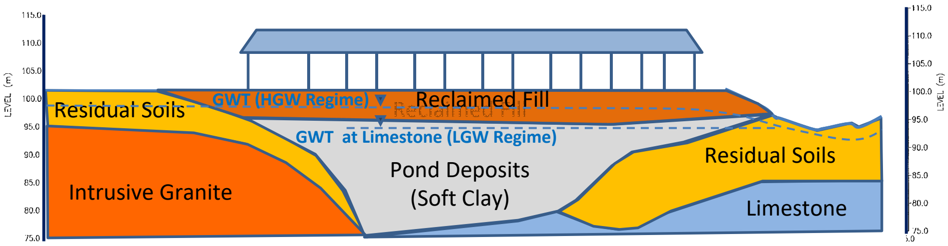
Case 1 : Deposition of Pond Sediments



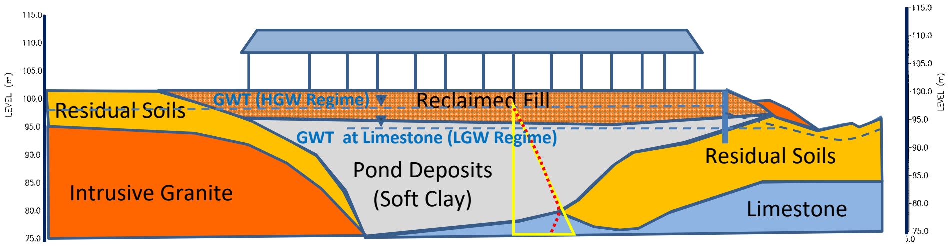
Case 1 : Land Reclamation for Development



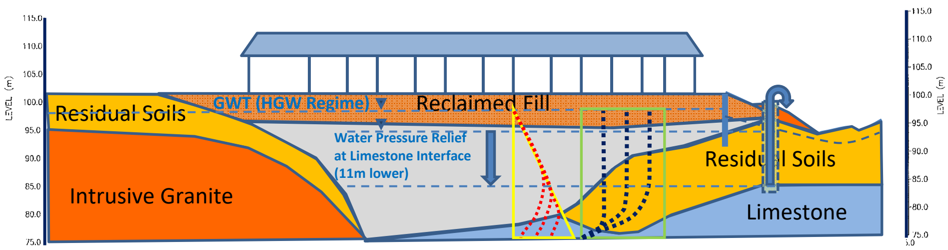
Case 1 : Housing Construction



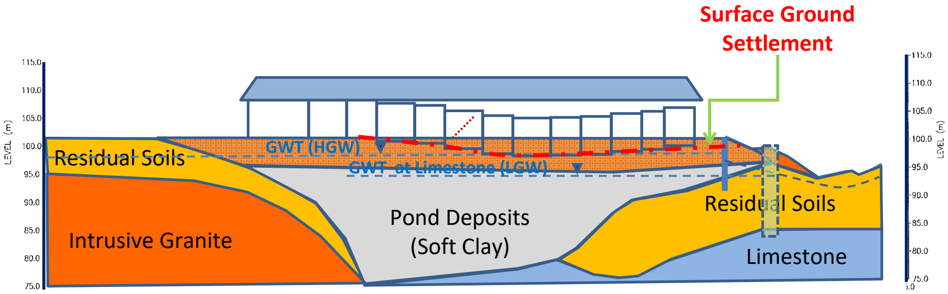
Case 1 : Site Preparation Works



Case 1 : Groundwater Pumping in Caissons



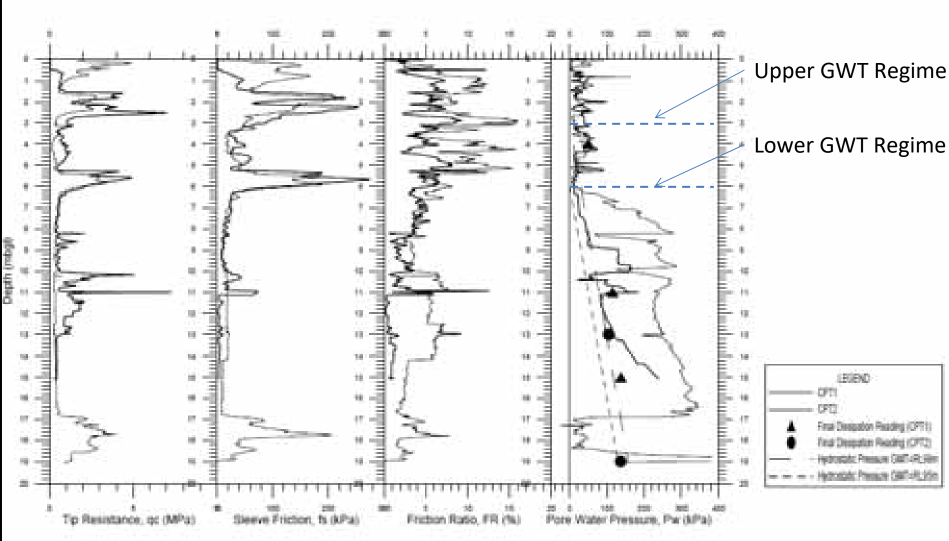
Case 1 : Consolidation Ground Settlement



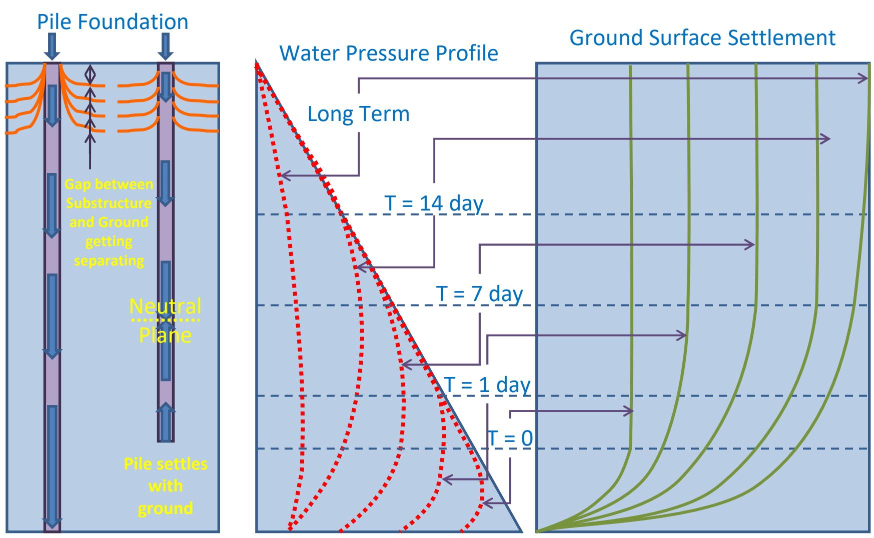
Case 1 : Mechanism of Distresses

- Pumping of Groundwater in Caisson further lower the water pressure at Limestone Interface (Slump Zone) from its original hydrostatic head of Lower Groundwater Regime to probably lowest head of 11m below (average base of Caisson)
- Huge water pressure reduction at Slump zone resulted in remarkable consolidation compression of clayey pond sediments bottom up
- Surface ground settlement is a result of accumulation of consolidation compression within pond sediments
- Surface ground settlement profile led to distortion of building frame and occurrence of cracking

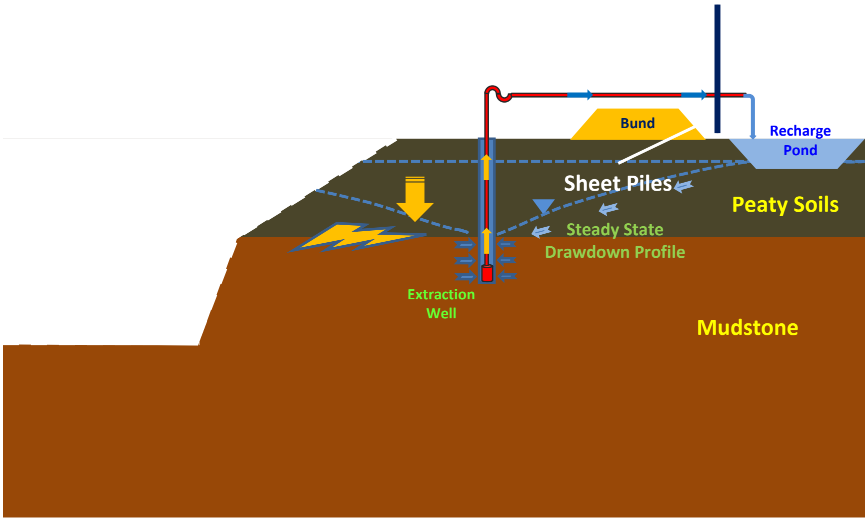
Piezocone Results



Case 1 : Mechanism of Distresses



Case 2 : Dewatering Scheme + Sheet Pile

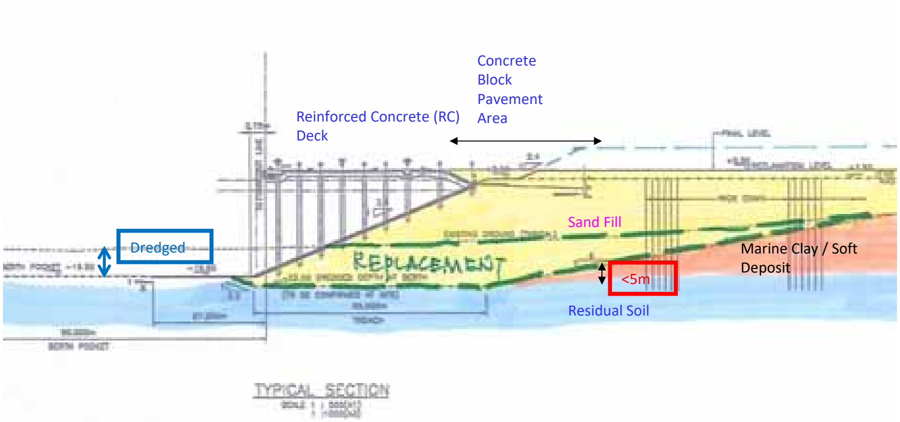


Case 3 : GEOTECHNICAL REVIEW ON REVETMENT DESIGN

Subsurface Investigation (SI) Works

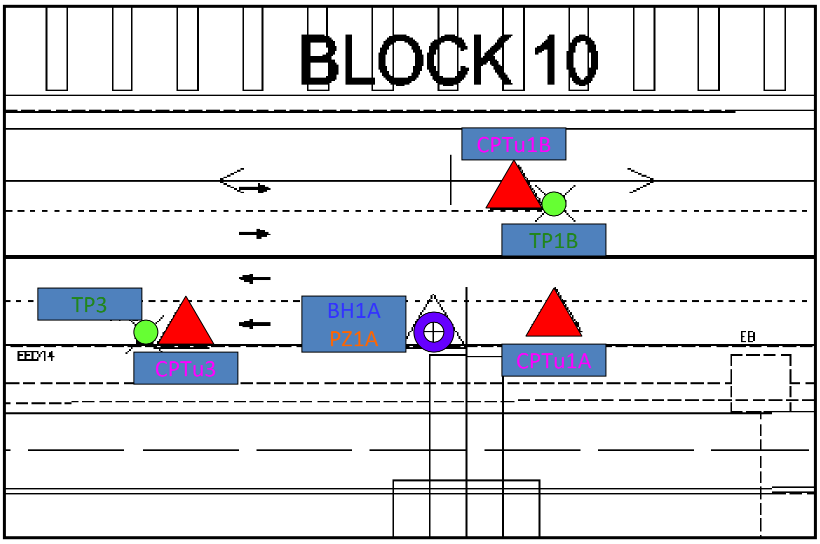
- Field Works :-
  - 2 nos. of Boreholes
  - 9 nos. of CPTu Tests
  - 6 nos. of Trial Pits
- Field Tests
  - Field CBR Tests
  - Field Density Tests
- Instrumentations
  - 2 nos. of Piezometer on land
  - 1 no. of Piezometer in sea

Soil Improvement Works before Reclamation & Construction of Concrete Block Pavement



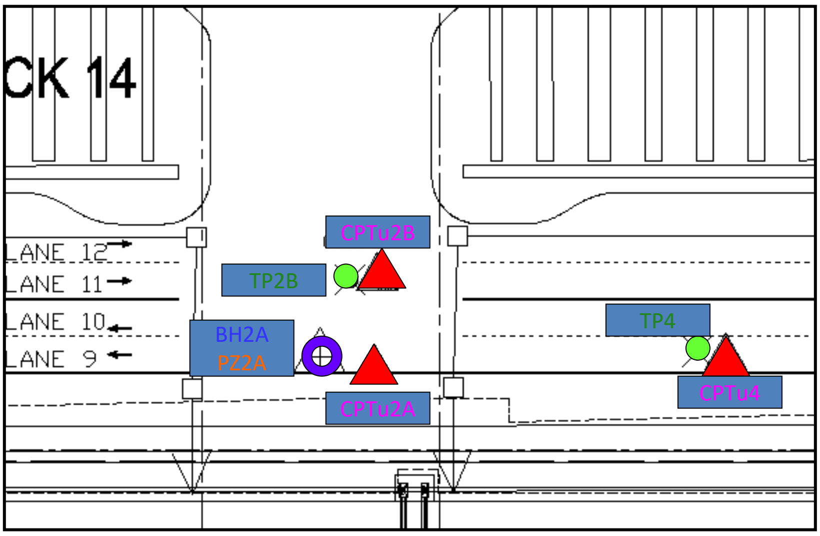
SI Layout Plan

Berth A



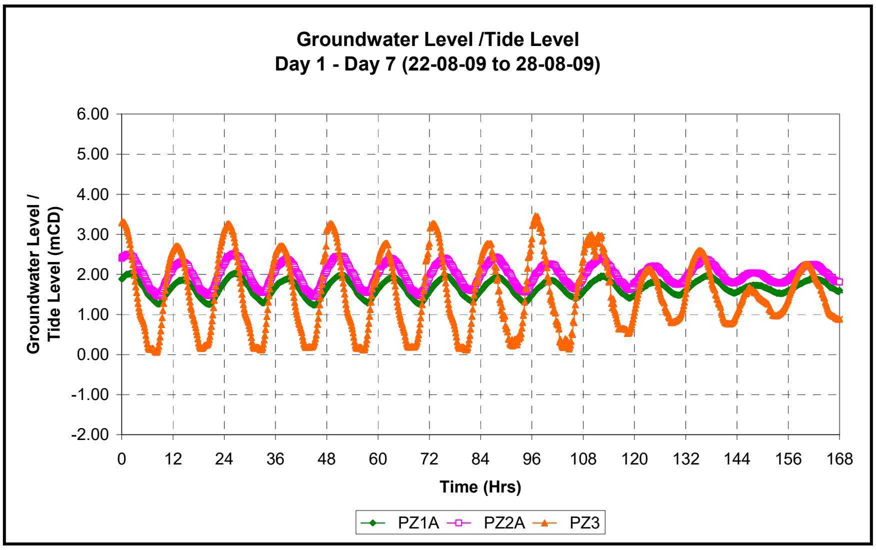
SI Layout Plan

Berth B

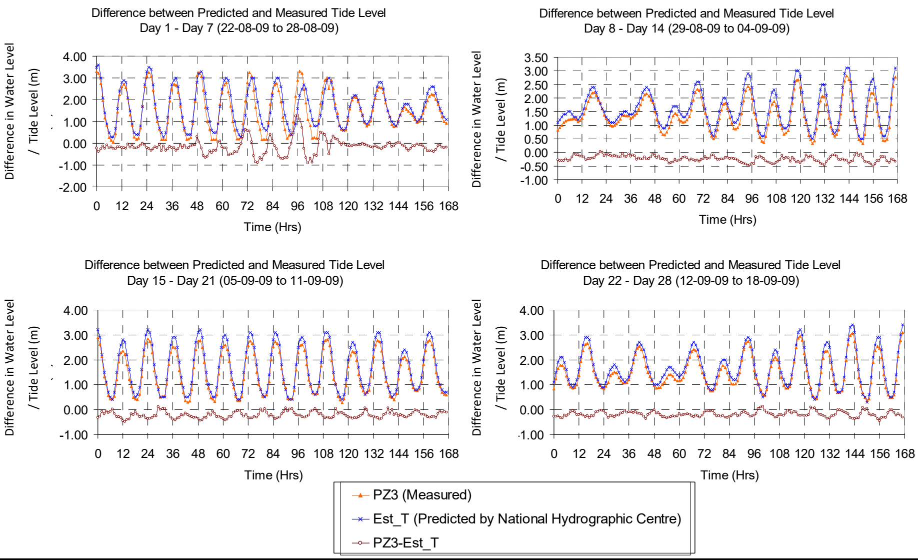


Automatic Water Level Measurement

Groundwater Level Monitoring



Predicted Vs Measured Tide Level



Revetment Design Check

DESTABILIZING FORCES:

F_d = Drag force

$W_s \sin\alpha$ = Submerged weight parallel to slope

Sliding Force, $F_s = t\ (\gamma_c - \gamma_w) \sin\alpha$

STABILIZING FORCES:

Fr = Frictional resistance (mat / subgrade) $= \mu F_n = \mu (W_s \cos\alpha - F_L)$

Where:

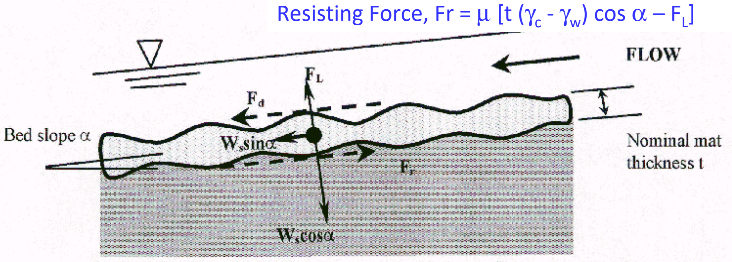
F_n = Normal force

$W_s \cos\alpha$ = Submerged weight normal to slope

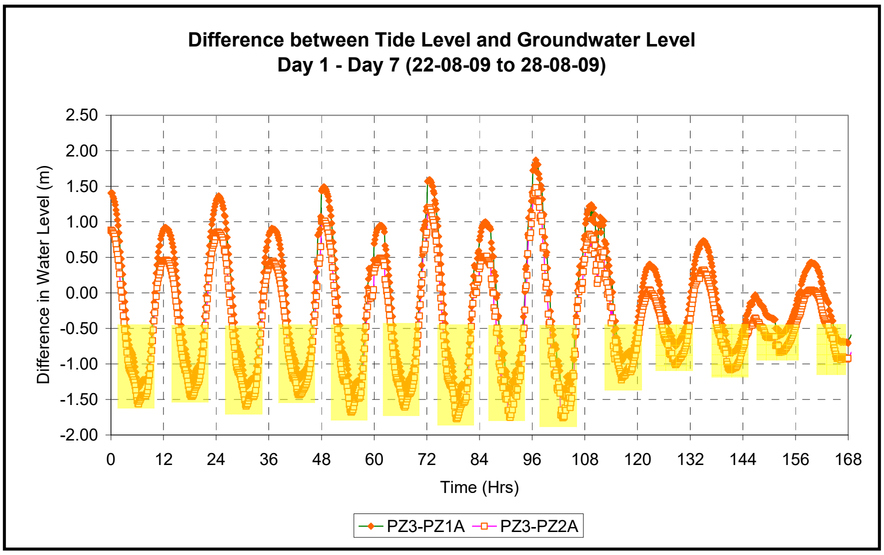
F_L = Lift force

μ = Coefficient of static friction

Resisting Force, $F_r = \mu\ [t\ (\gamma_c - \gamma_w) \cos\alpha - F_L]$

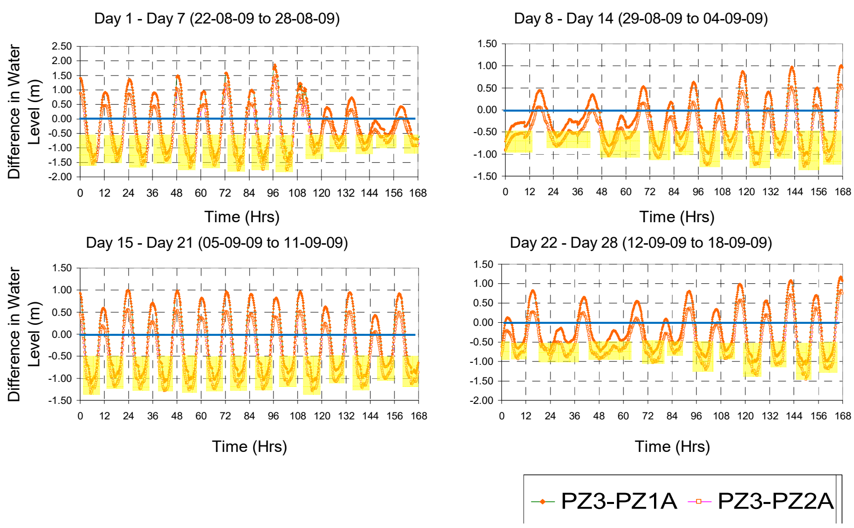


Reference: EM 1110-2-1614 (1995), *Design of Coastal Revetments, Seawalls, and Bulkheads*, U.S. Army Corps of Engineers, Washington



Revetment Design Check →Not OK

Potential Uplift Forces



Summary of Revetment Design Check

S/N	Thickness of Incomat (m)	Angle of Inclination (degree)	Uplift force (kPa)	Fs (kPa)	Fr (kPa)	FOS = Fr / Fs	Remarks
1	0.6	22.6	0	3.228	4.475	1.386	Design of Revetment "X" is **indequate** where achieved FOS_{max} is less than 1.5 and becomes unstable when subjected to uplift force of greater than **2.5kPa**
2			2.00	3.228	3.321	1.029	
3			2.50	3.228	3.032	0.939	
4	0.6	0.1	8.36	0.015	0.023	1.574	Max. uplift pressure that can be resisted by 0.6m thick Revetment "X" is **8.36kPa** when placed horizontally.
5	0.6	21.0	0	3.010	4.525	1.503	When assuming allowance for pressure relief has been made on the Revetment "X", the performance of Incomat would be satisfactory if the angle of slope is less than 21 degree.

Sufficient Pressure Relief (Filter Point and/or Weep Hole) is Important to Safeguard the Performance of Revetment "X" (Grout Filled Mattress) Resting on Inclined Sandfill slope

THANK YOU

Summary of Pile Instrumentation

- Proper planning of instrumented segment of test piles with due consideration of soil stratification, pile resistance profile (constant or varying profile with depth)
- Tensile cracking of concrete under tensile test load leading to irreversible stiffness alteration shall be carefully assessed for proper load transfer
- Solutions :
  - Identify expected profile of pile-soil friction based on stratification, soil consistency,
  - Gauge length shall be reasonably small where practical for proper axial load interpretation, instrumented segment assigned for pile load and movement
  - Minimum one axial load measurement per material stratum preferably at the either sides of the stratum interface
  - For material strata with varying pile-soil friction with depth, more instrumented segments are needed for refined interpretation of axial load & movement (for best fitting the pile movement profile)
  - At least one axial load measurement near to pile base for load transfer of mobilised base resistance

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Thank you

Lord Kelvin (1827 - 1907) :

> *When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of Science, whatever the matter may be.*

Session 3 : Case Studies on Ground Improvement Failures

Ir. Liew Shaw Shong

Ground Improvements

- Case Study 1 : Basal Reinforcement (Distress)
- Case Study 2 : Impact of Embankment on PVD Treated Ground (Failure)
- Case Study 3 : Performance of Stone Columns Treated Ground (Not a failure case, but interesting performance)

Role of Extendible Basal Reinforcement for Embankment Construction Over Soft Soils

- Introduction
- Problem Statements & Distress
- Back Analysis
- Discussions
- Conclusions
- Recommendations

Introduction

- Embankment ➔ Raised fill platform with side slopes to support structure and infrastructure developments.
- Stage construction + additional reinforcement ➔ Ensure acceptable side slope stability
- Basal reinforcement ➔ To minimise spreading failure of compacted embankment fill over weak supporting subsoils

Basal Reinforcement

- Shall be designed in accordance with BS8006.
- Consideration ➔ Strain compatibility between embankment fill and basal reinforcement system.
- Tensile strain in basal reinforcement shall be controlled to avoid cracking in embankment fill.

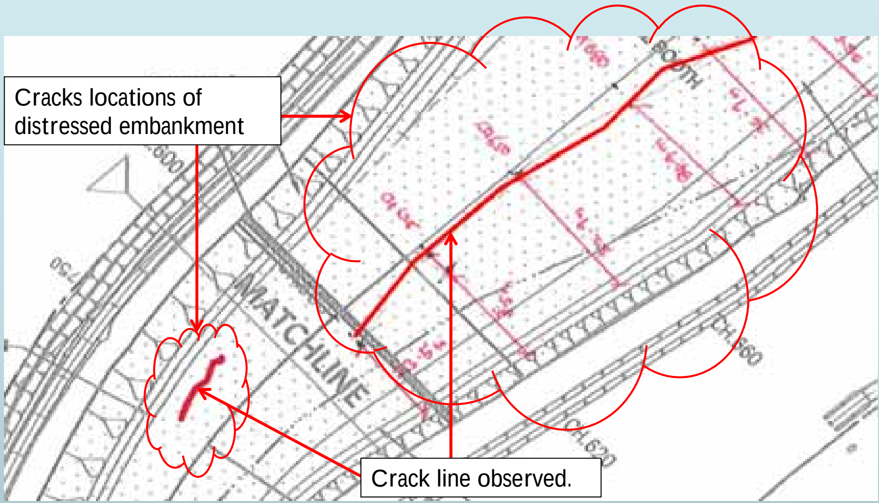
Basal Reinforcement

- If the embankment is strained to excessive tensile crack, the embankment fill material strength is doubtful.
- Thus, case study of an instrumented embankment construction with extendible basal reinforcement have been used.
- This may call for a review of the permissible strain of extendible basal reinforcement with brittle compacted fill.

Problem Statement & Distresses

- Problem Statements
  - Embankment Fill over Soft Deposits
  - PVD with Staged Construction
  - Basal Reinforcement for Temporary Embankment Stability
  - BS8006
  - Strain Incompatibility
- Distresses
  - Longitudinal flexural cracks on embankment surface

Embankment Distresses

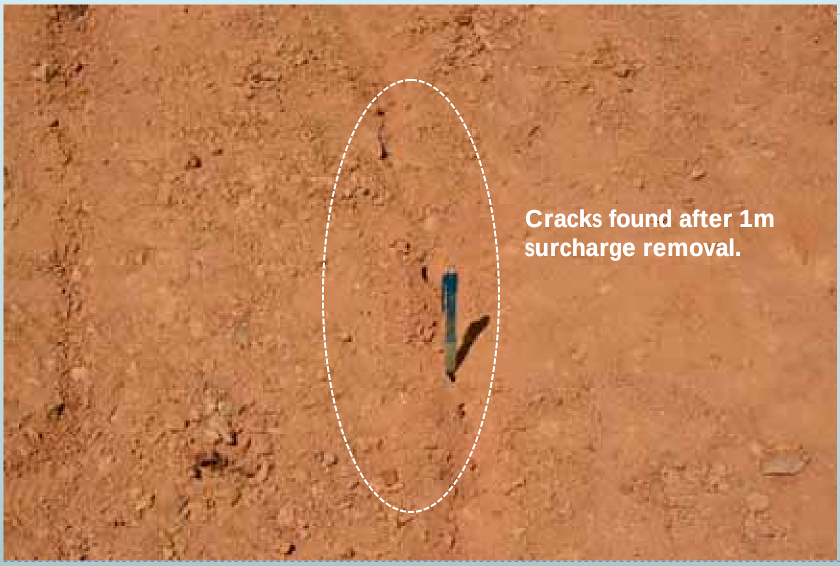


Embankment Distresses

Embankment Distresses

Embankment Distresses

Embankment Distresses

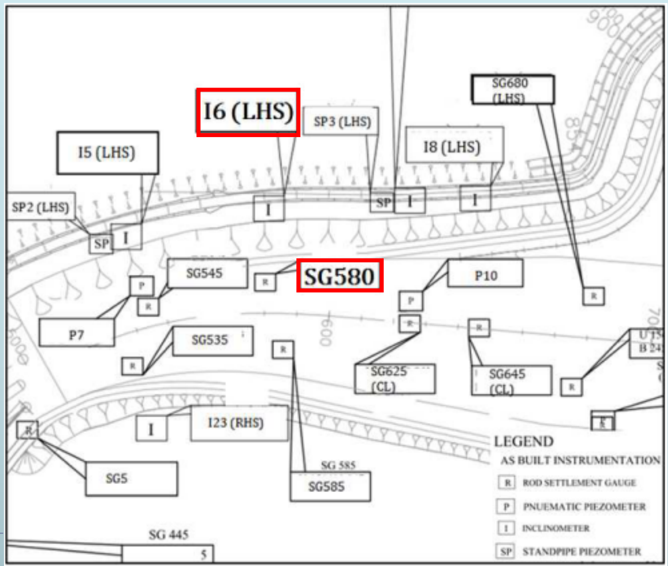


Embankment Distresses

Excavation on cracks found after 1m surcharge removal

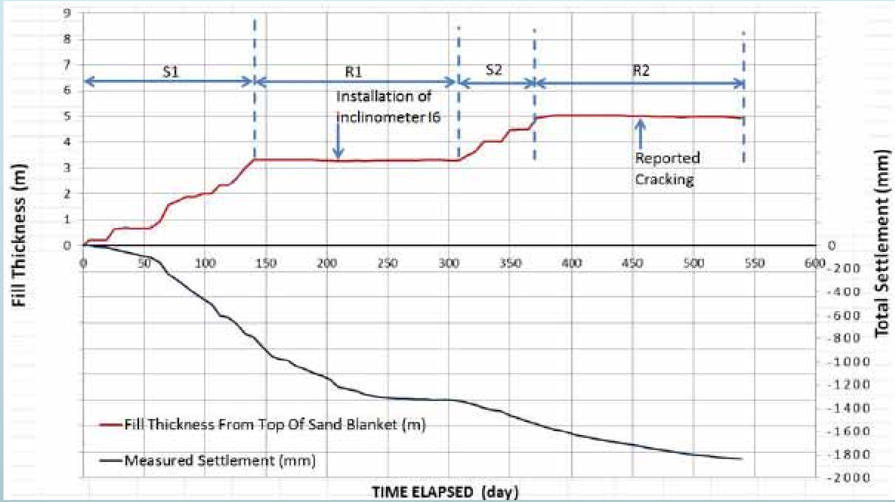
Instrumentation Layout

Instrumentation Layout Plan at Distresses area

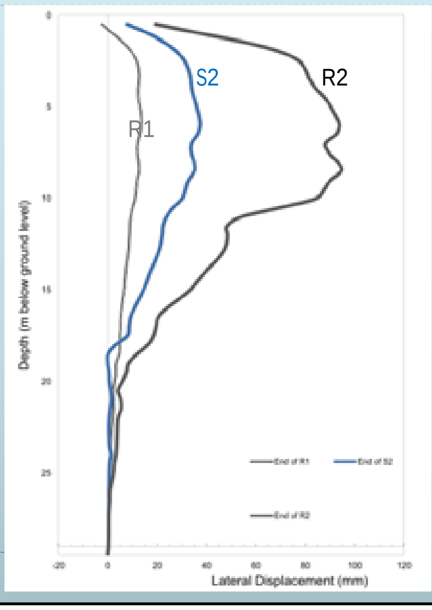


Instrumentation Results

Fill Thickness and Settlement of Embankment with time monitoring by SG580

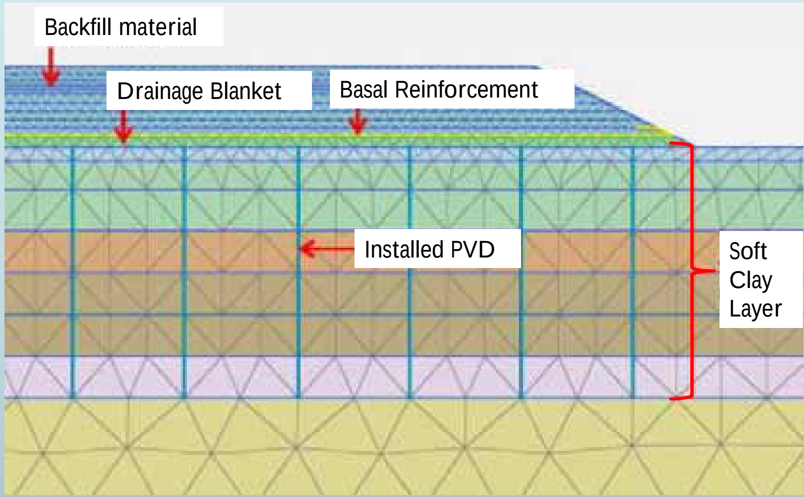


Instrumentation Results



Inclinometer I6 Monitoring Results

Finite Element Model



Finite Element Model

Back analysis to match lateral deformation and settlement profiles.

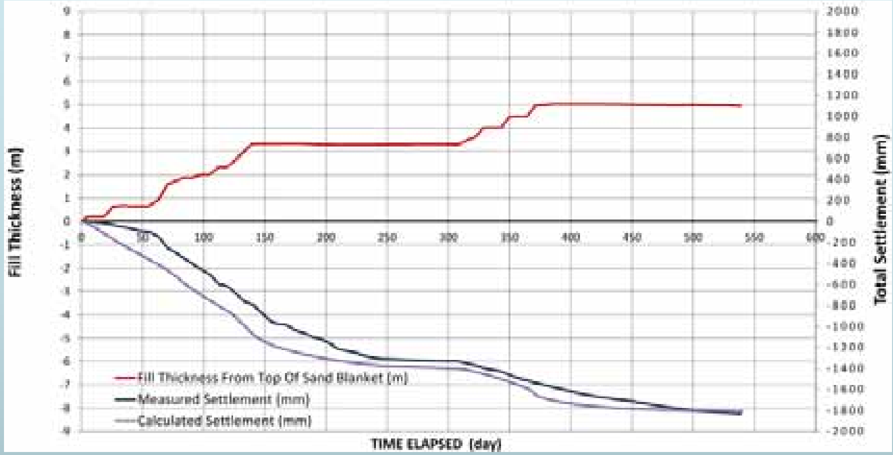
Two cases were modelled for back analysis:-

Case 1: Ultimate strength (600kN/m) mobilized at 10%

Case 2: Ultimate strength (140kN/m) mobilized at 1%

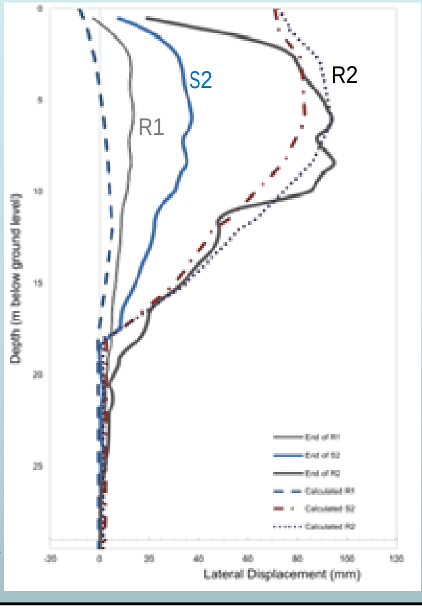
Finite Element Model

Comparison of Back Analysed Settlement Trend With Actual Measurement (Case 1)



Finite Element Model

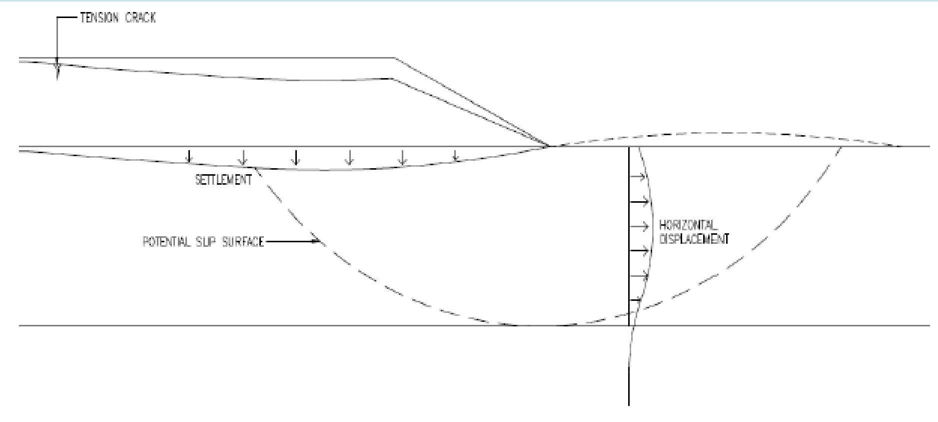
Comparison of Lateral Displacement Profile (Case 1)



Summary of Back Analyses

Stage	Tensile Stiffness	Mobilised Tensile Load / Tensile Strain	Maximum Lateral Deflection at Edge of Embankment (mm)
S1	Case 1	40.6kN/m / 0.68%	267
	Case 2	65.9kN/m / 0.47%	(173)
R1	Case 1	41.8kN/m / 0.70%	295
	Case 2	67.4kN/m / 0.48%	(180)
S2	Case 1	64.6kN/m / 1.08%	400
	Case 2	106.8kN/m / 0.76%	(253)
R2	Case 1	67.4kN/m / 1.12%	425
	Case 2	110.3kN/m / 0.79%	(265)

Probable Mechanism



Discussion

- Strain incompatibility between basal reinforcement and embankment fill could potentially cause embankment cracking.
- Average tensile strain of underlying weak subsoils is more than max. tensile strain in basal reinforcement.
- Results of back-analysis ➔ indicated mobilised tensile strength and strain < conventional assumed values for LEA stability analysis.

Conclusion

- Longitudinal cracks ➔ Outcome of plastic straining of upper weak alluvium within the underlying subsoil below the embankment loading.
- Review on current design practice by arbitrarily adopting unrealistic high mobilised strength is needed.
- Wishful high tensile strain assumed in LEA can lead to misrepresentation on safety margin of embankment.

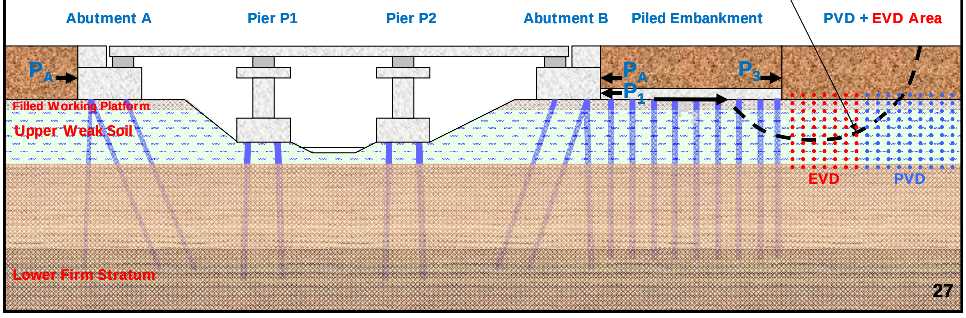
Recommendations

- Counterweight berm was proposed to solve the strain incompatibility between basal reinforcement and the subsoil.
- Instrument on basal reinforcement to reveal the distribution profile and performance of installed basal reinforcement.

Case 2: Case study on Piled Supported Embankment Failure

Site Conditions

- Embankment (maximum 5.4m high) with Piles & Ground Improvements
  - Ch3328 to Ch3375 (Top 10m soft Clay, S_u = 10~15kPa)
- Distressed Abutment
  - Abutment A @ Ch3266 (Top 15m soft Clay, S_u = 13~18kPa)
  - Abutment B @ Ch3328 (Top 9m soft Clay, S_u = 7~12kPa)



Findings from Site Inspection

- Piles & slab of piled embankment suffered structural distress
- Settlement of 0.4 to1.0m beneath piled embankment due to consolidation of subsoils under the working filled platform.
- Bearing distortions confirmed : Bridge deck moving from Abutment B towards Abutment A

Site Inspection Findings

- Piled Embankment 30m from Abutment B shown structural distress

Site Inspections Findings

- Piles of Piled Embankment has shown flexural cracks

Site Inspections Findings

- Damaged piled embankment slab damaged & 100mm gap at slab joint

Site Inspections Findings

- Settlement of 0.4 to 1.0m under the Piled Embankment

Site Inspections Findings

- Bearing distortion at Pier P2


Site Inspections Findings

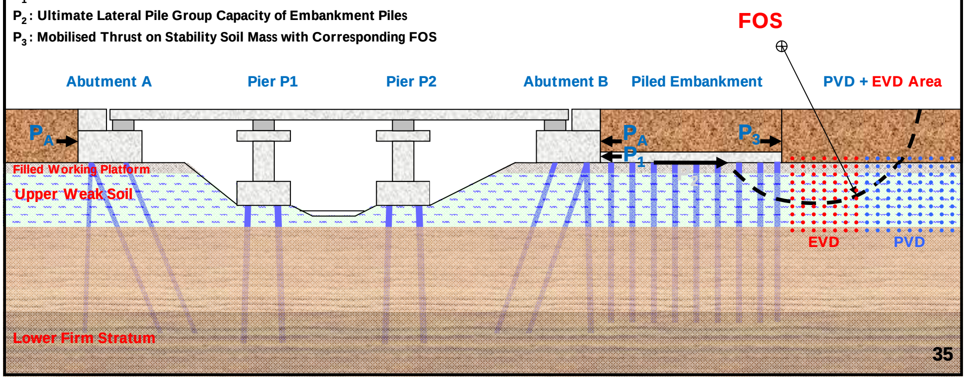
- Bearing distortion at Pier P1


P_A : Active Earth Pressure

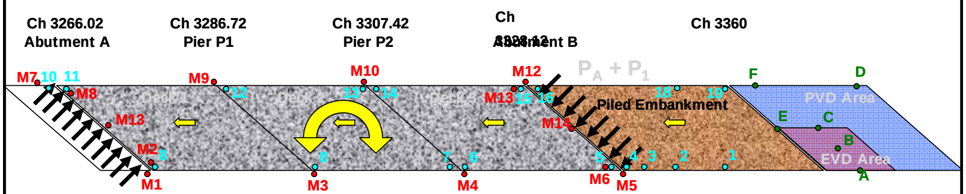
P_1 : Action/Reaction Force between Piled Embankment Slab & Abutment

P_2 : Ultimate Lateral Pile Group Capacity of Embankment Piles

P_3 : Mobilised Thrust on Stability Soil Mass with Corresponding FOS



- Settlement Markers (LDC) : 28 May -31 Jul 2005
- Displacement Markers (by LDC) : 02 Mar – 18 Jun 2006
- Displacement Markers (by G&P) : 25 Apr – 7 May 2007



P_A : Active Earth Pressure

P_1 : Action/Reaction Force between Piled Embankment Slab & Abutment

P_2 : Ultimate Lateral Pile Group Capacity of Embankment Piles

P_3 : Mobilised Thrust on Stability Soil Mass with Corresponding FOS

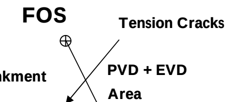
Movement Direction

Bearing Distortion

Clockwise Rotation

Anti-Clockwise Rotation

Developing Pile Plastic Hinge

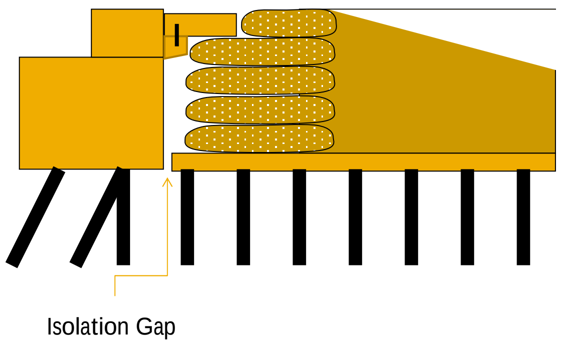


Investigation Findings

- Embankment (5.4m high)
  - Ch3375 : FOS ≅ 1.0 at Embankment on Ground Treatments
  - Causation : Inadequate FOS => Embankment instability exerting lateral stress to Piled Embankment on free standing piles due to subsoil consolidation
- Distressed Abutment
  - Abutment B : Laterally pushed by unstable embankment behind piled embankment
  - Abutment A & Two piers : Affected by lateral thrust from Abutment B (No observable distresses at the abutment pile foundation after exposure of piles)

Abutment Remedial Design

- Abutment Distress (Ch3266 to Ch3328)
  - Remedial proposal :



Conclusions

- Weak post-treatment soil strength unable to support embankment
- Creep movement of weak subsoil beneath embankment coupled with embankment instability due to low FOS
- Further consolidation of weak overburden soil, the lateral resistance of piled embankment in free standing pile conditions is weaken
- Monitored bridge displacement confirmed pattern of lateral movement of entire bridge & piled embankment
- Structural damage on embankment piles was expected as structural threshold has reached
- Use of residual strength is needed for rectifying failed embankment

Recommendations

- Construct new embankment slab at least 1m below the failed slab to prevent further consolidation settlement
- Extend piled embankment for embankment fill higher than 2m & provide isolation gap at the slab/abutment interfaces
- Use of higher strength RC pile for embankment piles
- Use of geotextile reinforcement to isolate embankment fill from both abutments to reduce direct lateral earth pressure on abutments

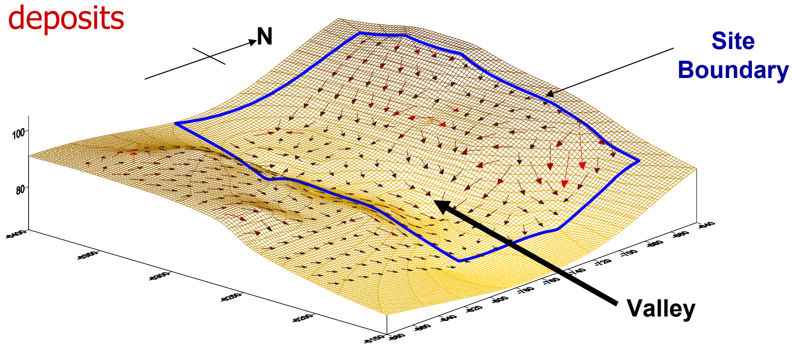
Case Study 3 : Performance of Stone Columns Supported RS Wall

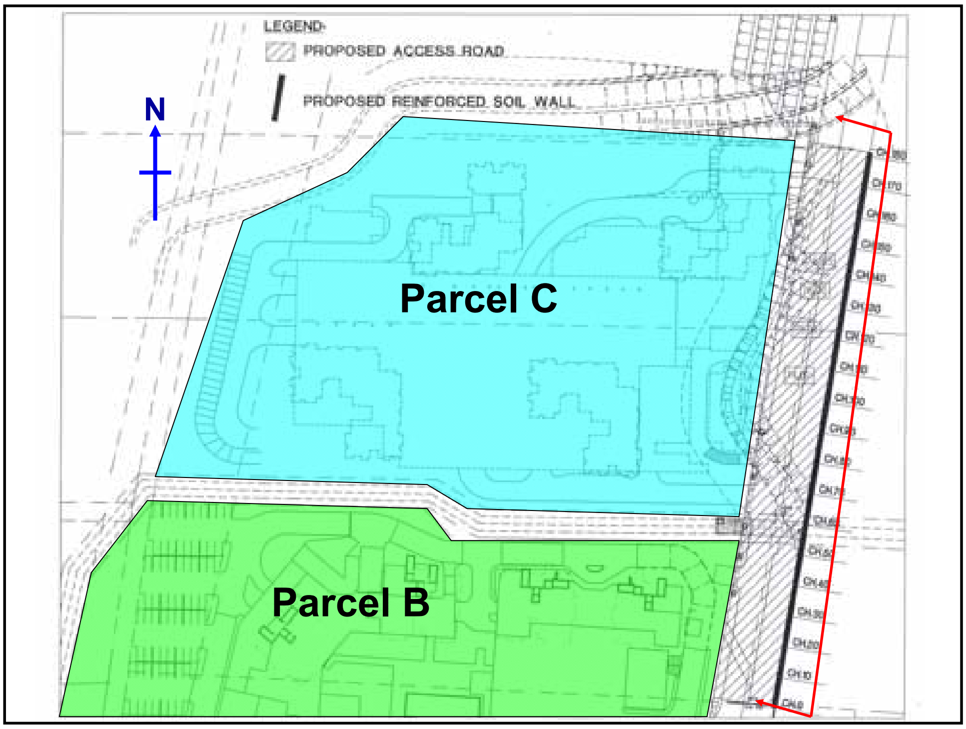
- Original Topography
- Subsurface Information
- Adopted Foundation System for RS Wall
- Design Consideration
- QA/QC During Construction
- Design Verification
- Conclusion

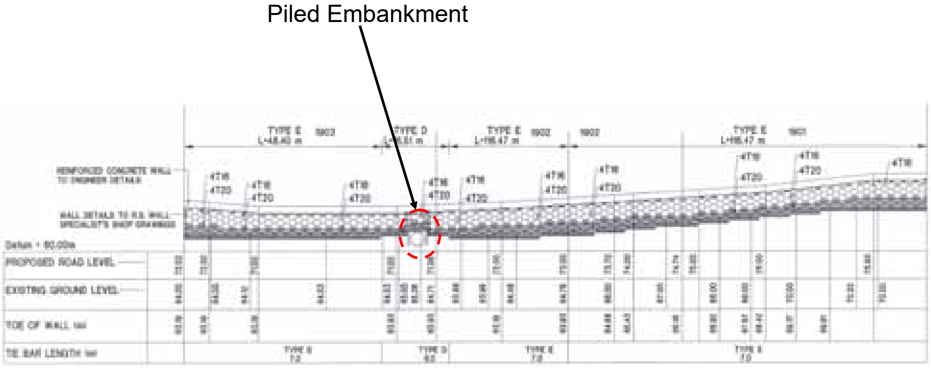
Original Topography of Site

- Original ground is hilly
- Surface runoff towards natural valley area
- Within proximity of previous water stream

→ Weak deposits



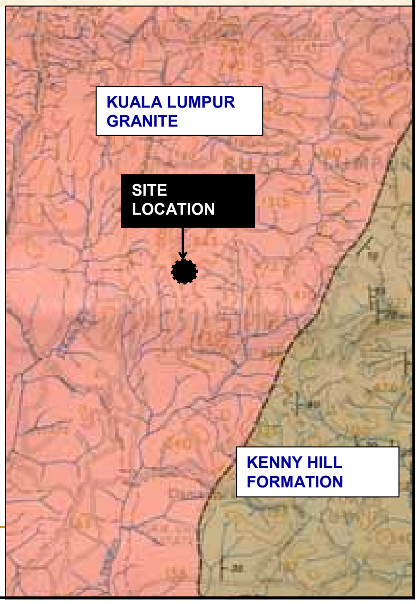




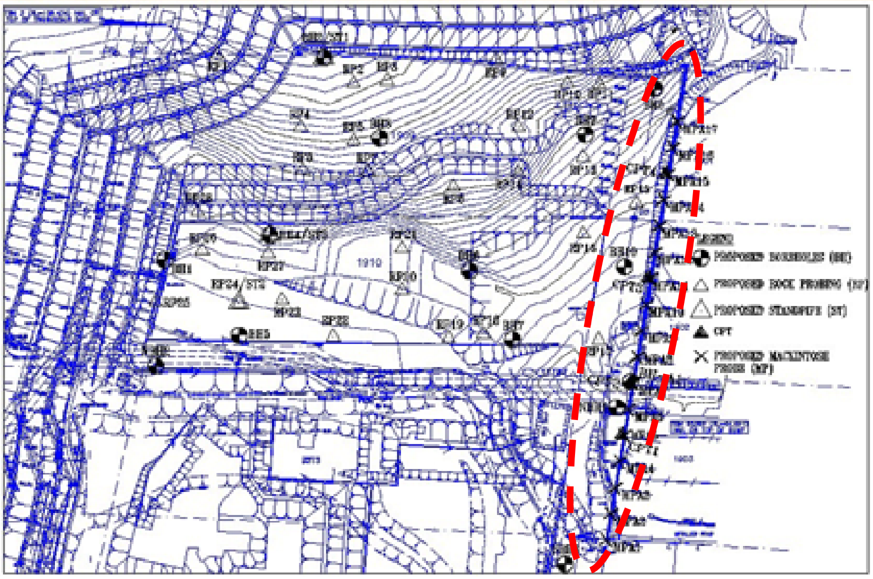
RS Wall Elevation Profile

SUBSURFACE INFORMATION

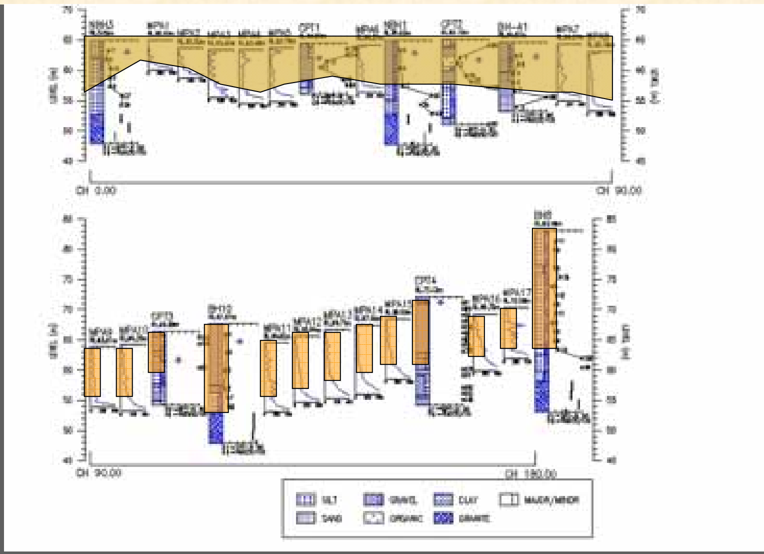
- Residual Soil
- Granitic Formation
- Intermediate Boulders



S.I. Layout Along RS Wall

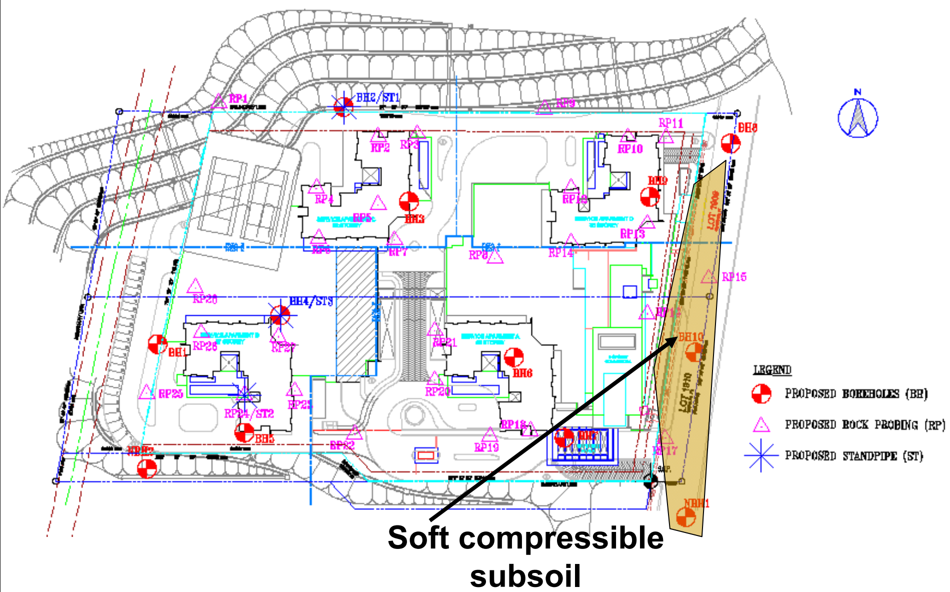


Subsurface Profile Along RS Wall



Soft Compressible Layer

Implications



ADOPTED FOUNDATION DESIGN SYSTEM FOR RS WALL

- 10m high reinforced soil wall on up to 12m thick soft compressible subsoil

➔Stone column

  - 1m diameter
  - 2m centre to centre spacing

ADOPTED FOUNDATION DESIGN SYSTEM FOR RS WALL

- Reasons
  - Reinforcement of weak subsoil
  - Drainage for dissipation of excess pore pressure generation
  - Improving strength and deformation properties of soil

DESIGN CONSIDERATIONS

- Bulging of individual stone column
- General shear of stone column
- Stress distribution between stone columns and subsoil

DESIGN CONSIDERATIONS

- Bearing capacity of subsoil and stone column
- Global stability of RS wall
- Overall ground settlement after improvement

QA / QC DURING CONSTRUCTION

- Material control
- Appropriate termination criteria of stone column installation
- Verification test (plate load test)

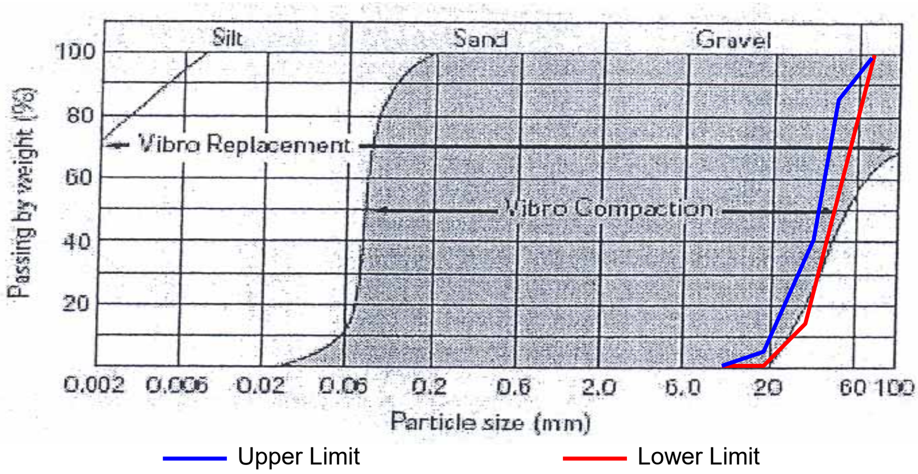
Material Control

- Clean, hard, durable
- Chemically inert natural materials

Test	Standard	Criteria	Frequency
Crushing Value	BS 882:1992	<30%	1 test per 30,000 tonnes of aggregate
Los Angeles Abrasion	ASTM C131	Max loss of 40% at 500 revolutions	
Flakiness Index	BS 882:1992	<30%	
Sulphate Soundness	ASTM C88	<12%	

Material Control

(Allowable grading of stone aggregates)



Range of Soils suitable for Vibro Compaction Methods

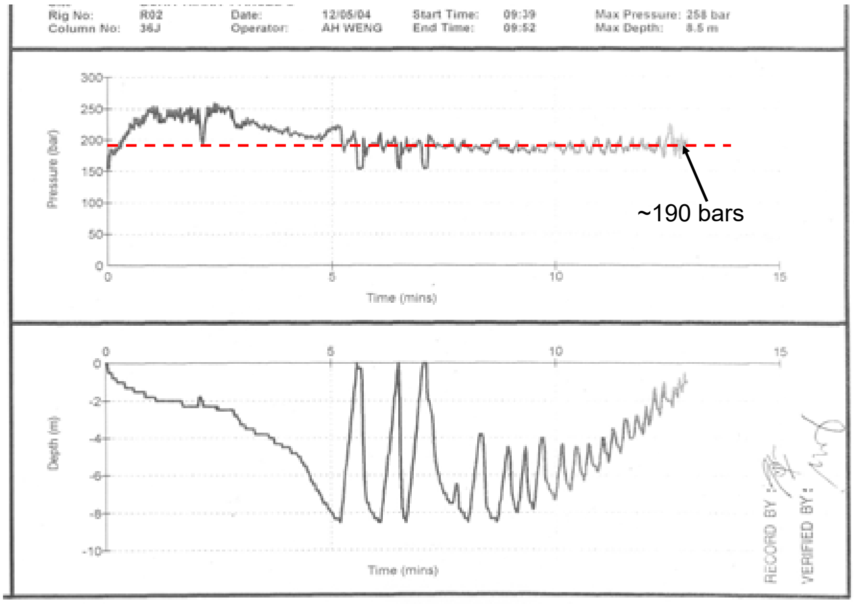
(Baumann and Bauer, 1974)

Termination Criteria

- Hydraulic pressure in the vibratory probe = 190 bars

TO BE VERIFIED BY PLATE LOAD TEST DURING FIRST COLUMN INSTALLATION

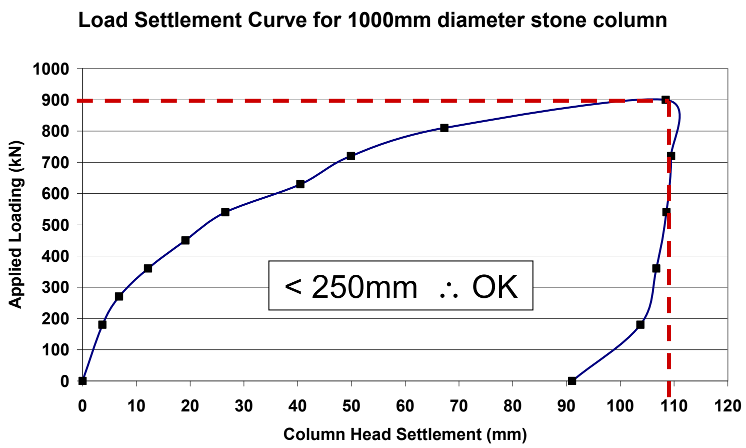
Termination Criteria



Verification Test (Plate Load Test)

Verification Test (Plate Load Test)

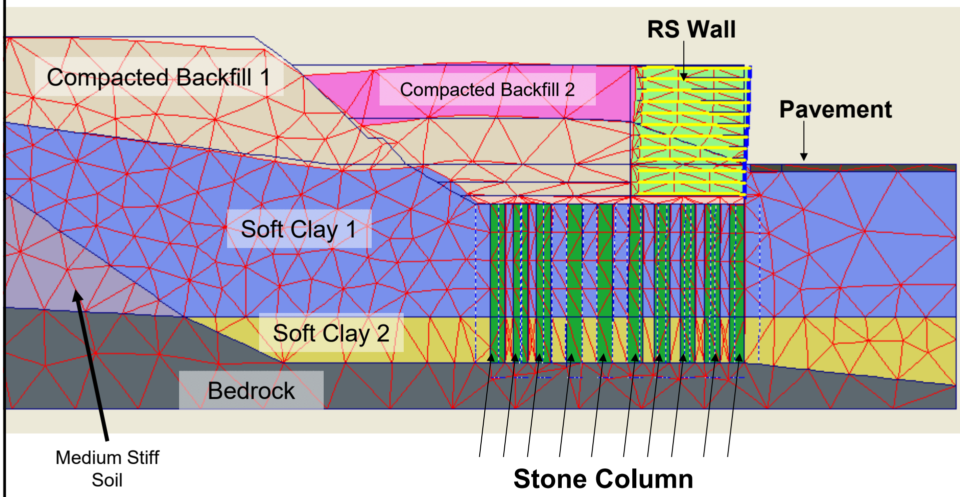
Verification Test



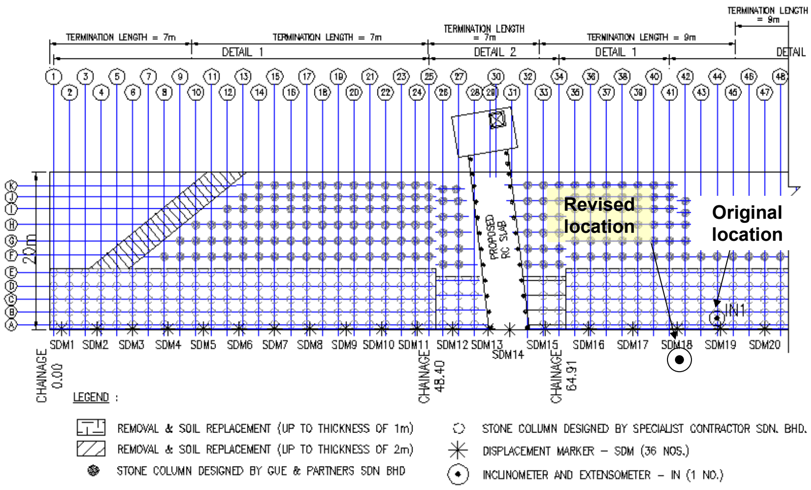
DESIGN VERIFICATION

- Finite element method (FEM) analyses using PLAXIS
- Monitoring instrumentation scheme

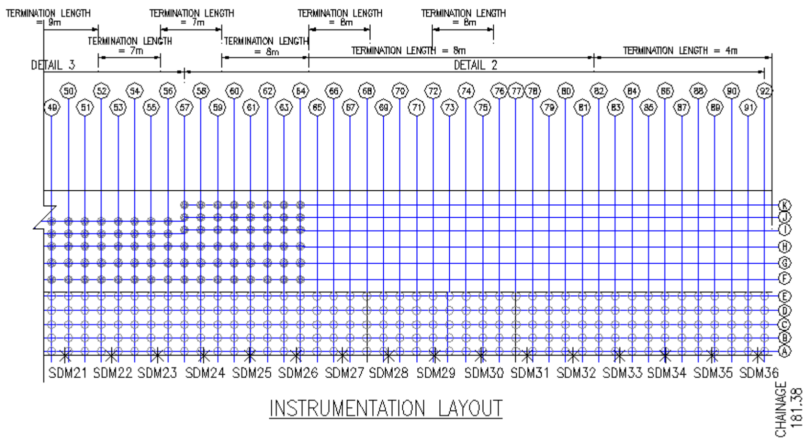
PLAXIS Model & Analyses



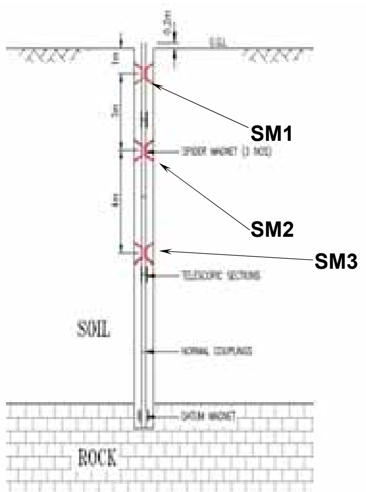
Instrumentation Monitoring Scheme



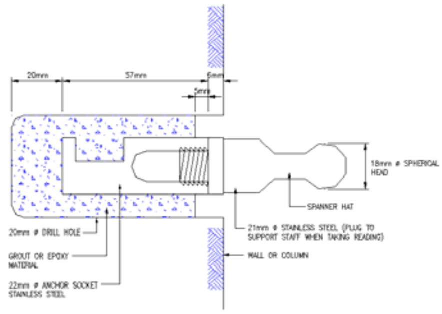
Instrumentation Monitoring Scheme



Instrumentation Monitoring Scheme

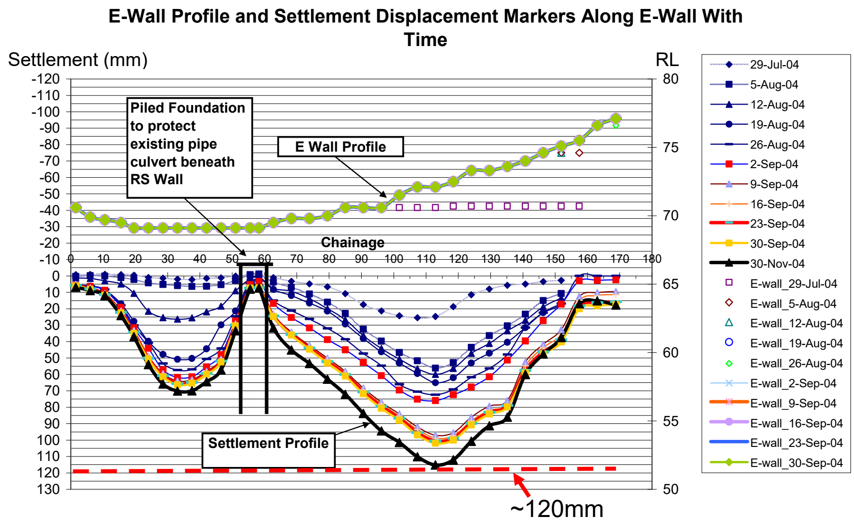


Inclinometer with Magnetic Extensometers

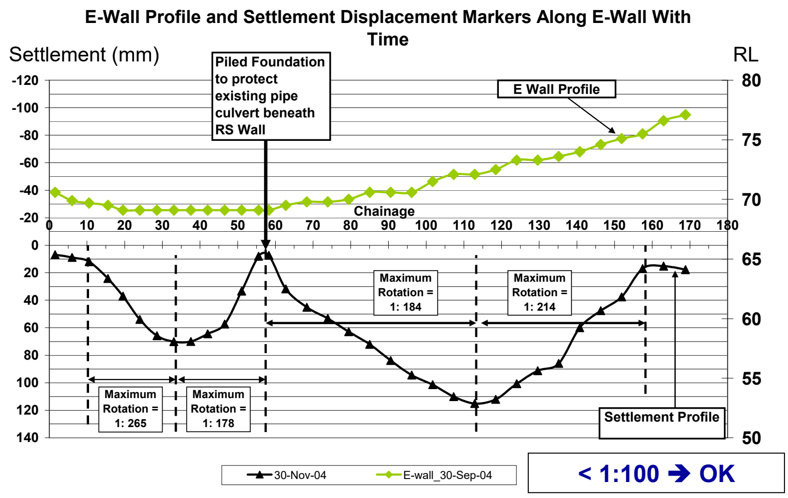


Details of Displacement Markers

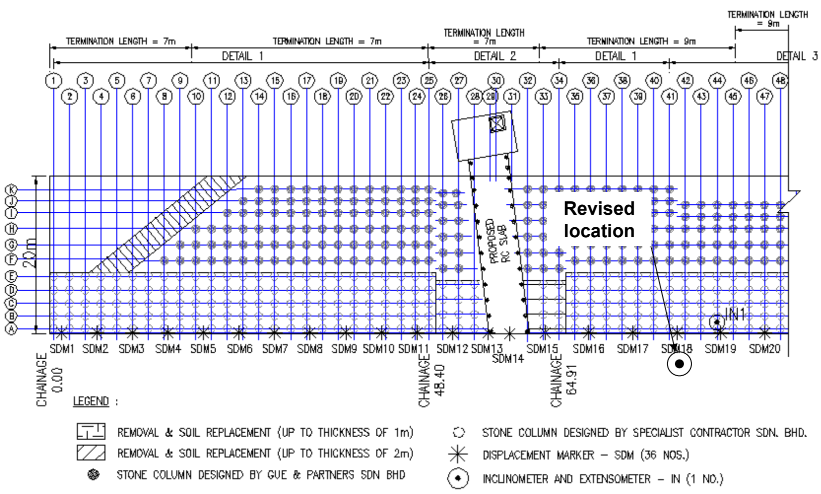
Instrumentation Results



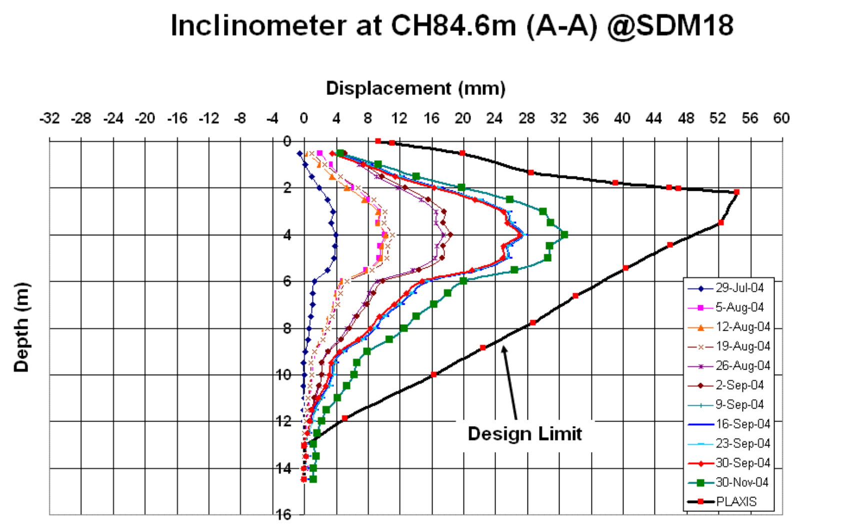
Instrumentation Results



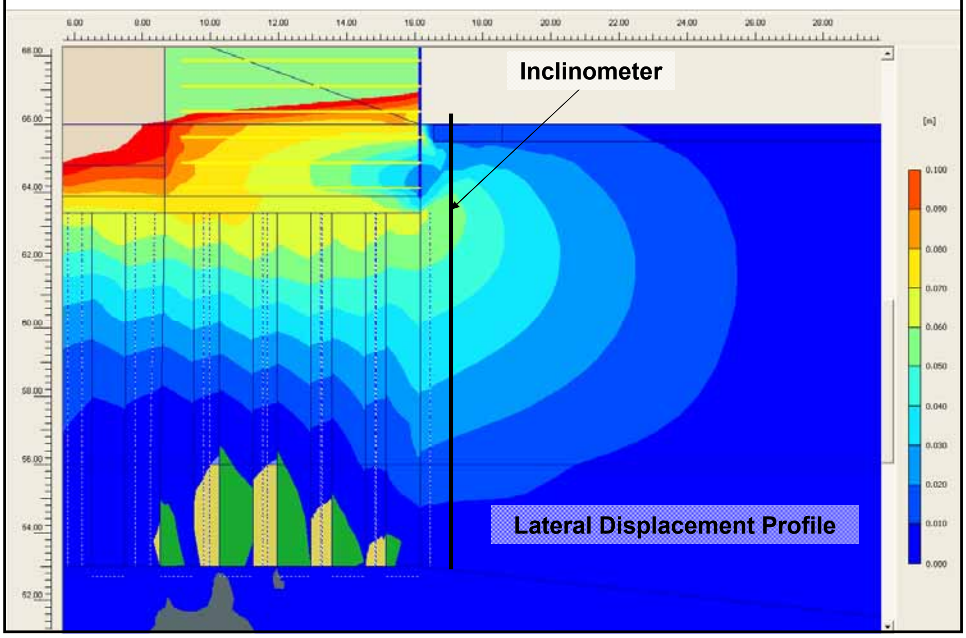
Instrumentation Monitoring Scheme



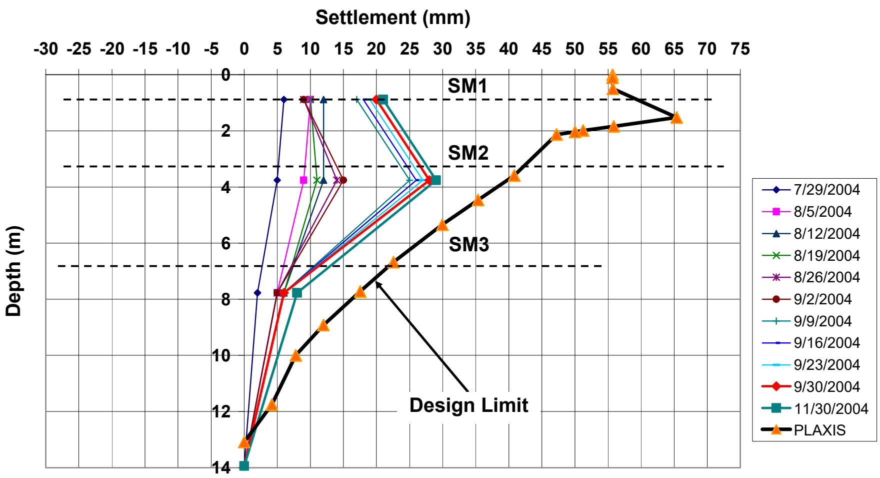
Instrumentation Results



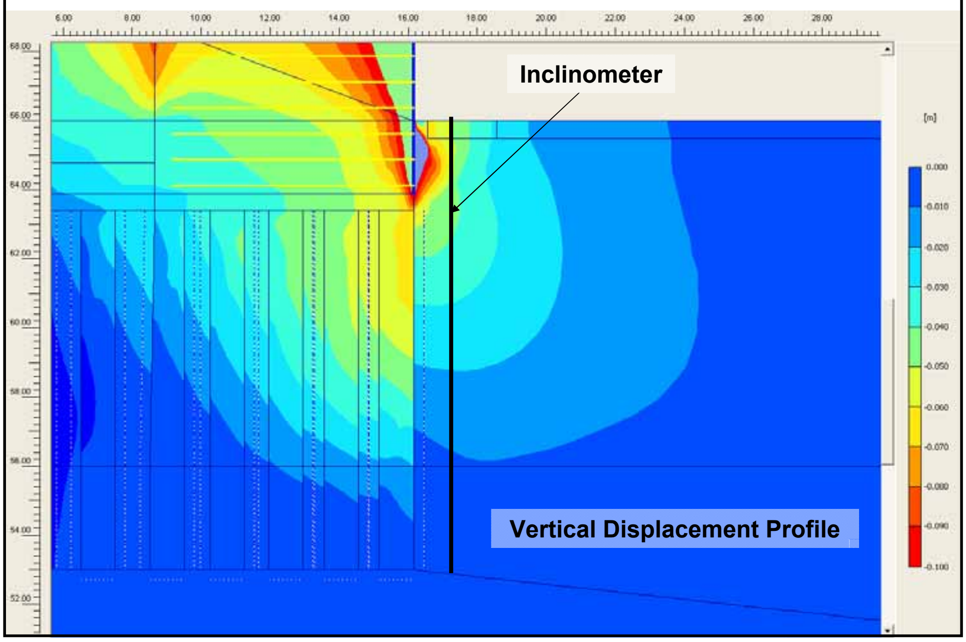
Instrumentation Results



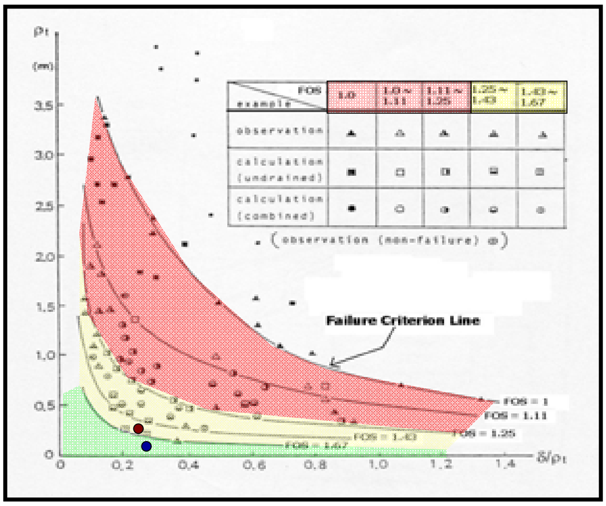
Instrumentation Results



Instrumentation Results



Instrumentation Results



Legend

- Current
- Predicted

(δ/ρt) Diagram with Factor of Safety (After Matsuo et al, 1977)

CONCLUSIONS

- Successful installation of stone columns within economical means

- To consider

  ➔ Design Aspects

  ➔ Quality Assurance and Quality Control during construction

CONCLUSIONS

- Use Observational Method and Finite Element Analysis

- Matsuo plot can also be applied to verify the FOS of RS wall

Thank You

Session 4 : Case Study of Slope Failures/Landslides in Tropical Residual Soils

Presented by:
Ir. Liew Shaw Shong

Contents

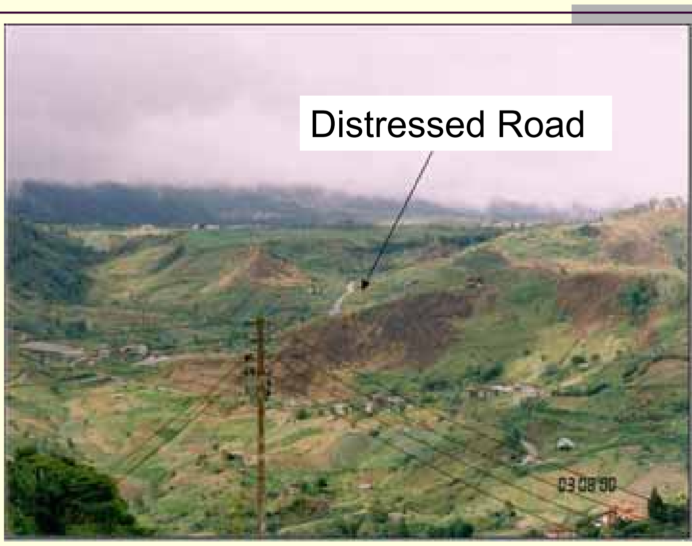
- A. Creep Movement of Slopes, Sabah.
- B. Cut Slope Failure in Skudai, Johor.
- C. Cut Slope Failure at Gua Musang, Kelantan.
- D. Cut Slope Failure at Kuala Lumpur.
- E. Filled Slope Failure at Salak Tinggi.
- F. Soil Nailed Slope Failure at Pahang.
- G. Cut Slope Failure at Kedah.

Case Studies

(http://www.gnpgroup.com.my/publication.asp)

◯ Case History Site

A. Creep Movement of Slope, Sabah

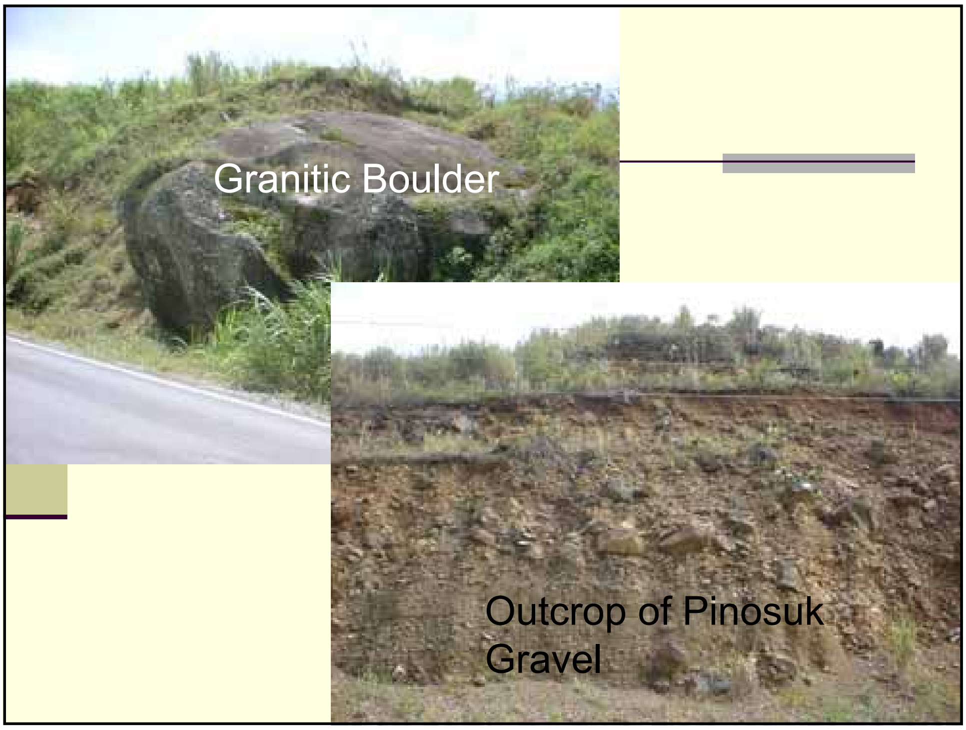


ents

nent and

Site Background

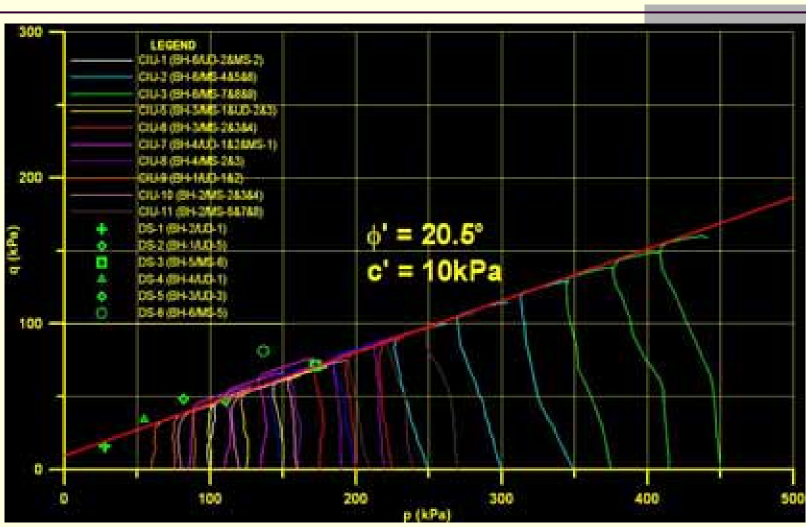
- RL1335m to RL1500m.
- Terrain : Undulating/Sloping.
- Outcrops: Granitic boulder/ Grey Shale/ Sandstones.
- Deposits of Pinosuk Gravel from Mt. Kinabalu.
- Glaciation & Ancient Mudflow.



SI & Laboratory Testing

- Six Boreholes & Inclinometers
- Six Piezometers (GWT : 1.5~2.5m)
- C.I.U. Tests & Direct Shear Box Tests (ϕ'=21º, c' = 10kPa).
- Others Properties : w_n = 7% to 13%, γ_{bulk}= 21~23.7kN/m^3
- Normally Consolidated

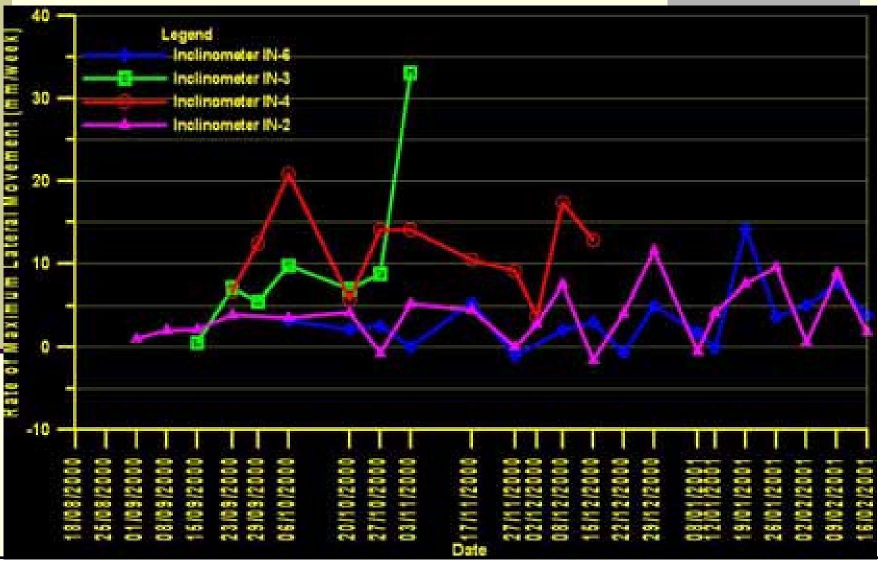
Shear Strength Test Results



Monitoring Results

- Inclinometers detected slip surface.
- Lateral Movement:
- Direction :225°~250°
- Max. Movement : 140mm (IN-4)
- Rate of Movement : 2~14mm/week (Max. 21mm/week)

Inclinometer Movement Rate



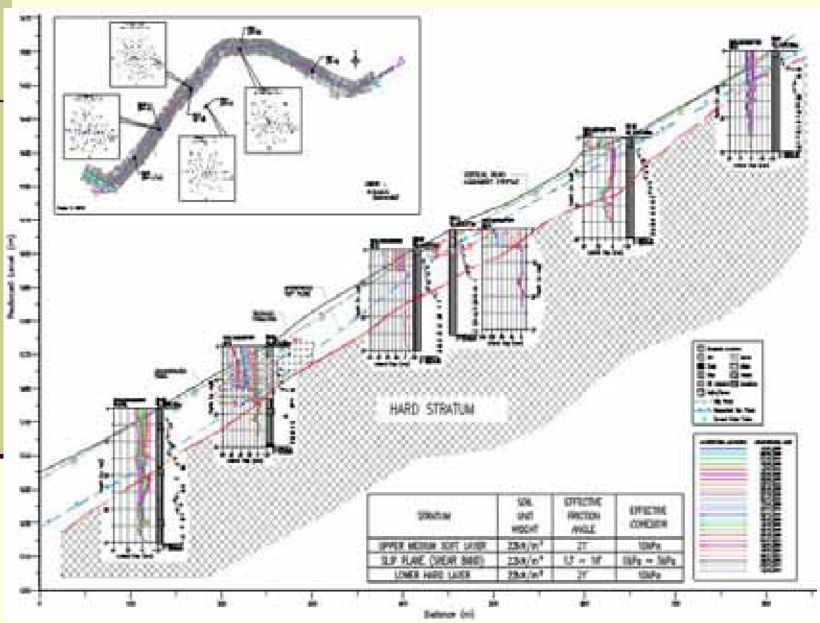
Engineering Assessment

- Interpreted laboratory shear strength parameters are too high to cause instability.
- Back-analysis shear strength parameters:

  ϕ'=13º~16º, c' = 0~5kPa

Findings

- Slip Surface : 6m (higher ground) to 15m (lower ground).
- Movement Direction: almost parallel to road alignment, towards river.
- Back-analysed shear strength < Interpreted laboratory test results.



Recommendations

- Carry out continuous sampling at shear plane to collect samples for testing.
- Carry out ring shear test or multiple reversal direct shear box test to determine residual strength.

B. Cut Slope Failure in Johor

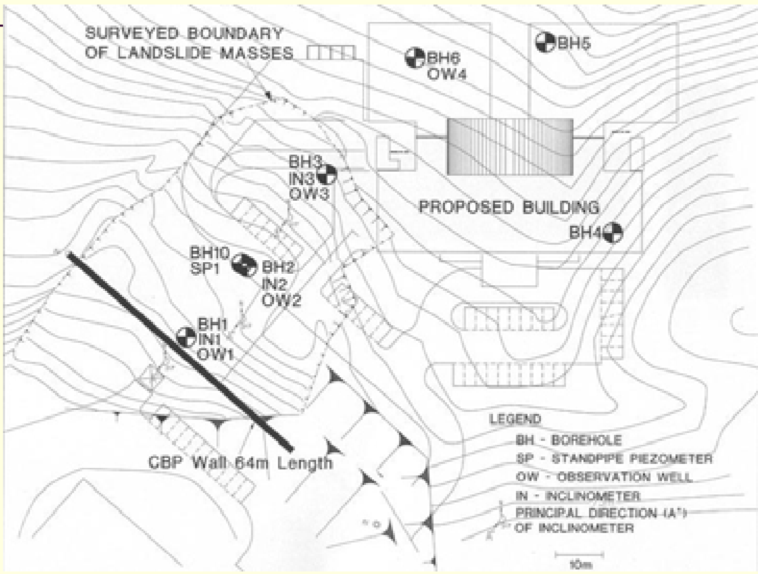
Site Background

- RL54m to RL106m.
- Terrain : Sloping.
- Geology: Mainly basic intrusive gabbro and intermediate intrusive.
- Two berms cut slope 1V:1.5H.
- Slope collapsed after heavy downpour.

SI and Instrumentations

- SI and instrumentation for failure investigations:
- 4 boreholes within failed mass area.
- 3 inclinometers.
- 3 observation wells and 1 standpipe piezometer.

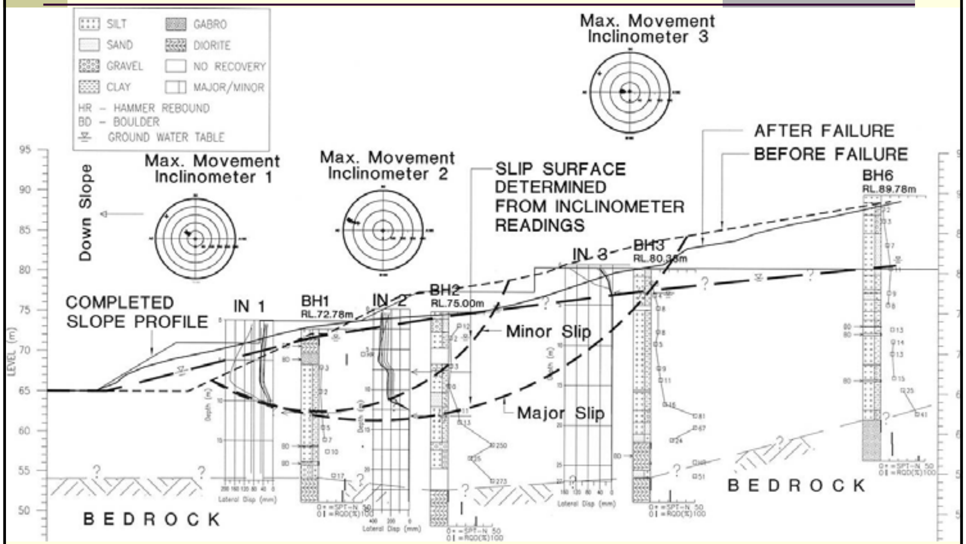
SI Layout Plan



Instrumentation Results

- IN-1 and IN-2 were sheared off at 10.5m and 12.0m below ground.
- IN-3 sheared off at 2.5m below ground.
- Observation wells were also sheared off.

Interpreted Slip Surfaces



Laboratory Test Results

- CIU test :

  a. Peak strength – c'=3.5kPa, ϕ'=32°

  b. Critical state strength – c'=0kPa, ϕ'=29°
- Direct Shear Box test : (fairly scattered)

  a. Peak strength – c'=15.7kPa, ϕ'=24°

  b. Residual strength – c'=5.9kPa, ϕ'=20°

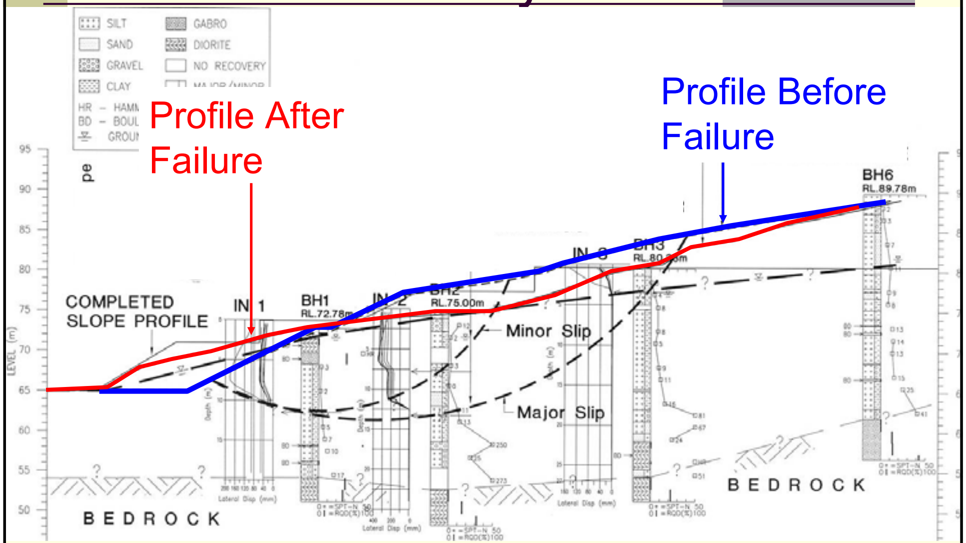
Back-Analysis

- Back-analyses were performed for 2 conditions:

  a. Slope profile after cutting, before failure. (critical state strength)

  b. Slope profile after failure. (residual strength)
- The interpreted slip surface and monitored groundwater level is used for back-analysis.

Slope Profile for Back Analysis



Back-Analysis Results

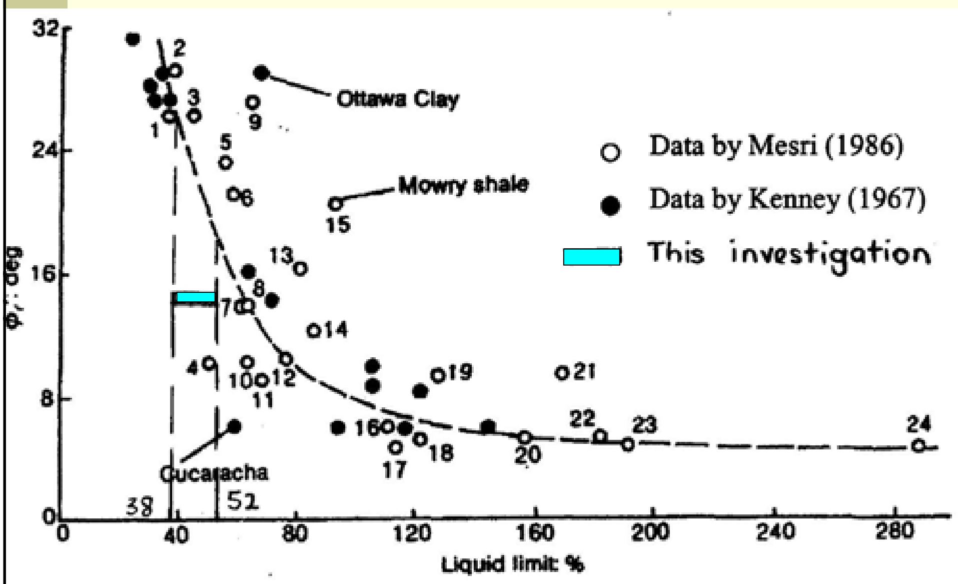
- Back-analyses using PC-Stabl6 and Plaxis.
- Back-analyses results :

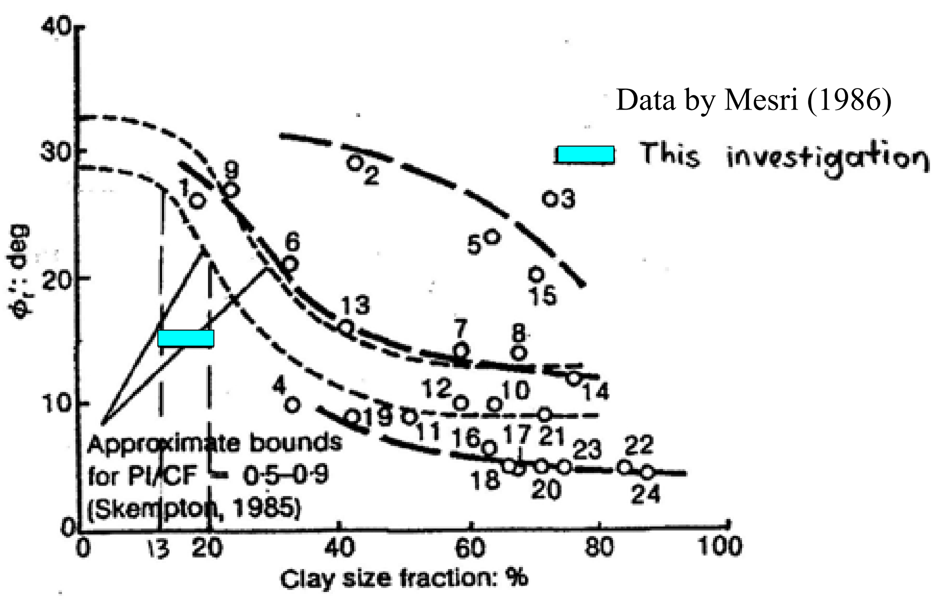
  a. Mobilised shear strength : c'=0 kPa, ϕ'=24^o – 25.9^o

  b. Residual strength : c'=0 – 0.5 kPa, ϕ'= 14.4^o – 15^o

Residual Strength

- Comparisons with literature:
  - a. Residual friction angle – Liquid Limit.
  - b. Residual friction angle – Clay size fraction.
- Back analysed residual friction angle are lower as compared to literatures.





Findings and Recommendations

- The investigation deduced that there is a thin layer at the slip surface with low shear strength.
- Boreholes are not able to capture the thin layer and could only be detected by inclinometer.
- Residual shear strength should be used for remedial design works.

C. Cut Slope Failure at Gua Musang, Kelantan

Site Observations

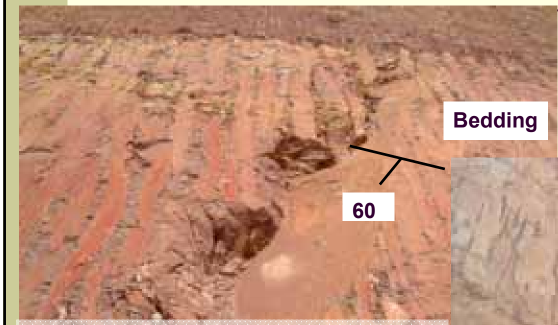
Site Background

- RL210m to RL330m.
- 7 Upper berms of 1V:1H Cut Slope & 5 Lower berms of 4V:1H Soil Nailed Slope
- Soil Nail = 12m with spacing of 1m(V):1m (H)
- Geology: Shale Facies in Gua Musang Formation which mainly consists of Mudstone & Sandstone
- A massive slope failure occurred before soil nails were installed at the lowest berm.

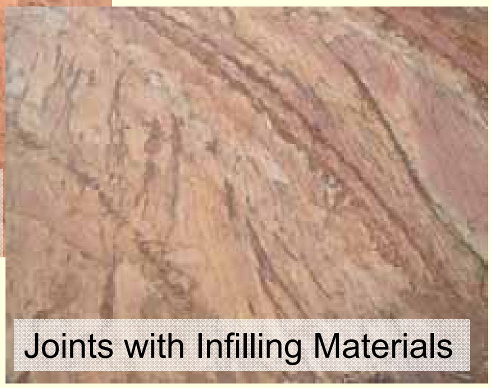
Geological Mapping

- 'Line Mapping' Method
  - To measure & record discontinuity along the exposed slope face
  - To detect anomalous features
  - Schmidt Rebound Hammer to give indication on weathering condition

Site Observations



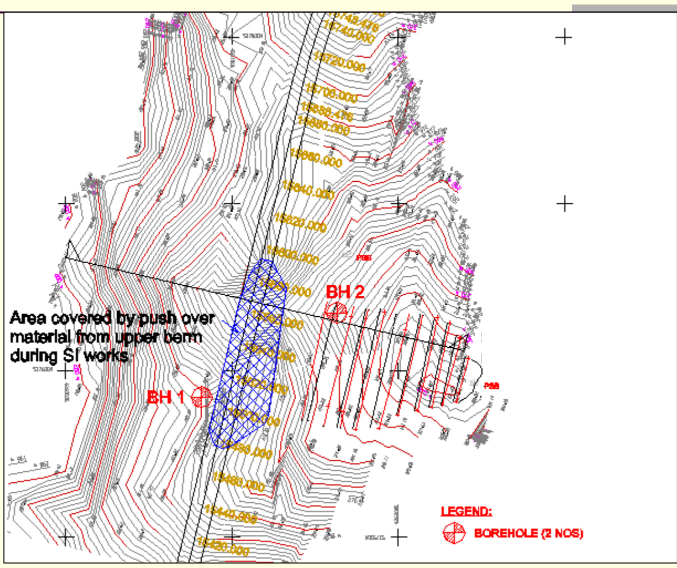
Bedding of Cut Slope Day-lighting Towards Main Road


Joints with Infilling Materials

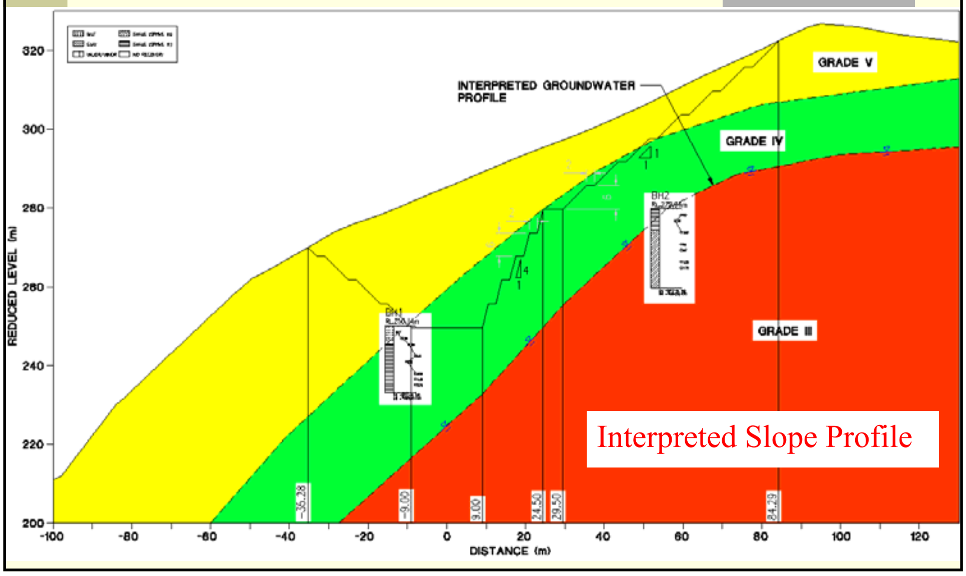
SI & Laboratory Works

- 2 boreholes
- 3 C.I.U. Tests
- 2 Multiple Reversal Direct Shear Box Tests
- Grade IV Material
  - a. Peak strength – $c'=30kPa$, $\phi'=33^o$
  - b. Residual strength – $c'=0kPa$, $\phi'=33^o$
- Grade III Material
  - a. Peak strength – $c'=30kPa$, $\phi'=39^o$
  - b. Residual strength – $c'=0kPa$, $\phi'=33^o$

SI Layout Plan

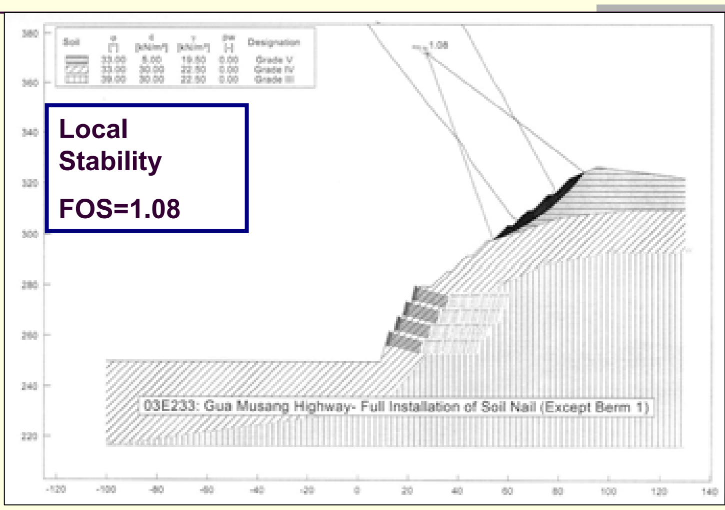


Slope Profile



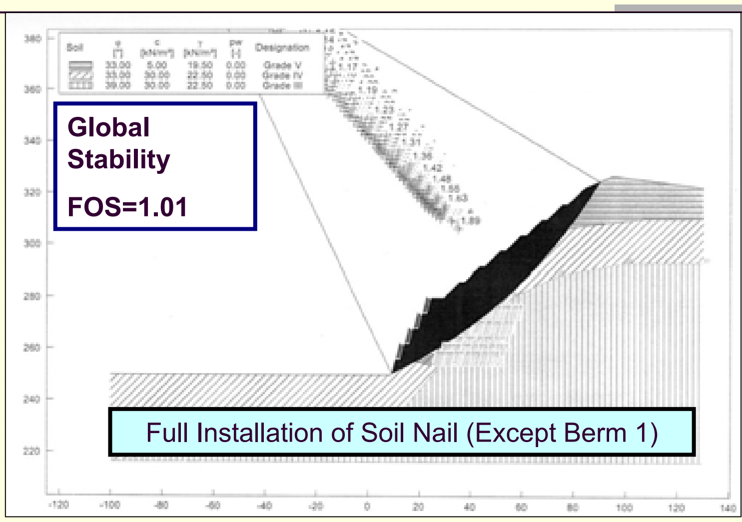
Engineering Assessment

Slope Stability Analyses



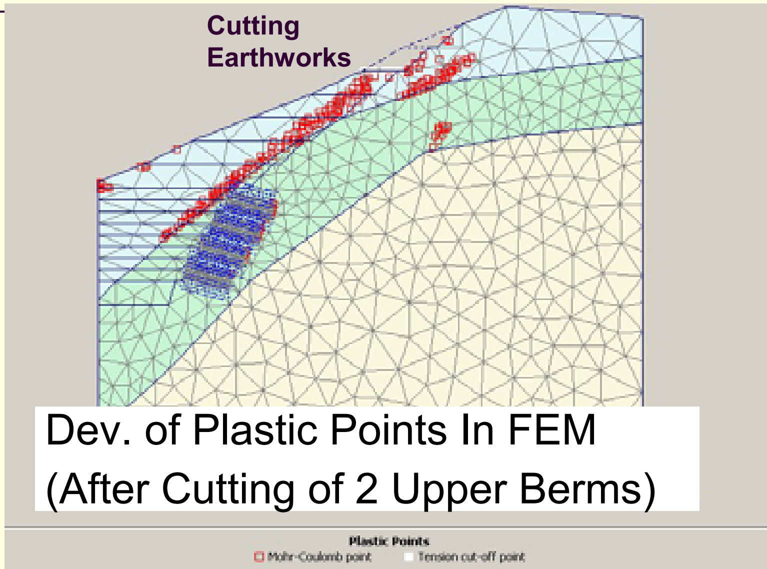
Limit Equilibrium Method

Slope Stability Analyses

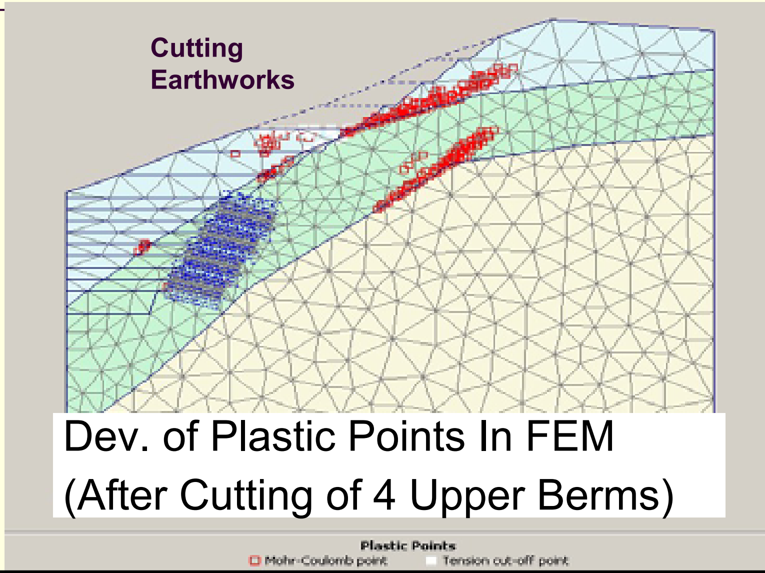


Limit Equilibrium Method

Finite Element Analyses

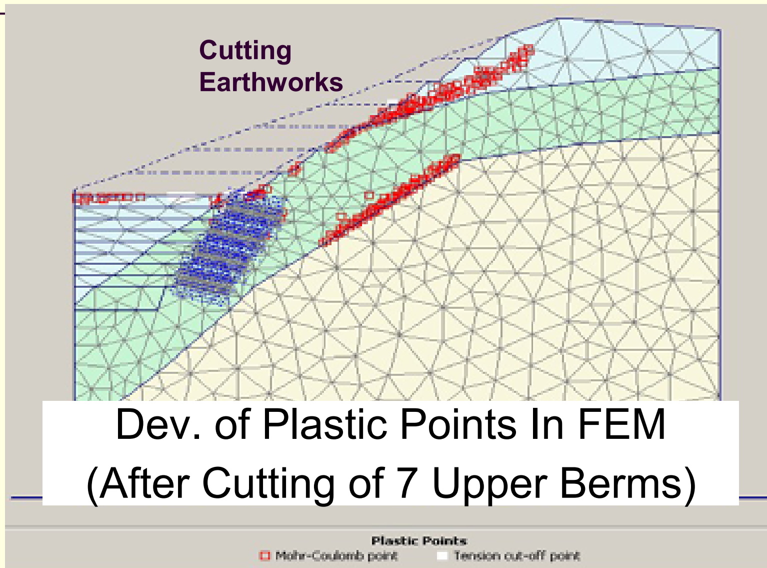


Finite Element Analyses



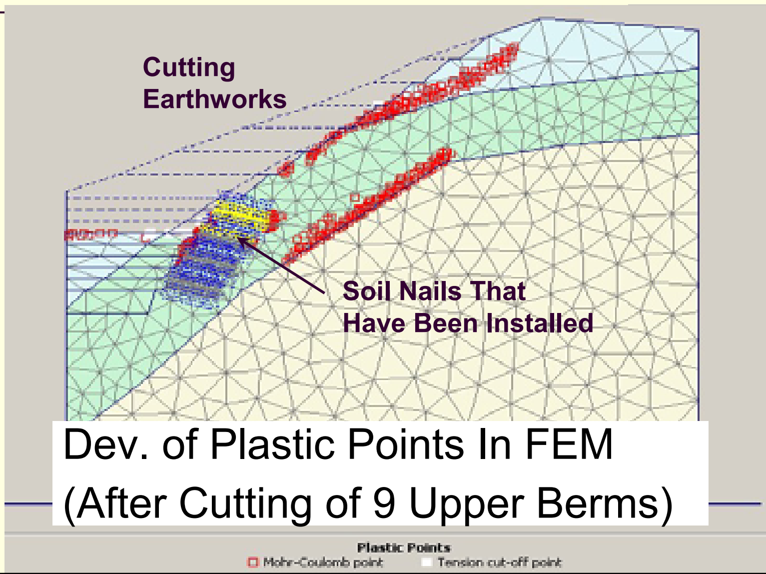
Dev. of Plastic Points In FEM
(After Cutting of 4 Upper Berms)

Finite Element Analyses



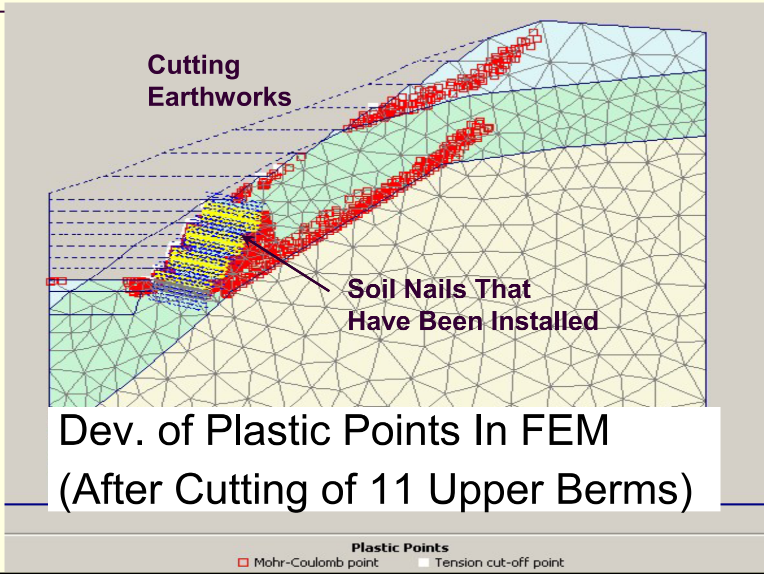
Dev. of Plastic Points In FEM
(After Cutting of 7 Upper Berms)

Finite Element Analyses



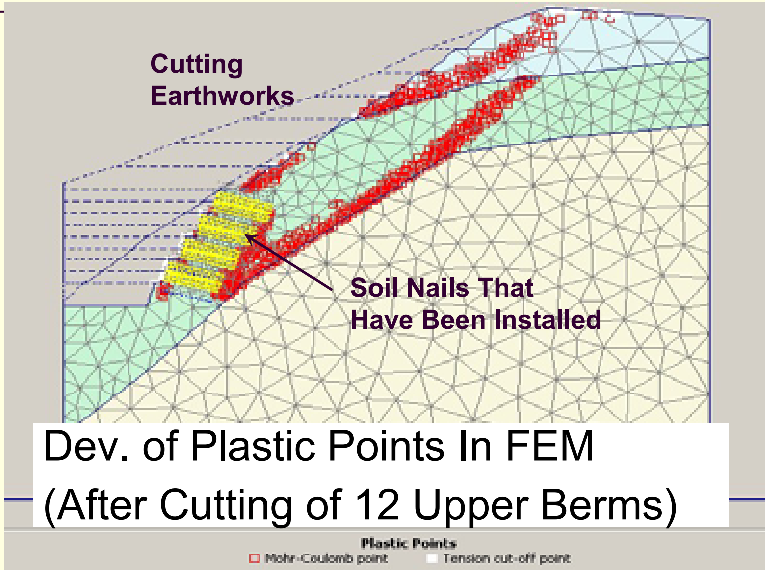
Dev. of Plastic Points In FEM
(After Cutting of 9 Upper Berms)

Finite Element Analyses



Dev. of Plastic Points In FEM
(After Cutting of 11 Upper Berms)

Finite Element Analyses



Dev. of Plastic Points In FEM
(After Cutting of 12 Upper Berms)

Findings

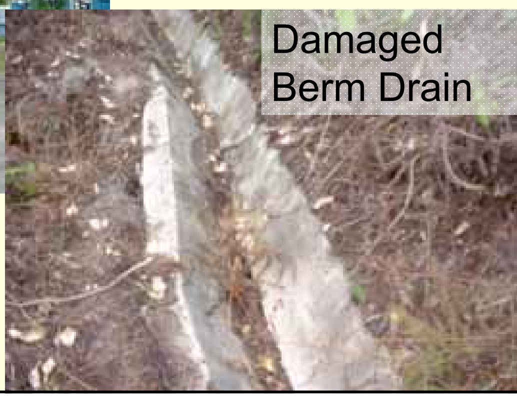
Possible Causes of Failure

- Steep upper cut slope of 1V:1H.
- Inadequate soil nail length of 12m.
- Day-lighting geological structures of Grade III to V materials at the upper cut slope.
- Progressive failure have leaded to develop of a continuous shear surface.

D. Cut Slope Failure at Kuala Lumpur

Site Observations

Closed Drain at Toe of Slope



Damaged Berm Drain

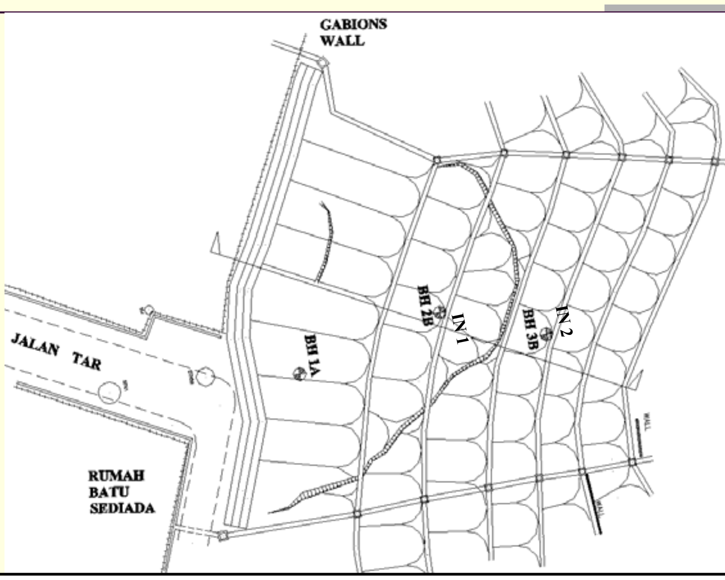
Site Background

- The cut slope with 6 berms was formed in 90s
- Slope gradient varies from 1V:1.72H (lowest berm) to 1V:1H (highest berm)
- RL75m to RL110m.
- Geology: Granite formation.
- Slope movement was detected in Nov 2002 and obvious tension cracks were found at the lowest three berms.

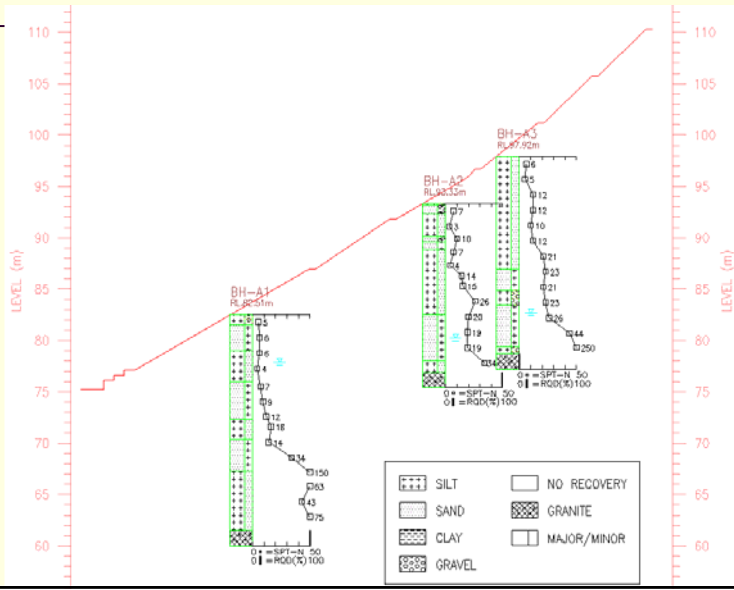
SI & Instrumentation

- SI and instrumentation for failure investigations:
- 3 boreholes
- 22 Mackintosh Probes
- 2 inclinometers
- 3 observation wells

SI & Instrumentation Layout Plan



Slope Profile



Laboratory Test Results

- 8 C.I.U. tests
- 2 Multiple Reversal Direct Shear Box Tests
- Interpreted Moderate conservative soil parameters:

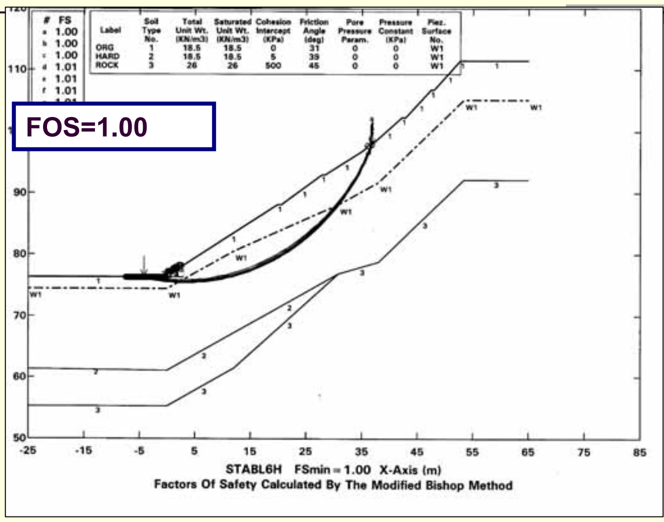
  $c' = 2\text{kPa}$, $\phi' = 31^{o}$

Instrumentation Results

- Max lateral movement (IN. 1)

  ~ 8mm with the depth of shear plane of about 7m tallies with stability analyses.

Slope Stability Analyses

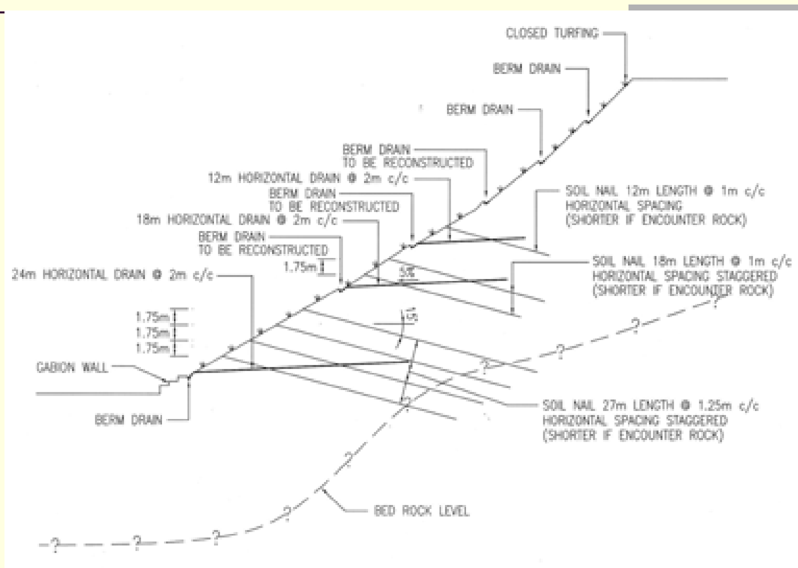


Limit Equilibrium Method

Proposed Remedial Works

- Installation of Soil Nails (12m,18m and 27m).
- Installation of horizontal drains.
- Repairing and re-construction of berm drains.

Proposed Remedial Works



Completed Soil Nailed Slope

Findings

Possible Causes of Failure

- The gradient of the cut slope is steep and is not stable in long term
- Slope strengthening works with installation of soil nails and subsoil drainage system have proven an effective solution to stabilise the distressed slope.

E. Fill Slope Failure at Salak Tinggi

Site Background

- Fill slope over a natural valley to form platform.
- Three berms slope : 20m height.
- Another three slopes on top of platform.
- Geology: Kenny Hill formation with interbedded sandstone and siltstone.
- Slope collapsed after heavy downpour.

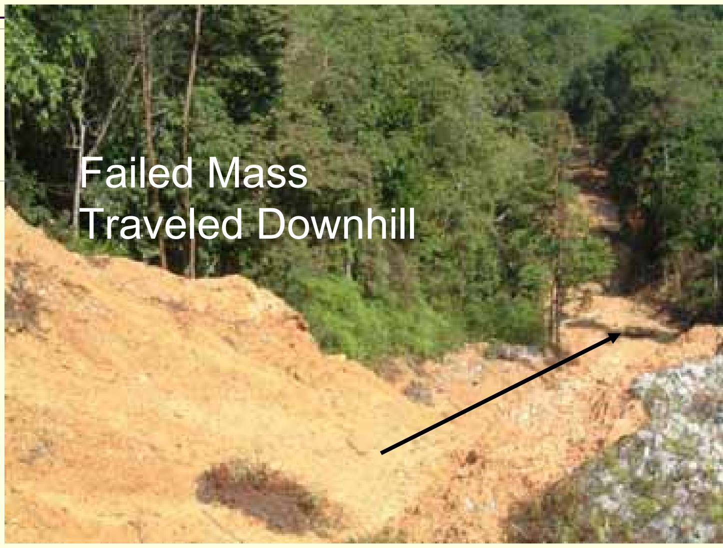
Site Observations

platform and travele
valley.

- Failed mass travele
downhill along valle

Site Observations

g



SI and Laboratory Tests

- 3 boreholes were sunk.
- Sandy material – weathering from sandstone.
- CIU tests.
- Interpreted shear strength: $c'=2kPa$, $\phi'=32^o$.

Probable Causes of Failure

- Valley terrain.
- Steep fill slope gradient – steepest gradient of 1V:1H.
- Marginal FOS when groundwater level rises near to ground surface.
- Poor drainage system lead to saturation and erosion.

Remedial Works

- Fill embankment over valley.
- Fill embankment comprises of :
  rock toe and seven berm slope (1V:2H).
- Provision of extensive subsoil drainage:
  French drain and drainage blanket.
- Upgrading and construction of new drainage system.

After Completion of Construction Works

F. Soil Nailed Slope Failure at Pahang

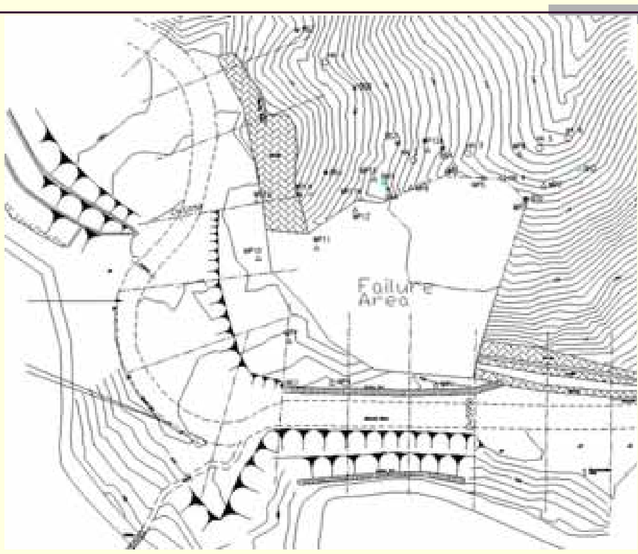
Site Observations

Soil nails hanging on failed slope

Site Background

- Geology: Granite and metamorphic rocks
- Slope with varying degrees of weathering: rock to soil.
- 7.5 berms of 4V:1H Soil Nailed Slope
- Maximum height = 45m
- 12m soil nail length at 1.5m c/c

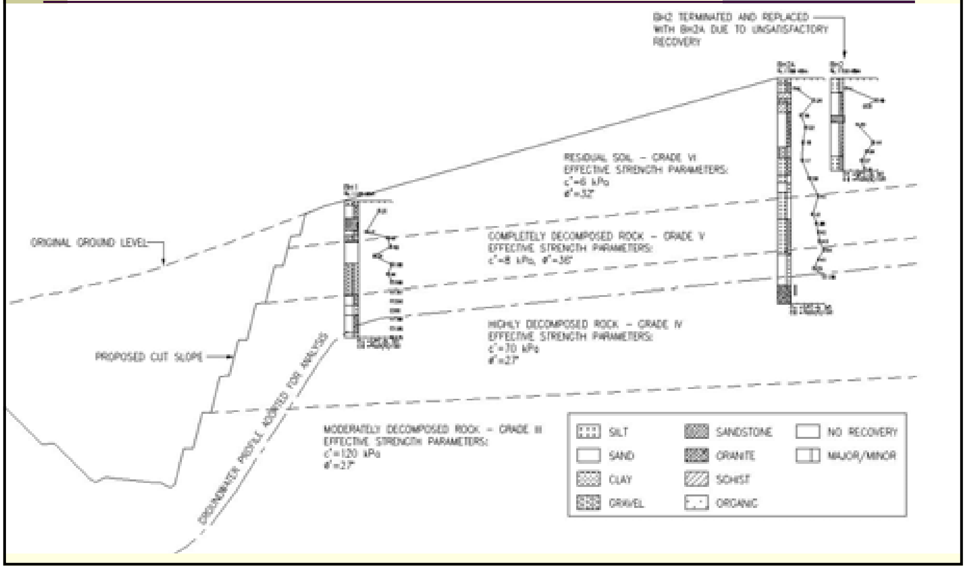
Site Plan showing Failure Area



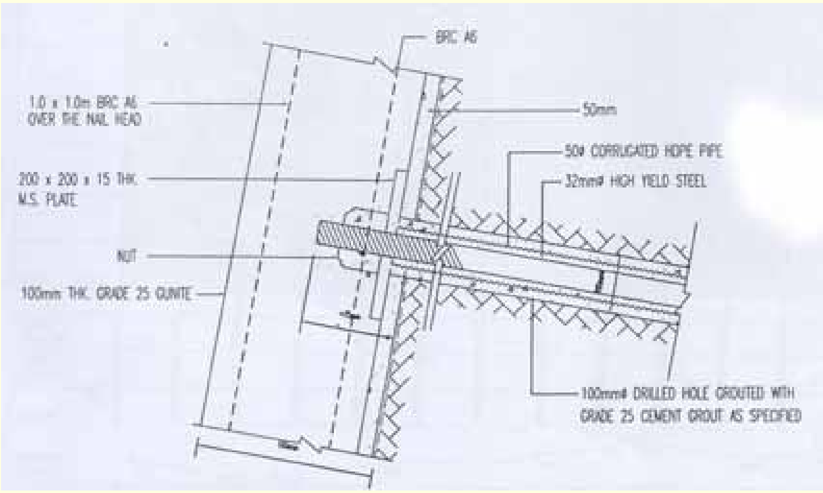
SI & Laboratory Works

- 2 boreholes at the slope.
- 3 Consolidated Isotropically Undrained Triaxial (C.I.U.) tests.
- 6 Direct Shear Box Tests.
- Hoek-Brown failure criteria for weathered rock mass.

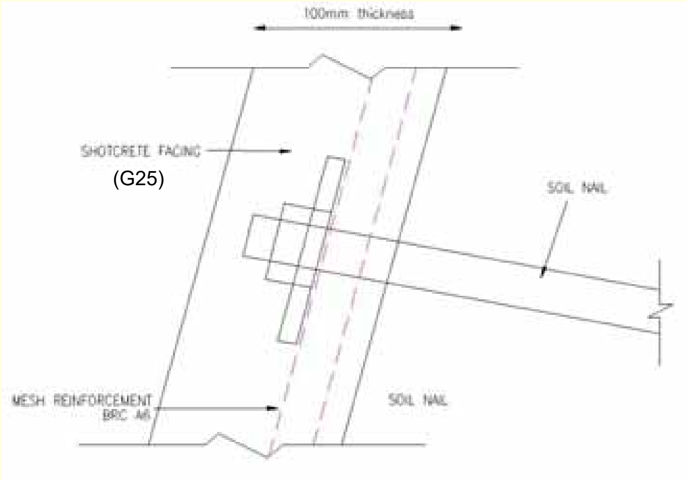
Interpreted Subsoil Profile



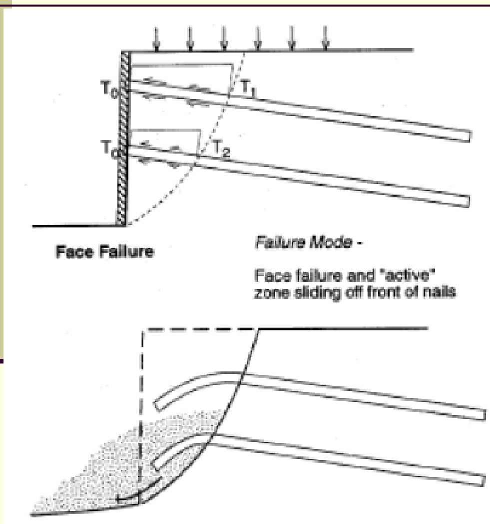
Shotcrete Facing as per Construction Drawing



Shotcrete Facing as Constructed at Site

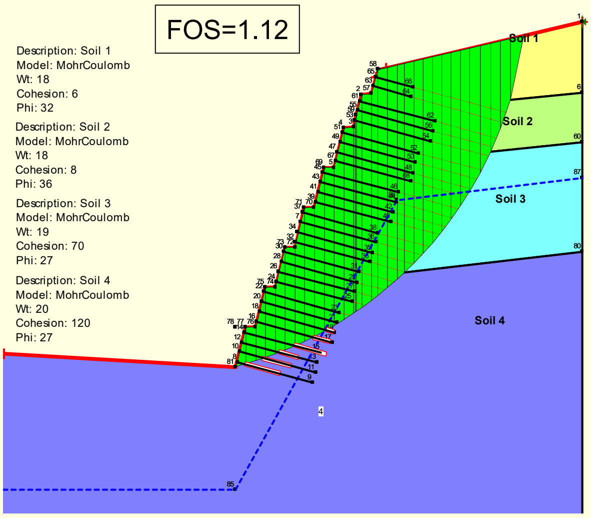


Facing Failure Mode for Soil Nailed Wall



Note: Figure extracted from "The Manual for Design and Construction of Soil Nail Walls" FHWA

Slope Stability Analysis



Findings

Possible causes of failure:

- Inadequate design of shotcrete facing of soil nailed slope.
- FOS against overall failure is inadequate and marginally stable.
- Rainfall/groundwater is not a triggering cause to failure.

Recommendation & Conclusion

- SI and geological mapping for slope are essential for slope design especially for soil nailed slopes.
- Design shall be reviewed during construction to verify the design assumptions especially subsoil profile.
- Progressive failure mechanism is prominent in high cut slope.

Recommendation & Conclusion

- 4 modes of failure: nail tendon failure, nail pull-out failure, facing failure and overall failures shall be checked. Facing failure check is usually neglected.
- Facing design is critical especially when soil nailed slope is steep and high.
- More research is required on establishing engineering parameters of weathered rock mass of different formation in Malaysia.

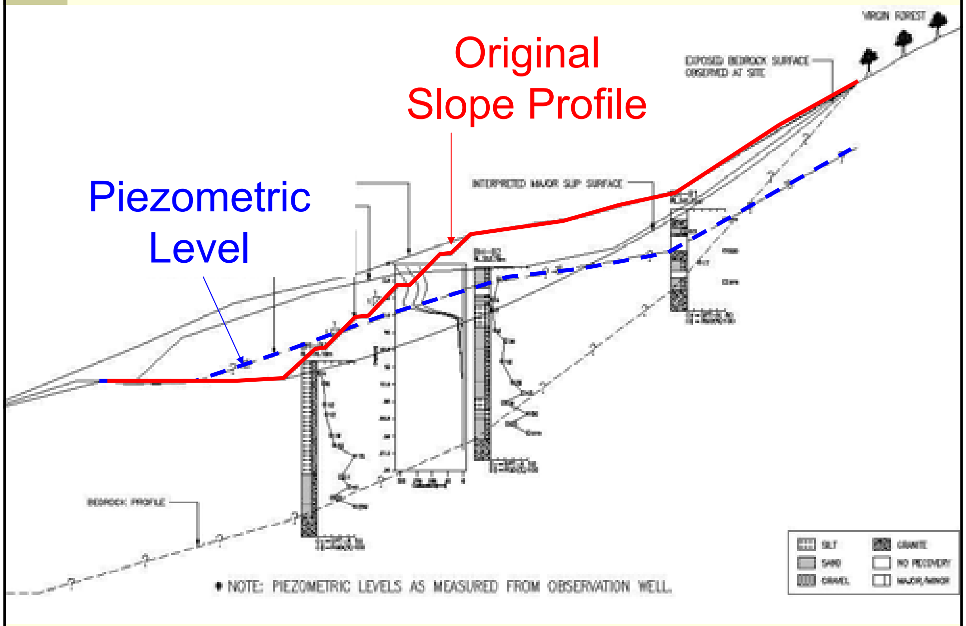
G. Cut Slope Failure at Kedah

Site Background

- High ground RL300m – RL350m.
- Bedrock : Intact granite bedrock with prismatic feldspar phenocrysts.
- 5 to 6 berms : 27m height.
- Slope gradient 1V:1H.
- Two failure incidents:

  a. Localised stretch (50m).

  b. Major slope failure (250m) after 1 month following heavy rainfall.



Laboratory Test Results

- Sandy material within failed mass.
- CIU test :

  a. c_p'=2kPa, ϕ_p'=30^o

  b. $c'_{\varepsilon(max)}$=1.9kPa, $\phi'_{\varepsilon(max)}$ =28^o
- Back Analysis :

  a. c_m'=0kPa, ϕ_m'=30^o

Findings

Possible causes of failure:

- FOS against overall failure indicates the slope is at the verge of failure for the water level measured during investigation.
- Rainfall leading to rise of groundwater is the triggering cause to failure.

Conclusions

- Main Contributory Factors for Slope Failure (Static) :
  - Inherent weak strength & sensitive materials
  - Adverse geological & hydro-geological features
  - Morphological features
  - Steep slope geometry
  - Gravity force
  - Weathering
  - Inadequate design & lack of maintenance
- Triggering Factors (Dynamic) :
  - Rainfall/leaking utilities/rapid drawdown (soil saturation/ rise of GWT)
  - Human disturbance (excavation/surcharge/vegetation removal/vibration)
  - Earthquake/volcanic eruption/thunder
  - Erosion

Thank You

G&P Geotechnics Sdn Bhd

SESSION 5 : Case Studies of Foundation Distresses

By Ir. Liew Shaw Shong

Case Study 1 : Reduced Empty Pre-bored Jack-in Pile Capacity in Meta-Sedimentary Formation

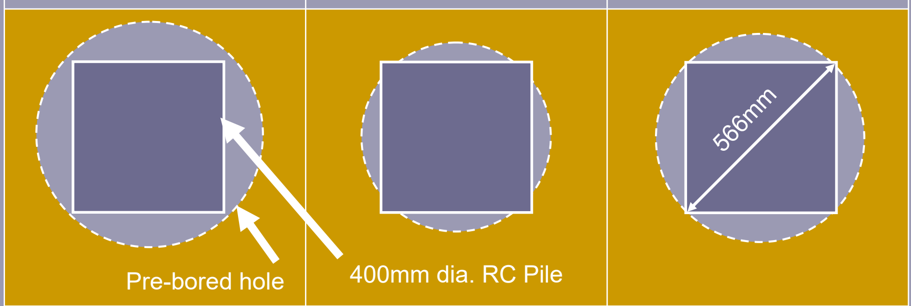
- Overview of pile installation & Performance
- Subsurface Information
- Contractually Scheduled MLT Results
- Additional MLT Results
- Investigation Findings
- Conclusions & Recommendations

Overview Foundation System

- 400mm RC square pile
- Pre-boring was deployed to
  - Overcome intermittent hard layer
  - Avoid shallow pile penetration
- Jack-in pile installed inside pre-bored hole

Pre-bored Hole Diameter

600mm diameter	500mm diameter	550mm diameter

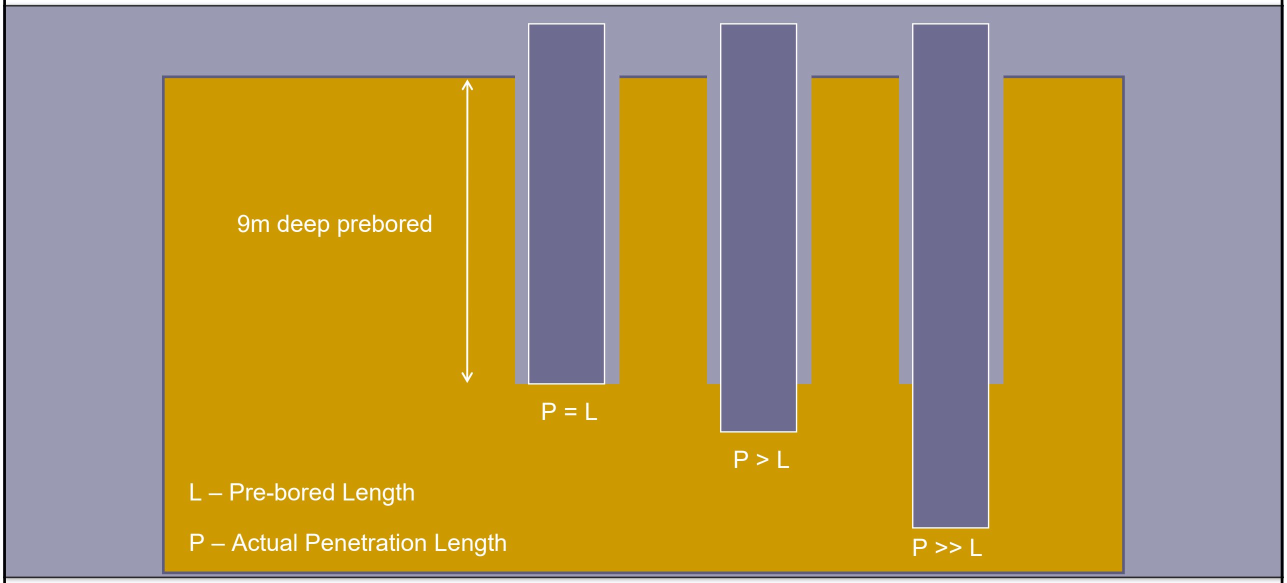


Too large pre-bored hole	Too small pre-bored hole	Compromised pre-bored hole (Adopted)

Void in Pre-bored Hole Annulus

Collapsed Debris in Pre-bored Hole Annulus

Actual Scenario of Installed Piles



MLT Results

Maintained Load Test (MLT)	Pre-bored Diameter (mm)	Pile Penetration below Piling Platform (m)	Max. Jack-in Load at Termination (kN)	Achieved Maximum Test Load (kN)	Pile Top Settlement	
					At Working Load (mm)	At Max. Test Load (mm)
MLT 1	600	9.40	2160	2220 (1.71xWL)	14.0	46.00
MLT 2	500	9.30	2600	2220 (1.71xWL)	23.50	42.00
MLT 3	550	12.50	2860	2600 (2.00xWL)	5.80	21.80
MLT 4	550	9.50	2860	1406 (1.50xWL)	16.50	24.50
MLT 5	550	13.50	2860	1950 (1.50xWL)	8.50	13.00

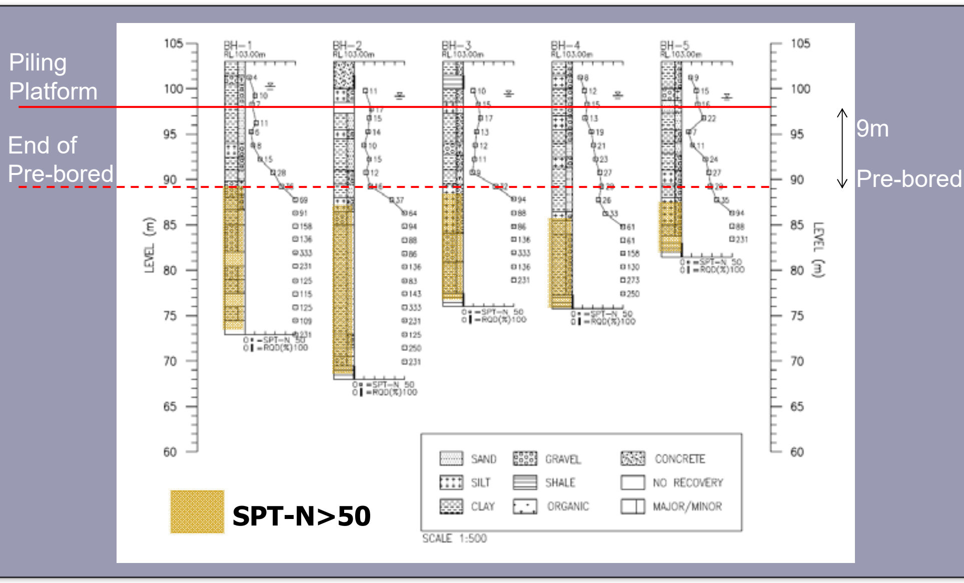
Jack-in Pile Termination Criteria

- All piles were jacked to 2.2 times pile working load
- Settlement < 5mm during 30 seconds holding period for 2 consecutive times

BUT

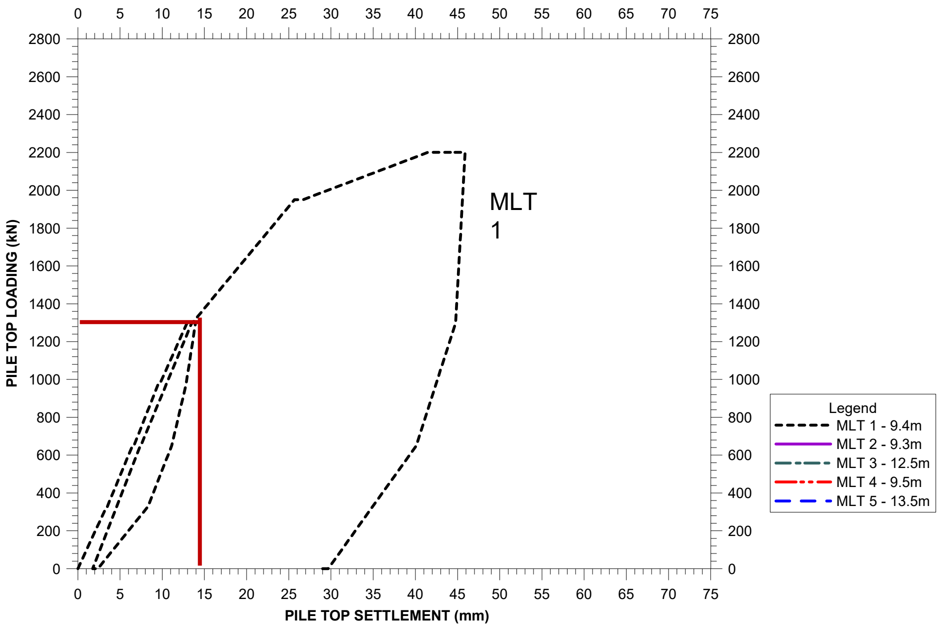
- **Max Test Load < Jack-in Load**
- **Non-conforming Piles Settlement Criteria**

Boreholes Information

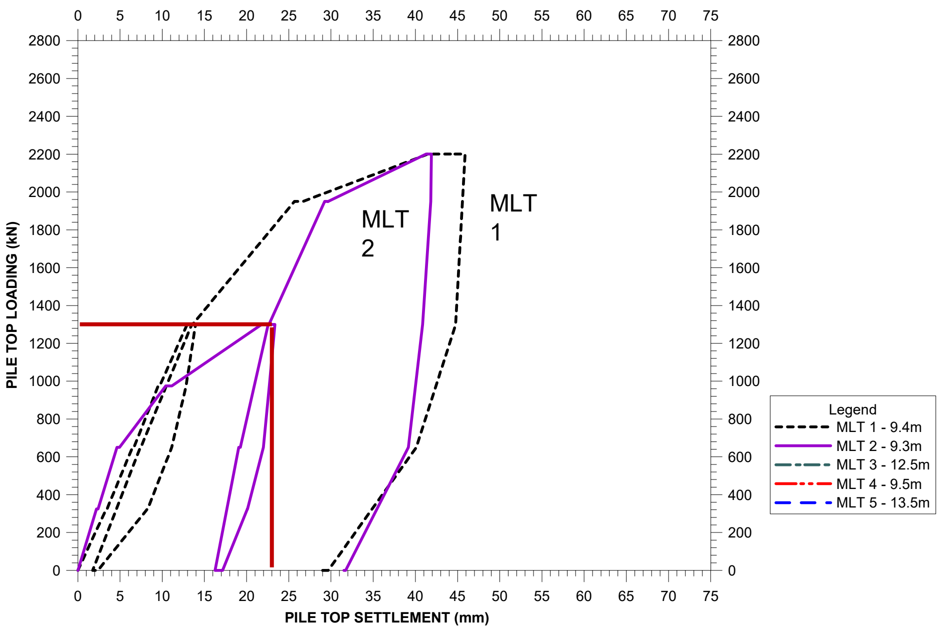


Photos of Exposed Subsoils

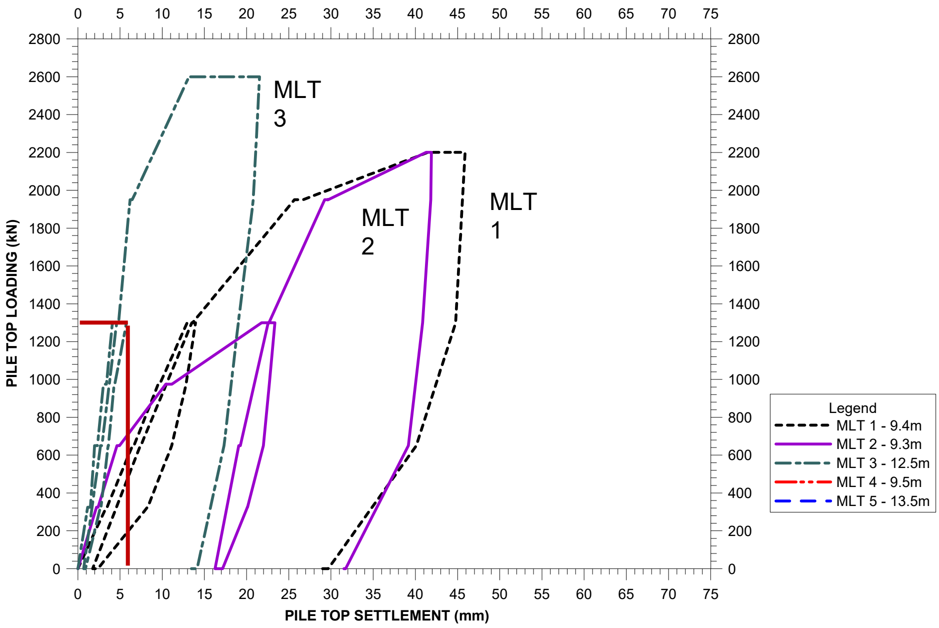
Contractually Scheduled MLT Results

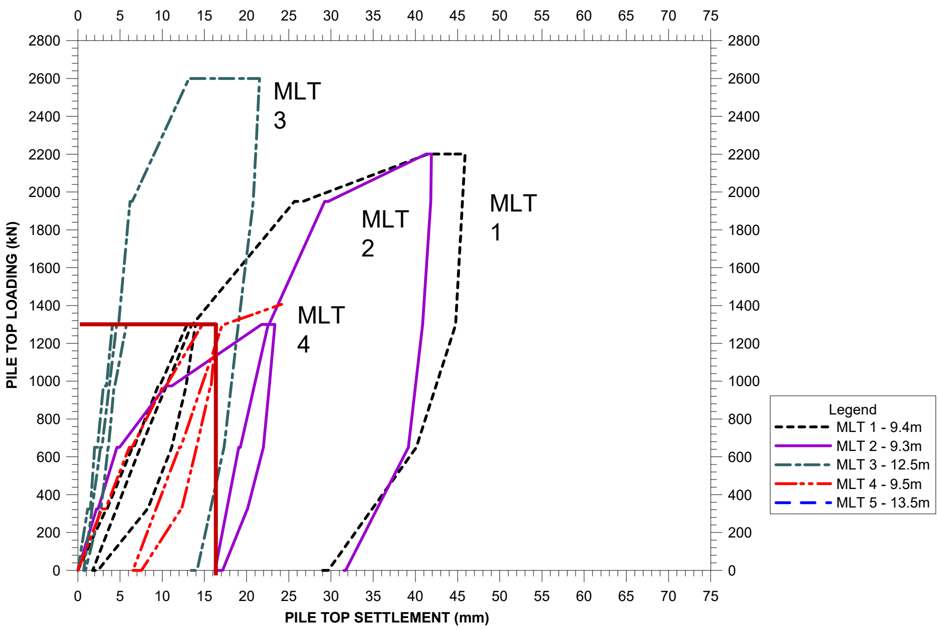


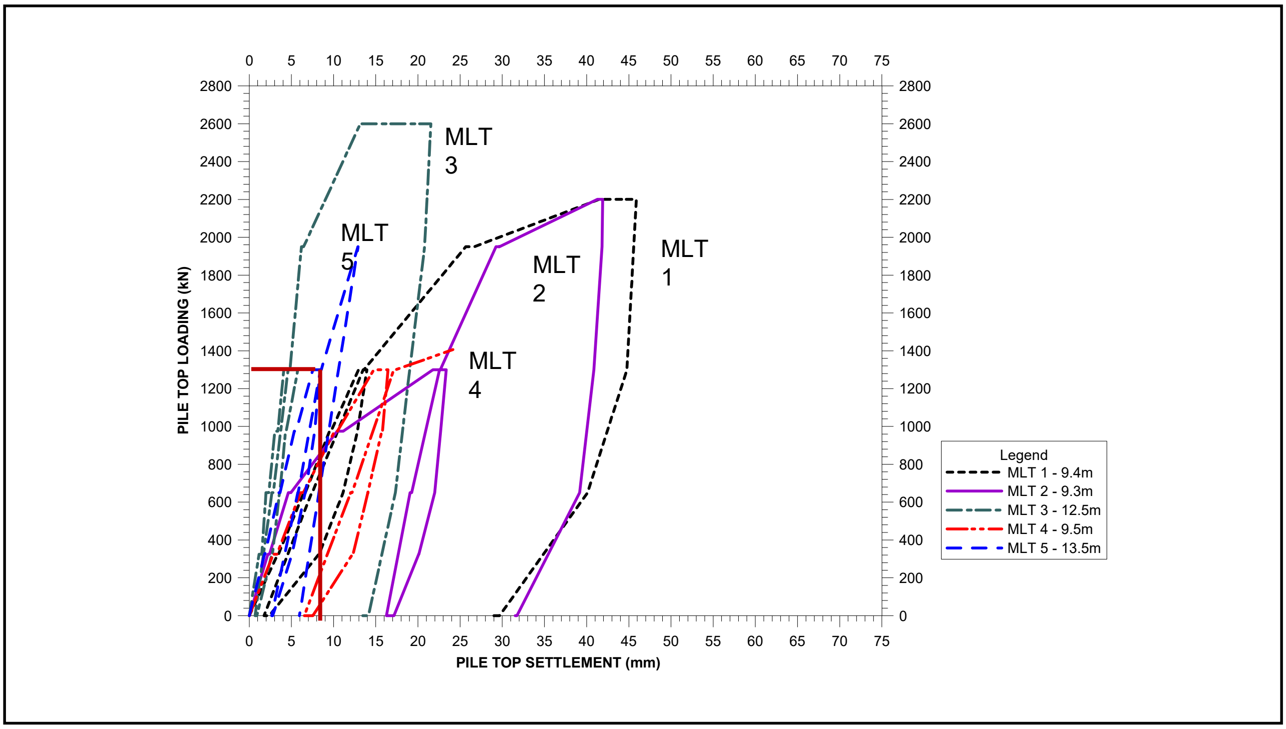
PILE TOP LOADING (kN)
PILE TOP SETTLEMENT (mm)
MLT 1
Legend
MLT 1 - 9.4m
MLT 2 - 9.3m
MLT 3 - 12.5m
MLT 4 - 9.5m
MLT 5 - 13.5m



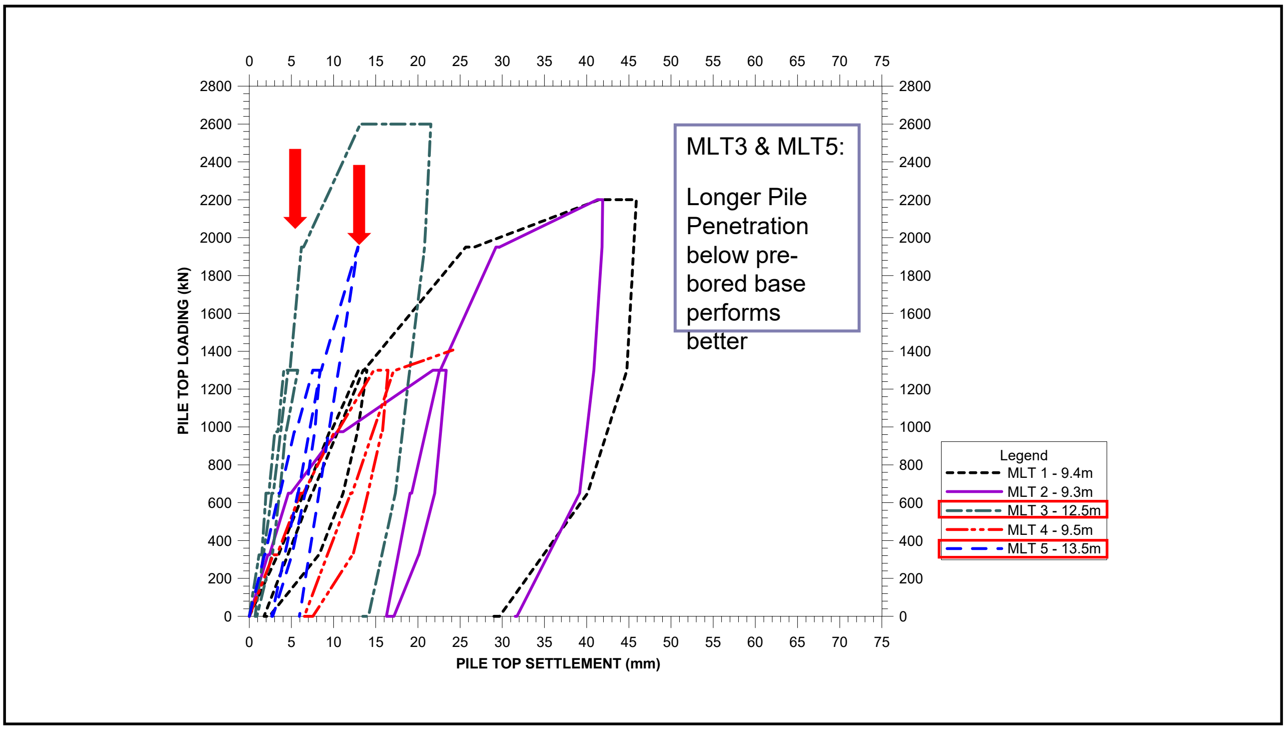
PILE TOP LOADING (kN)
PILE TOP SETTLEMENT (mm)
MLT 2
MLT 1
Legend
MLT 1 - 9.4m
MLT 2 - 9.3m
MLT 3 - 12.5m
MLT 4 - 9.5m
MLT 5 - 13.5m


MLT 3
MLT 2
MLT 1
PILE TOP LOADING (kN)
PILE TOP SETTLEMENT (mm)
Legend
MLT 1 - 9.4m
MLT 2 - 9.3m
MLT 3 - 12.5m
MLT 4 - 9.5m
MLT 5 - 13.5m


MLT 3
MLT 2
MLT 1
MLT 4
PILE TOP LOADING (kN)
PILE TOP SETTLEMENT (mm)
Legend
MLT 1 - 9.4m
MLT 2 - 9.3m
MLT 3 - 12.5m
MLT 4 - 9.5m
MLT 5 - 13.5m



MLT 3
MLT 5
MLT 2
MLT 1
MLT 4
PILE TOP LOADING (kN)
PILE TOP SETTLEMENT (mm)
Legend
MLT 1 - 9.4m
MLT 2 - 9.3m
MLT 3 - 12.5m
MLT 4 - 9.5m
MLT 5 - 13.5m



MLT3 & MLT5:
Longer Pile Penetration below pre-bored base performs better
PILE TOP LOADING (kN)
PILE TOP SETTLEMENT (mm)
Legend
MLT 1 - 9.4m
MLT 2 - 9.3m
MLT 3 - 12.5m
MLT 4 - 9.5m
MLT 5 - 13.5m

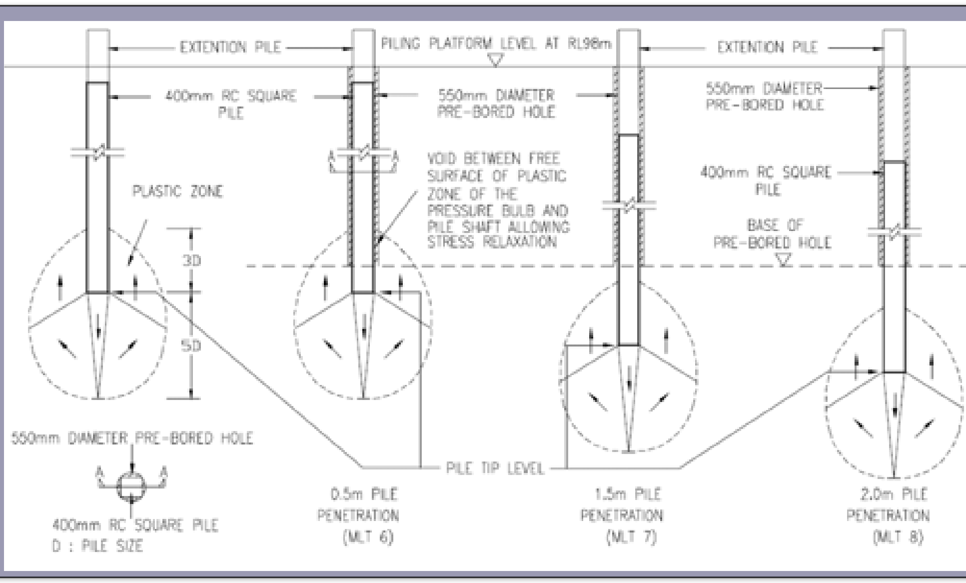
Additional MLT Results

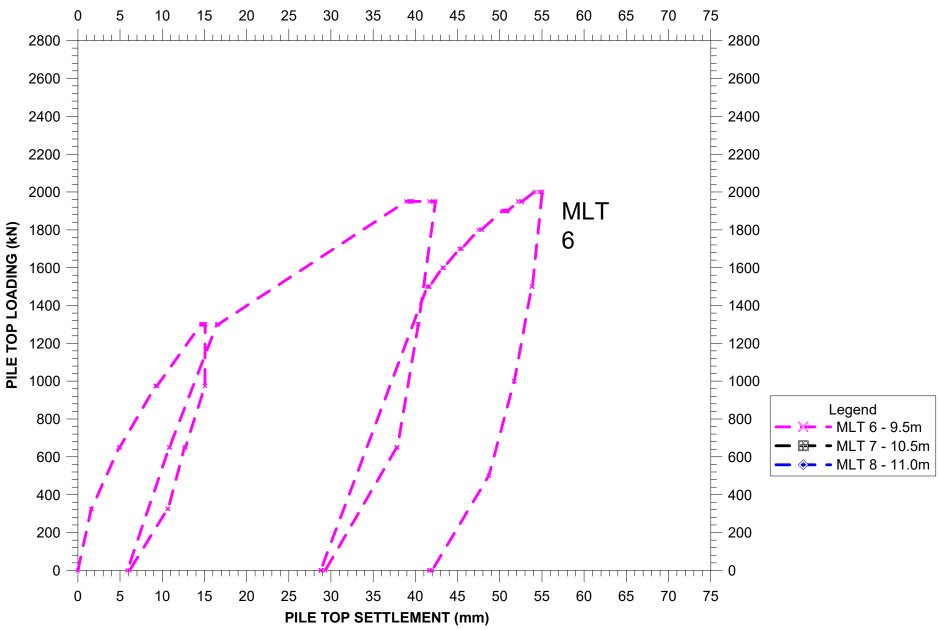
Additional MLT

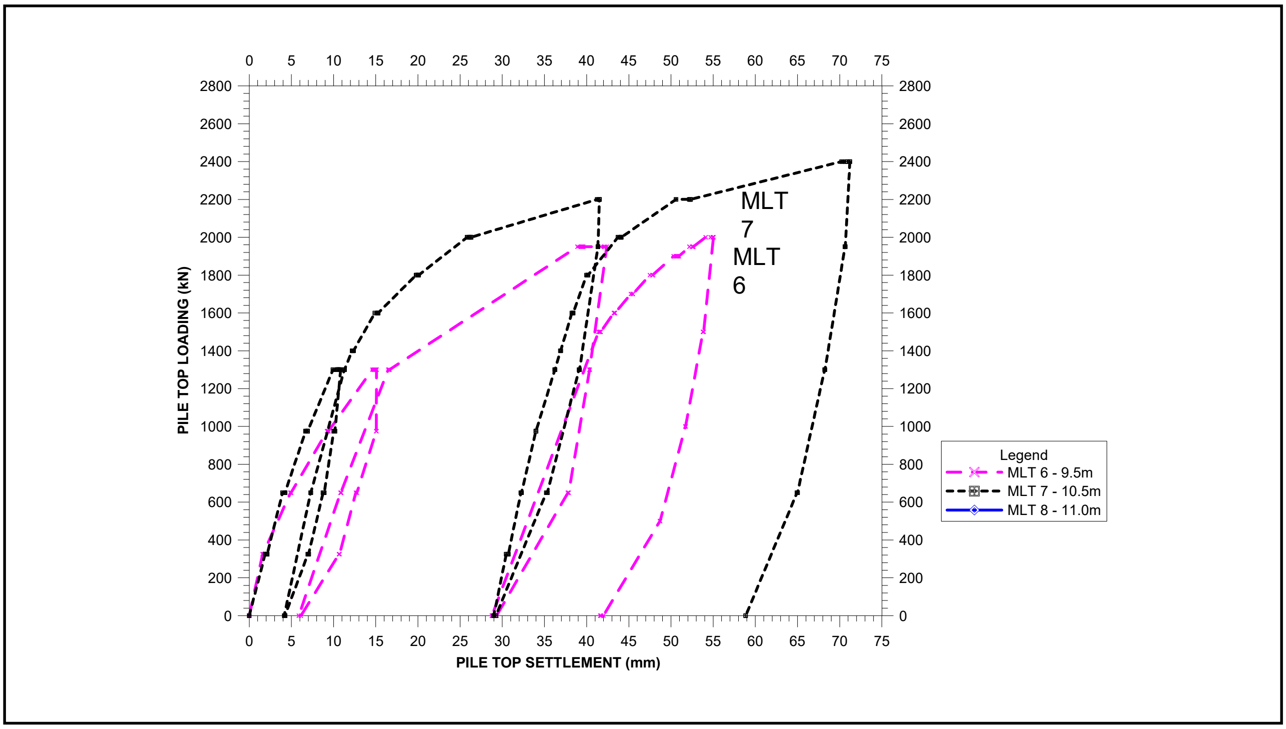
- 3 nos additional MLT at various penetration below pre-bored base:

- MLT6 – 0.5m below pre-bored base
- MLT7 – 1.5m below pre-bored base
- MLT8 – 2.0m below pre-bored base

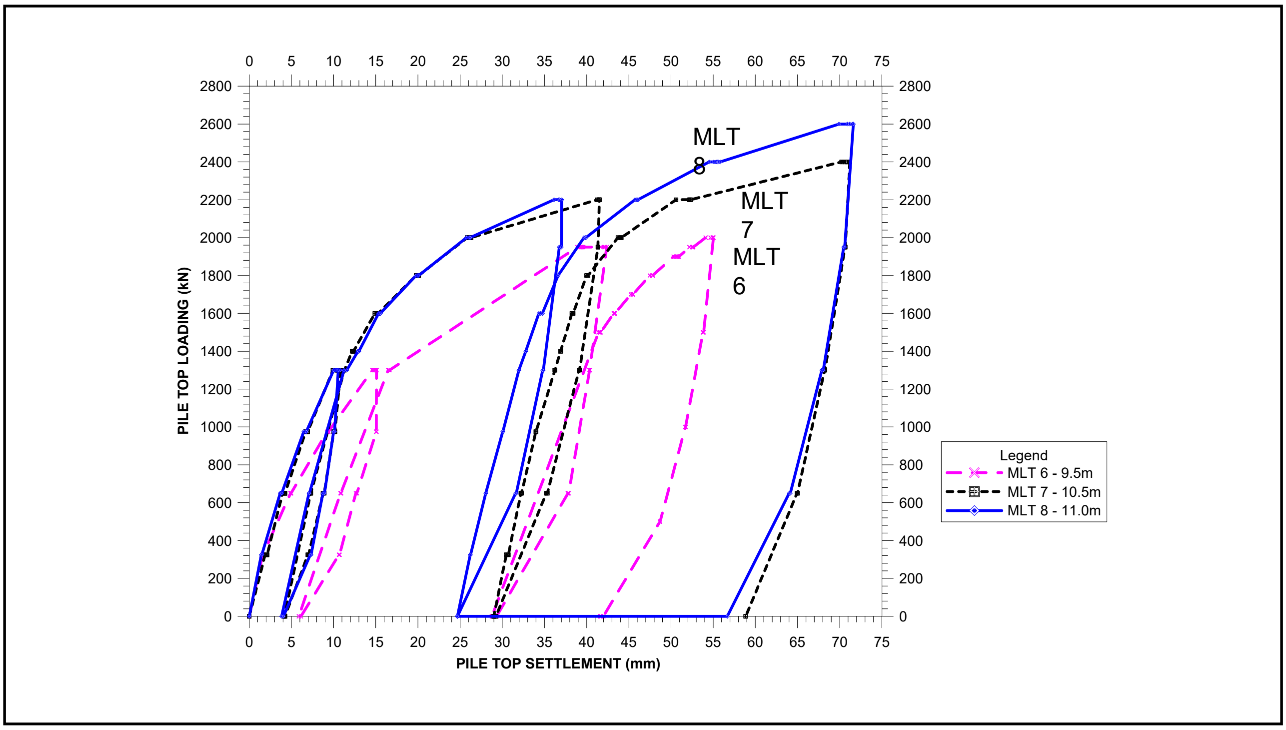
Additional MLT







PILE TOP LOADING (kN)
PILE TOP SETTLEMENT (mm)
MLT 7
MLT 6
Legend
MLT 6 - 9.5m
MLT 7 - 10.5m
MLT 8 - 11.0m



PILE TOP LOADING (kN)
PILE TOP SETTLEMENT (mm)
MLT 8
MLT 7
MLT 6
Legend
MLT 6 - 9.5m
MLT 7 - 10.5m
MLT 8 - 11.0m

MLT	Pre-bored Diameter (mm)	Pile Penetration below Piling Platform (m)	Max. Jack-in Load at Termination (kN)	Achieved Maximum Test Load (kN)	Pile Top Settlement	
					At Working Load (mm)	At Max. Test Load (mm)
MLT 1	600	9.40	2160	2220 (1.71xWL)	14.0	46.00
MLT 2	500	9.30	2600	2220 (1.71xWL)	23.50	42.00
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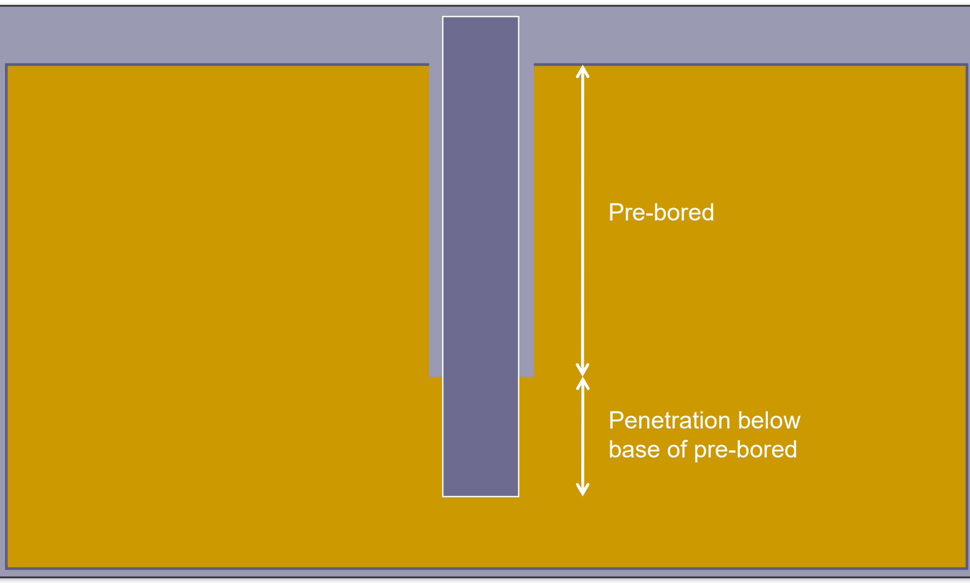
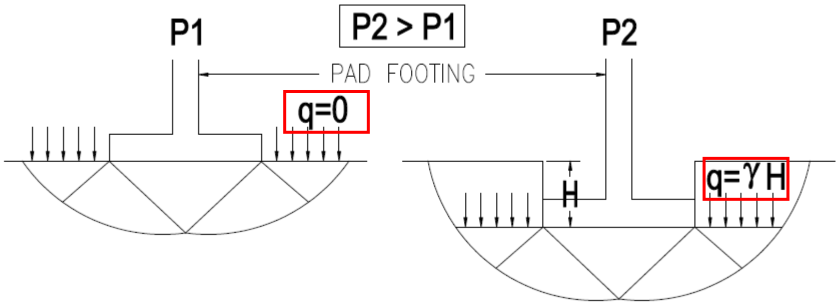
MLT 4	550	9.50	2860	1406 (1.50xWL)	16.50	24.50
MLT 5	550	13.50	2860	1950 (1.50xWL)	8.50	13.00
MLT 6	550	9.50	2860	1950 (1.50xWL)	15.08	42.38
MLT 7	550	10.50	2860	2400 (1.85xWL)	11.29	41.93
MLT 8	550	11.00	2860	2600 (2.00xWL)	10.30	50.35

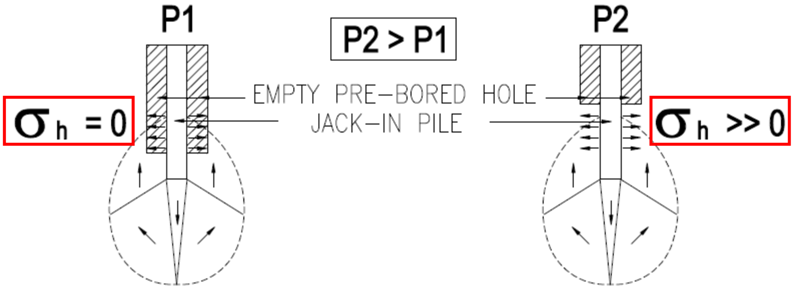
Investigation Findings



Analogy of Footing



Bearing Improvement with Toe Confinement



Conclusions & Recommendations

- Pile performance improved with longer pile penetration below pre-bored base
- Existence of pile toe softening due to relaxation of pile tip founding material
- Sufficient pile penetration below pre-bored base is important
- Recommend to seal the pre-bored hole with grout

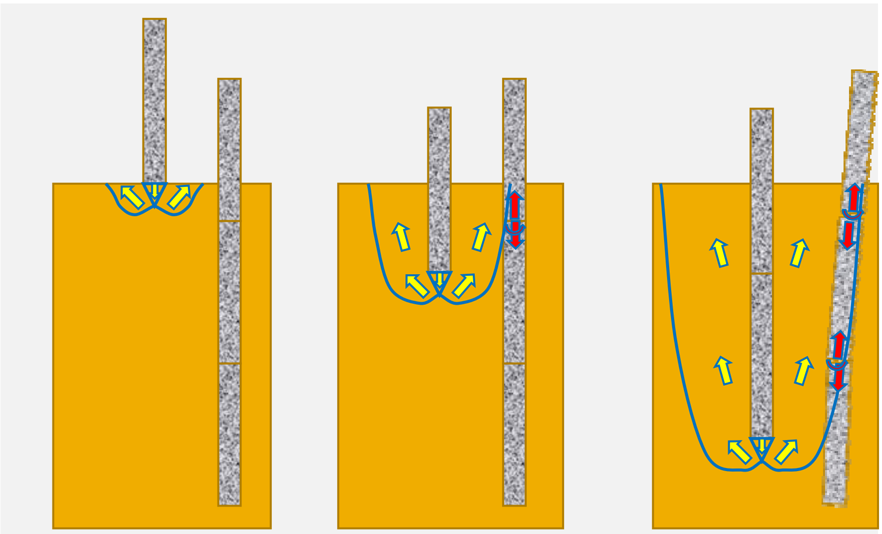
Case Study 2: Pile Heave & Lateral Soil Displacement

- Rapid pile installation in incompressible soft soil induces
  - Vertical heave in shallow depth (relatively less confinement from weight of overburden soils)
  - Lateral displacement in deeper depth (with soil confinement)
- Consequences :
  - Up-heaving soil movement causes tensile stress on pile & toe lift up during driving & downdrag after pore presure dissipation
  - Lateral soil displacement causes flexural stress on pile & pile deviation
  - Excessive combined tensile and flexural stresses lead to pile joint dislodgement
  - Excessive foundation settlement in post construction (pile toe uplifting & downdrag settlement)

Pile Joint Dislodgement

- Pile joints could be dislodged due to excessive flexural and tensile stresses induced by ground heave and radial soil displacement
- Detectable using High Strain Dynamic Pile Test (HSDPT)

Mechanism of Pile Heave & Soil Displacement



Case Study - HSDPT

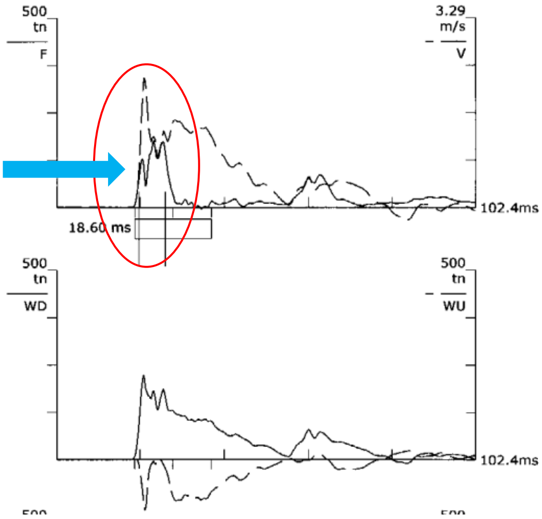
- Monitoring of pile top settlement during the HSDPT re-strike tests is summarised as below:

Cumulative Pile Top Settlement (mm)	Pile C	Pile A	Pile B	Pile D	Pile E
Upon resting 7-ton hammer on pile top	80	98	125	103	92
At the end of Restriking Test	275	399	497	186	182

Case Study - HSDPT

- Pile B
- Initial Blow

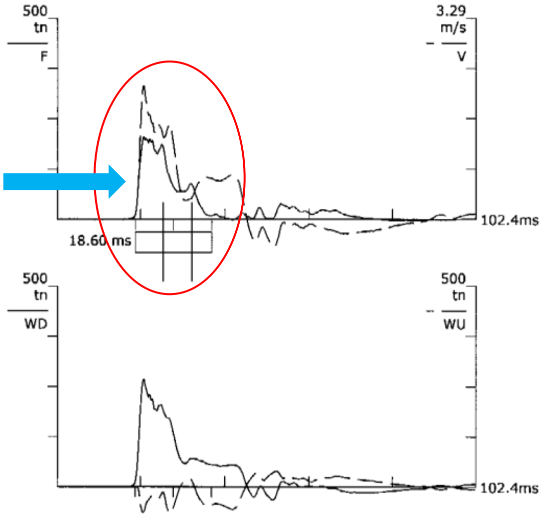
One Pile Length (12m) was DETECTED with Major Discontinuity at ‘toe’ (reflection)



Case Study - HSDPT

- Pile B
- Blow No. 4

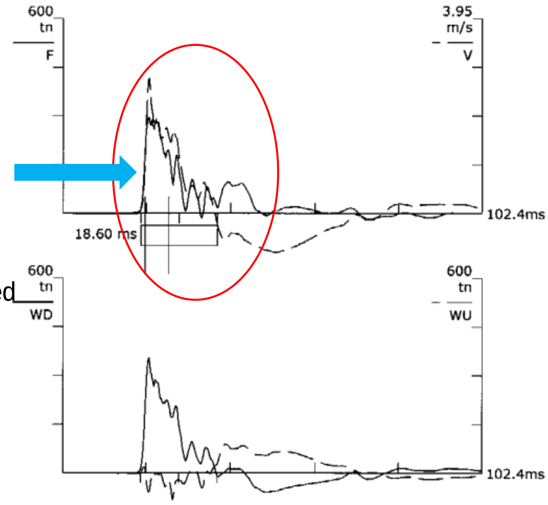
First Joint Discontinuity closed up after few blows; Two Pile Lengths was revealed with another Major Discontinuity at new 'toe' (reflection)



Case Study - HSDPT

- Pile B
- Blow No. 17

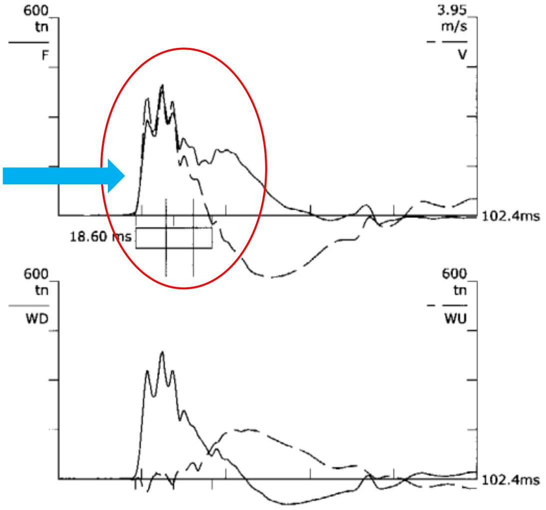
Second Major Joint Discontinuity also disappeared;
Total of Three Pile Lengths was observed



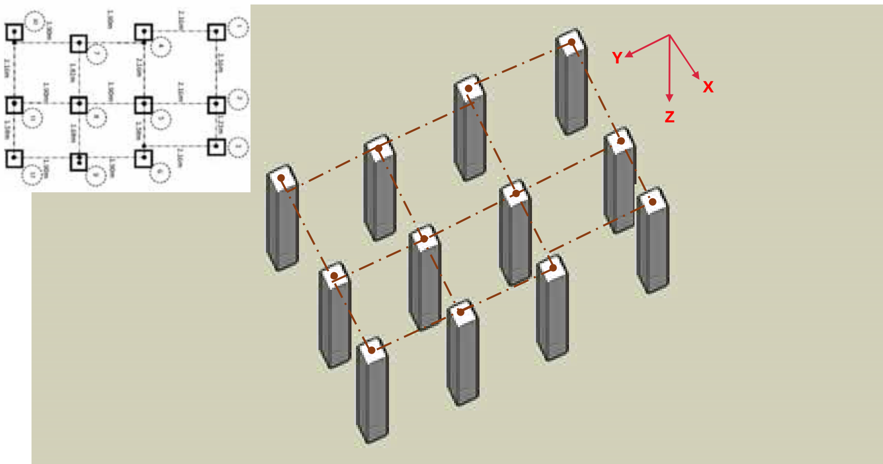
Case Study - HSDPT

- Pile B
- End of Blow

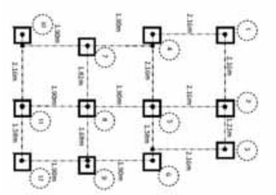
Minor velocity reflections were observable at first and second pile joints

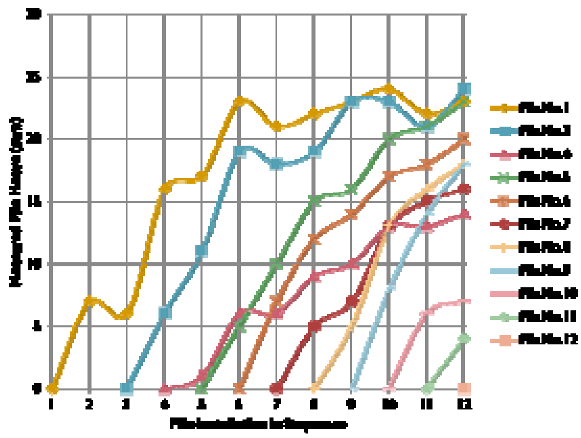


Pile Heave Monitoring Program



Pile Heave Monitoring Result





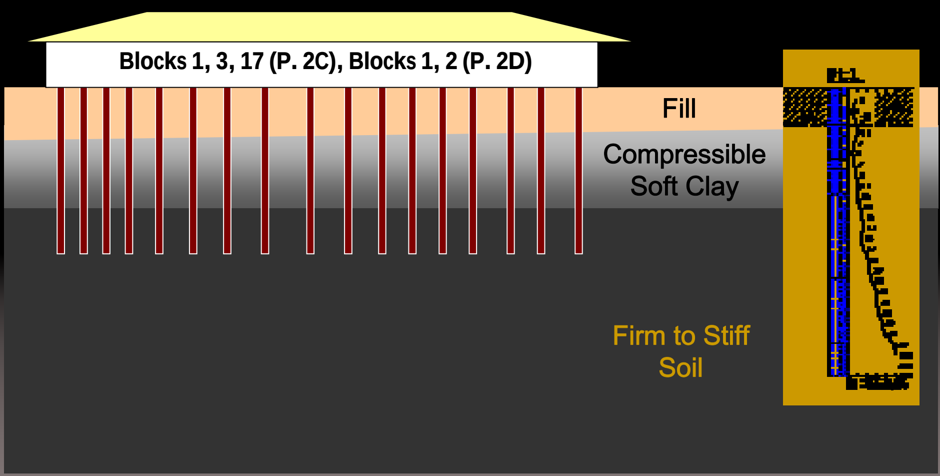
Summary

- Ground heave & radial soil displacement due to rapid installation of displacement pile in soft incompressible soft clay can pose serious integrity problem on pile foundation.
- Solutions :
  - Use larger pile spacing & reduce rate of clustered pile installation for adequate time for dissipation of excess pore pressure
  - Simultaneous pile installation at mirror pile location from centre outwards to minimise net lateral displacement, but this improves nothing on ground heave
  - Stronger pile structural strength & joint to withstand tensile & flexural stresses
  - Staggered pile installation sequence or install piles at alternate locations
  - Restrike all piles with HSDPT to detect pile integrity if ground or soil heave is observed.

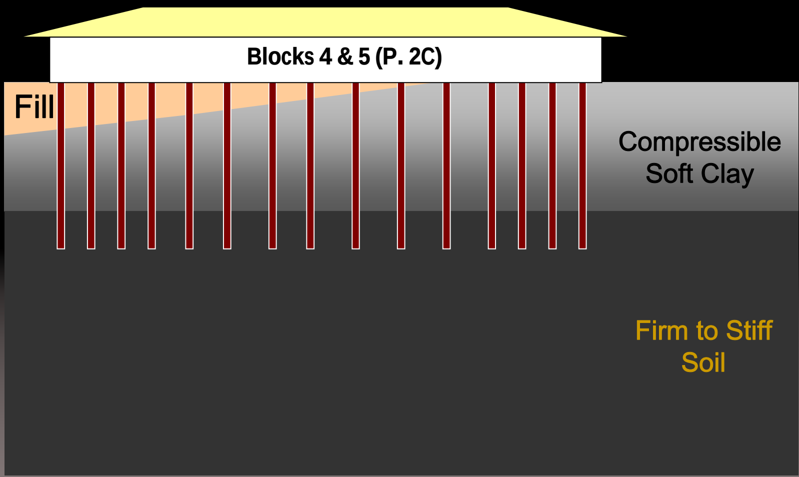
Case Study 3 - Geotechnical Review on Foundation Settlement

- The underlying soils are mainly soft & compressible soils
- Characteristics:
  - Compressible
  - Settling under loading (eg. fill) with time

General Subsoil Profile



General Subsoil Profile



Site Observations

- Cracks on wall – mostly diagonal – due to differential settlement

Site Observations

- Distress due to differential settlement

Probable Causes

1. Collapse settlement of unsaturated fill
   - Occurs when saturation of loose fill (eg. during raining)
   - S.I. results confirmed existence of fill at most areas

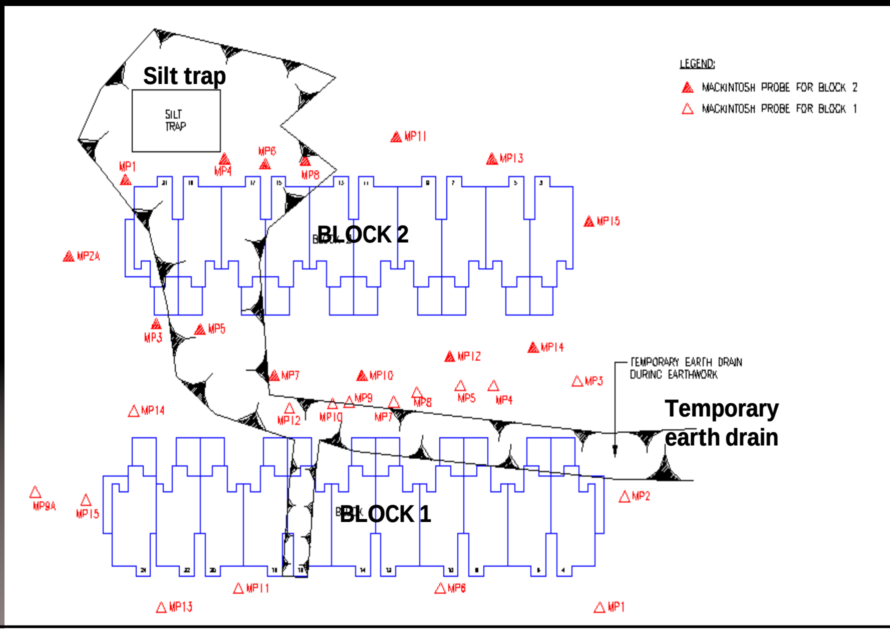
Probable Causes

2. Long term settlement of compressible soft soil
   - Occurs when filling over soft soil
   - S.I. results confirmed existence of soft soil

Probable Causes

3. Left-over soft deposits within silt trap & temporary drains
   - Results in localised soft spots – more compressible
   - Additional S.I. results confirmed existence of soft soil

Phase 2D1



Probable Causes

Subsoil settlement

↓

Additional drag load on pile

↓

Pile settlement

↓

Differential settlement due to different load, support, fill & soft soil thickness

↓

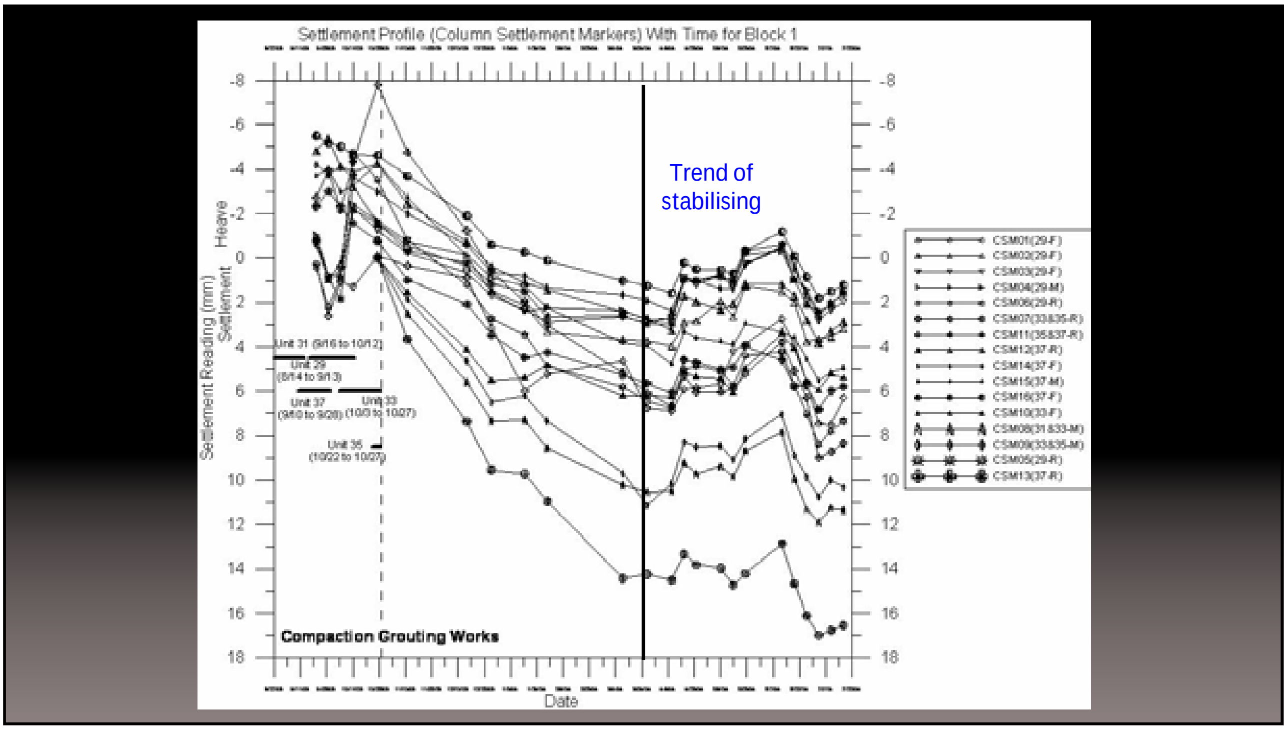
Distress on Structures

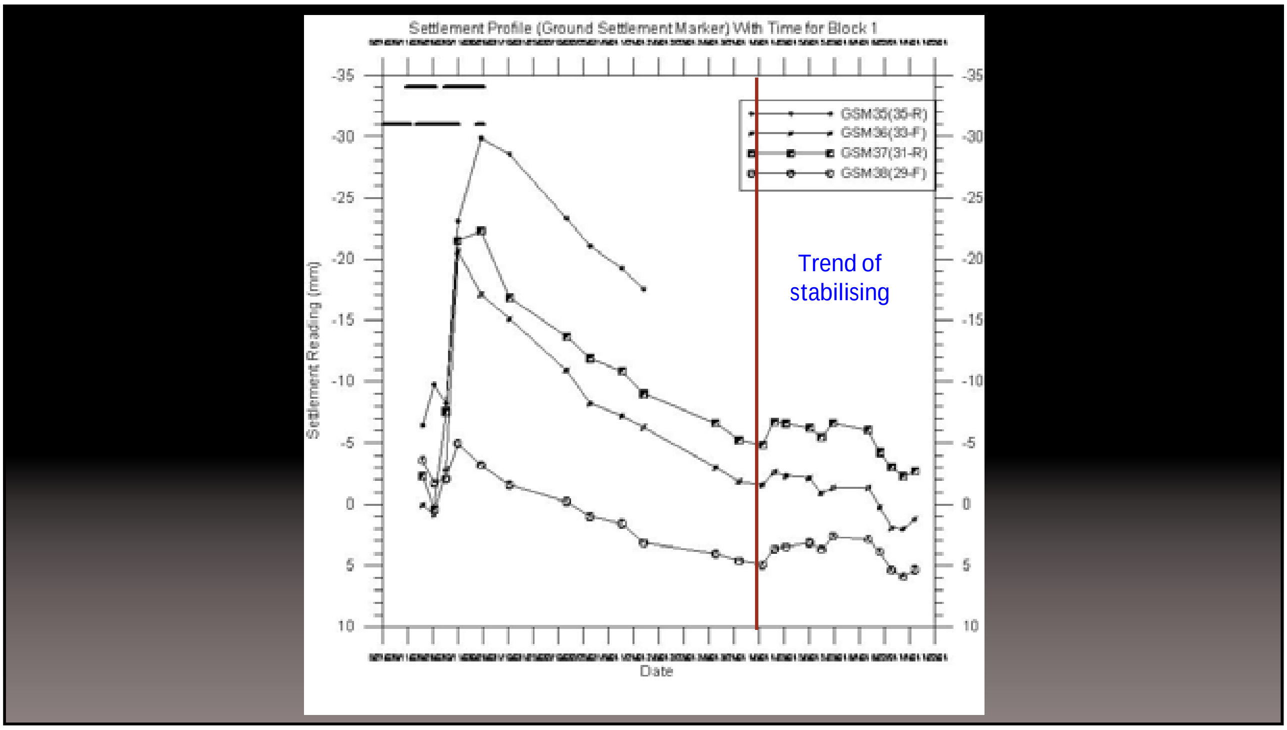
Remedial Works by Specialist Contractor

- Grouting has been carried out by specialist contractor at Block 1 of Phase 2C2
- Purpose: Fill in voids and densify compressive soft soil to eliminate ground settlement

Remedial Works by Specialist Contractor

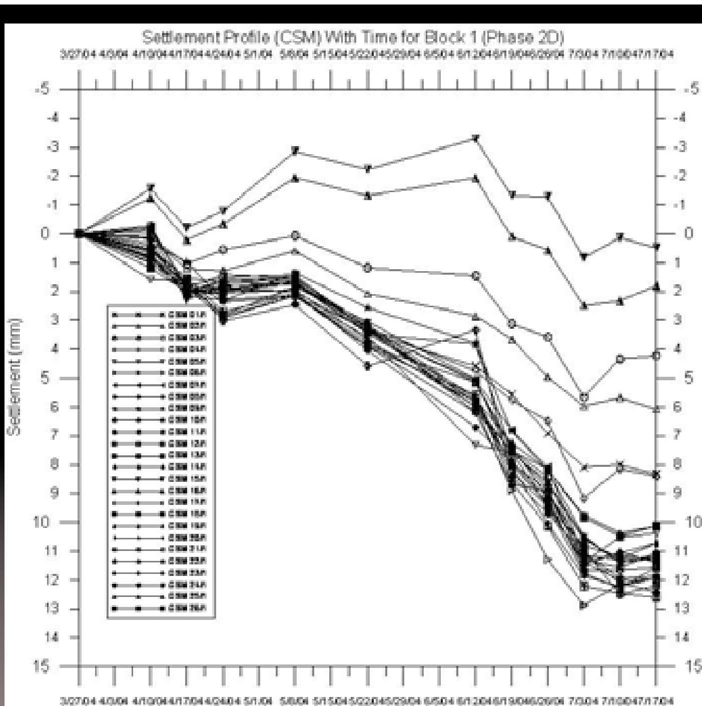
- Settlement is stabilising after grouting treatment

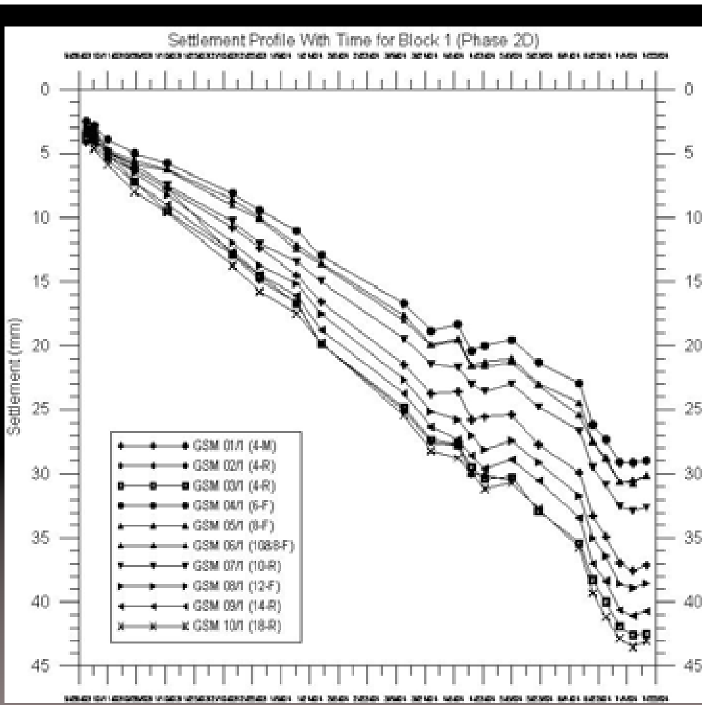

Settlement Profile (Column Settlement Markers) With Time for Block 1
Trend of stabilising
Compaction Grouting Works
Unit 31 (9/16 to 10/12)
Unit 29 (8/14 to 9/13)
Unit 37 (9/10 to 9/28)
Unit 33 (10/3 to 10/27)
Unit 35 (10/22 to 10/27)
Settlement Reading (mm)
Heave
Settlement
Date
CSM01(29-F)
CSM02(29-F)
CSM03(29-F)
CSM04(29-M)
CSM06(29-R)
CSM07(33&35-R)
CSM11(35&37-R)
CSM12(37-R)
CSM14(37-F)
CSM15(37-M)
CSM16(37-F)
CSM10(33-F)
CSM08(31&33-M)
CSM09(33&35-M)
CSM05(29-R)
CSM13(37-R)


Settlement Profile (Ground Settlement Marker) With Time for Block 1
GSM35(35-R)
GSM36(33-F)
GSM37(31-R)
GSM38(29-F)
Trend of stabilising
Settlement Reading (mm)
Date

Monitoring Results

- Crack monitoring (3 months)
- Settlement monitoring (10 months)
  - Ground settlement
  - Column settlement





Settlement Profile With Time for Block 1 (Phase 2D)
Settlement (mm)
0
5
10
15
20
25
30
35
40
45
GSM 01/1 (4-M)
GSM 02/1 (4-R)
GSM 03/1 (4-R)
GSM 04/1 (6-F)
GSM 05/1 (8-F)
GSM 06/1 (10&8-F)
GSM 07/1 (10-R)
GSM 08/1 (12-F)
GSM 09/1 (14-R)
GSM 10/1 (18-R)

Thank You

SESSION 6 : Case Studies of Wall Failures

Ir. Liew Shaw Shong

TWO CASE STUDIES OF COLLAPSED TEMPORARY EXCAVATION USING CONTIGUOUS BORED PILE WALL

Ir. Liew Shaw Shong

Outline of Presentation

- Common Probable Causes of Excavation Failure
- Investigation Procedure
- Case Study 1 & Case Study 2
  - Background
  - Chronological Events
  - Causes of Failures
  - Lessons Learnt

Common Probable Causes of Excavation Failure

- Describe the product or service being marketed

A) Natural Disasters : fire, earthquake, tsunami, tremor, wind, rainfall and flood

B) Act of Sabotage: explosive substances

C) Material Defects: reused steel strutting sections with poor conditions, concrete properties

D) Design: modelling and design parameters, robustness and ductility

E) Construction: sequences of works, excavation depth

F) Maintenance: drainage system, no timely review of instrumentation results

Investigation Procedure

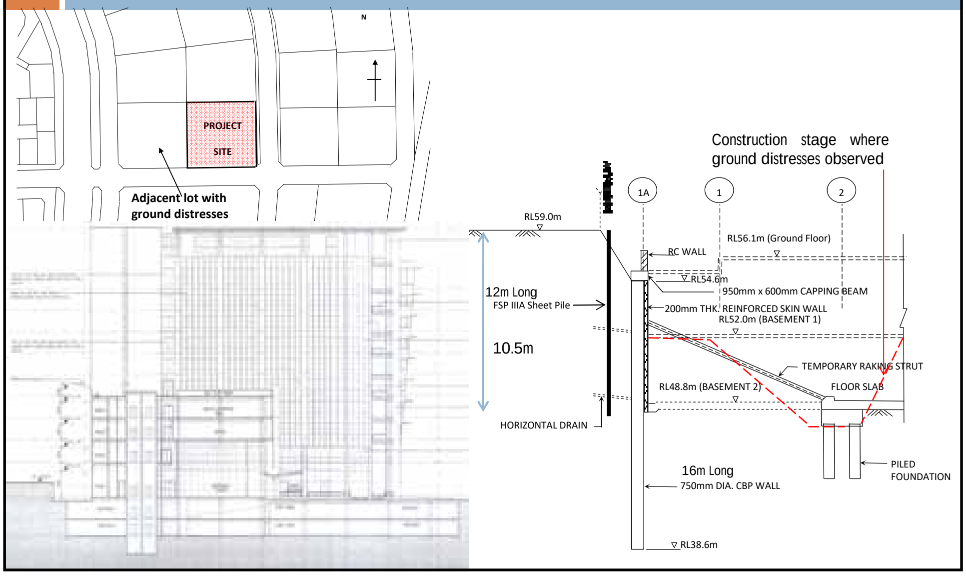
1. Check safety factor of the original design
2. Check the as-built construction for any deviations from original design
3. Identify design shortcomings, material defects, workmanship deficiencies, if any
4. Interview design team, construction management team, site personnel and eye witnesses
5. Consult other experts if required, for matters beyond the investigator's expertise or knowledge of the facts
6. Identify possible collapse scenarios and rationalise conflicting facts or evidences
7. Determine the major contributory and triggering factors that cause the collapse
8. Conduct advanced non-linear analysis / tests to ascertain the collapse mechanism
9. Confirm the collapse mechanism with those from facts and evidences
10. Write report

CASE STUDY 1 (CS1)

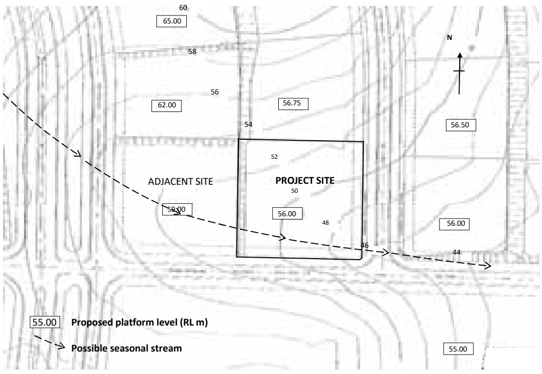
CS1: Excessive Movement of CBP Wall

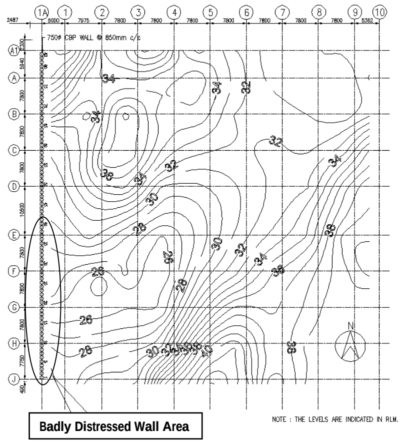
- Two-Storey Basement
- Temporary Excavation with Berms & Raking Struts to Lower Basement Slab
- Distresses observed in the middle of Temp. Excavation
  - Ground Distress
  - CBP Wall tilted and Structurally damaged
- Remedial Works
- Summary of Findings & Lessons Learnt

CS1: Excessive Movement of CBP Wall

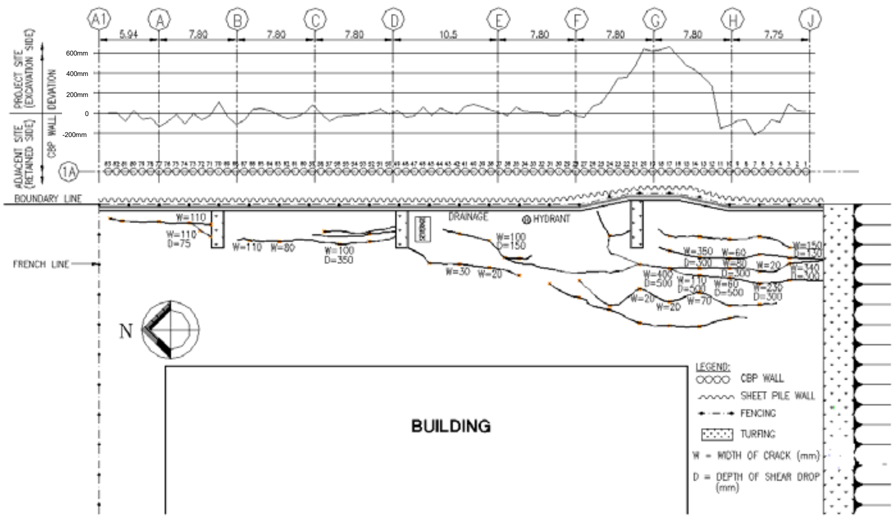


CS1: Excessive Movement of CBP Wall





CS1: Excessive Movement of CBP Wall



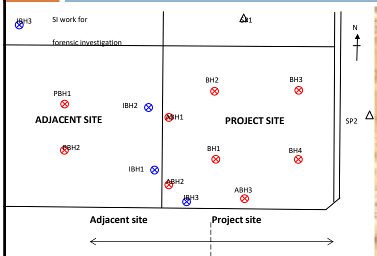
CS1: Excessive Movement of CBP Wall

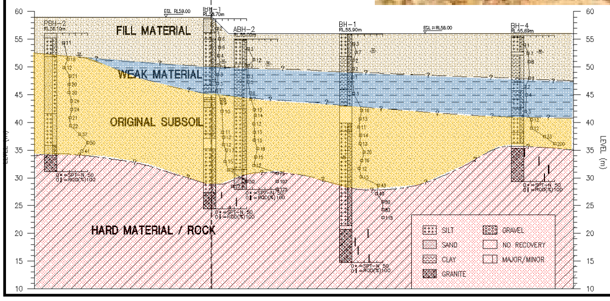
CS1: Excessive Movement of CBP Wall

Ground Distress at Active Wedge

Repairing of CBP Pile

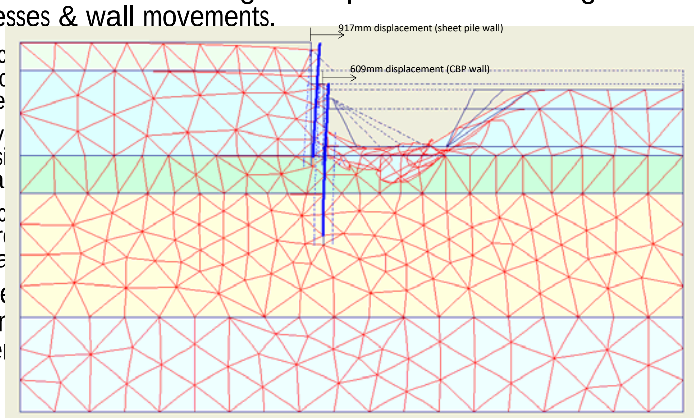
CS1: Excessive Movement of CBP Wall





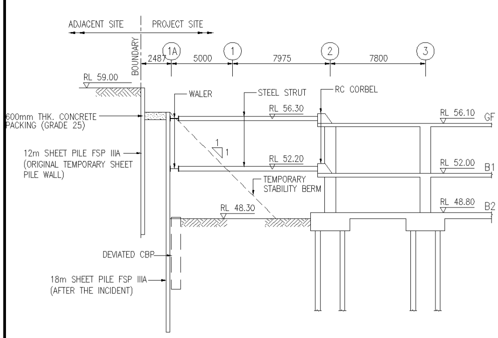
CS1: Excessive Movement of CBP Wall

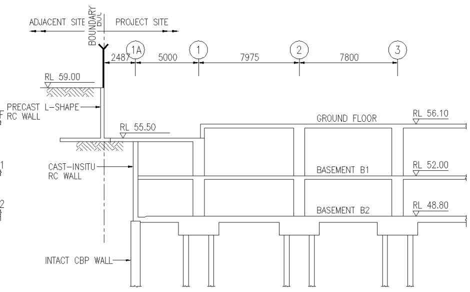
- Back Analysis
- Finite Element analysis (PLAXIS) to simulate the construction sequences of excavation & to investigate the probable causes of ground distresses & wall movements.
  - Exc ... exc ... she ... rary
  - Ov ... resi ... wa ... ateral ... e CBP ... ndition
  - Exc ... for ... una ... ral
- The re ... wall r ... settle ... red



CS1: Excessive Movement of CBP Wall

- Remedial Solution





CS1: Excessive Movement of CBP Wall

Repairing Crushed CBP

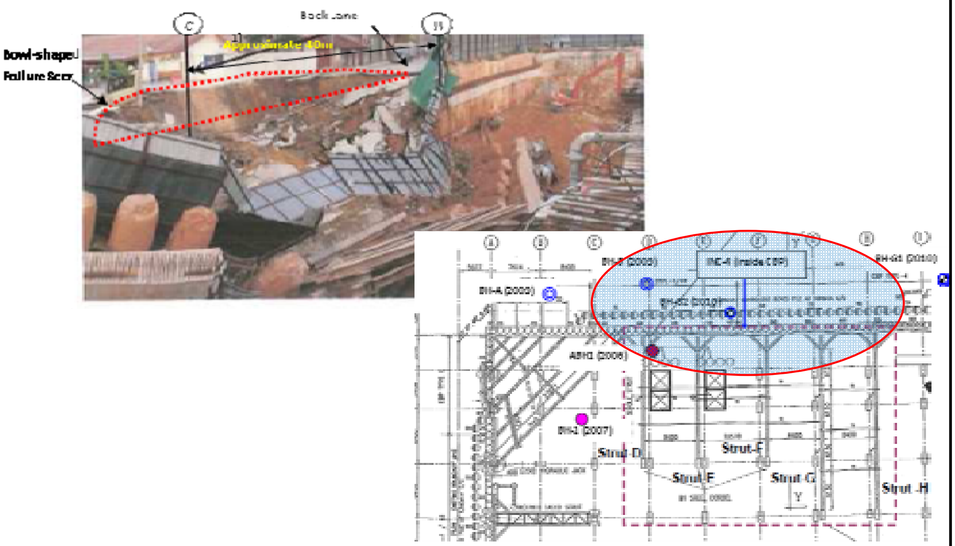
Shear Failure of Corbel Support

CS1: Excessive Movement of CBP Wall

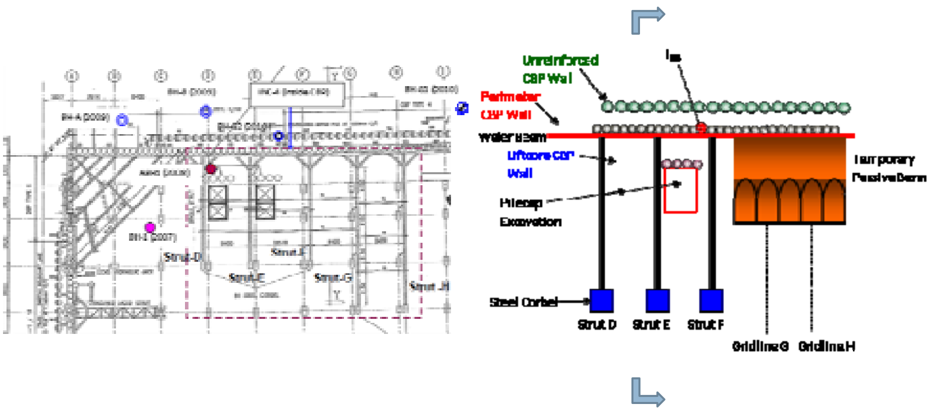
- Summary of Findings & Lessons Learnt
  - Building platform formed over natural valley containing thick fill over previous soft deposits provides prerequisite condition for ground distresses during temporary localized deep pile cap excavation & removing passive berm excessively without planned strut supports.
  - Occurrence of tension cracks during initial open excavation and installation of sheet piles suggested that the underlying subsoil at the valley area are inherently vulnerable to ground disturbance and hence are prompted to distressing.
  - Perched groundwater regime can occur in backfilling over natural valley leading to unfavourable behaviour of backfill.
  - Desk study of pre-development ground contours is highly recommended.

CASE STUDY 2 (CS2)

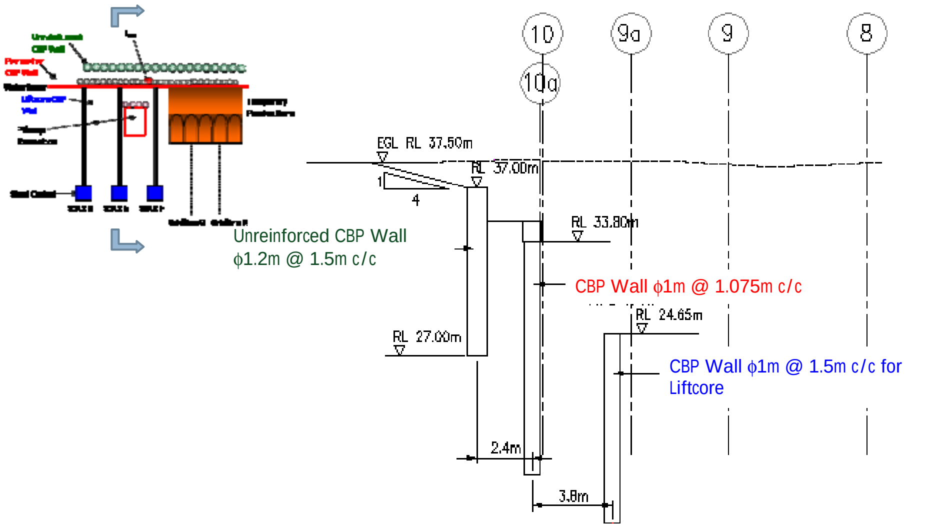
CS2: CBP Wall Failure



CS2: Retaining Wall System

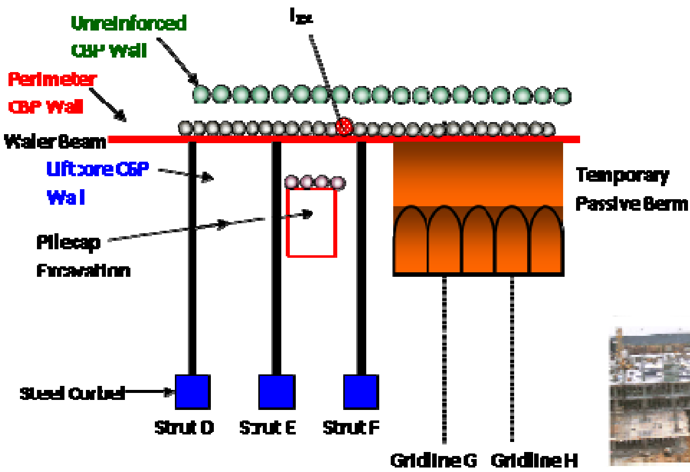


CS2: Retaining Wall System



CS2: Important Events Before Collapse

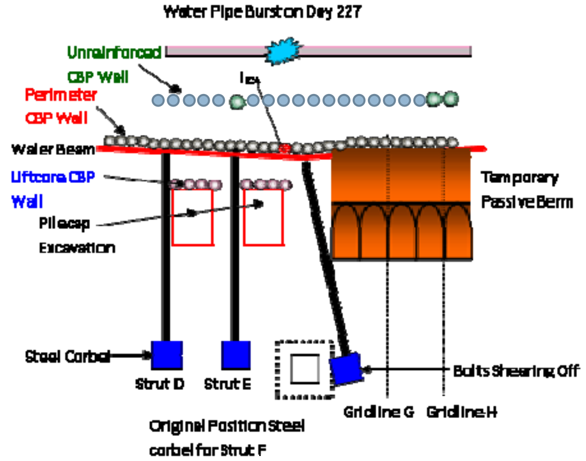
Original struts position for Struts D, E and F with passive berm retained at Gridlines G and H.



CS2: Important Events Before Collapse

Day 227

Water pipe burst incident on Day 227 which caused the steel corbel for strut F being sheared off as reported.



Observations of investigator:

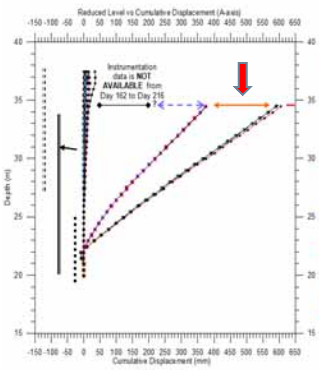
Although strutting subcontractor did not design the strutting system for one strut failure scenario, the retaining wall system still managed to distribute the loads from Strut F vertically to soil and laterally to Struts D & E and passive berm safely but with large incremental movement registered at Inclinometer I_{IC4}.

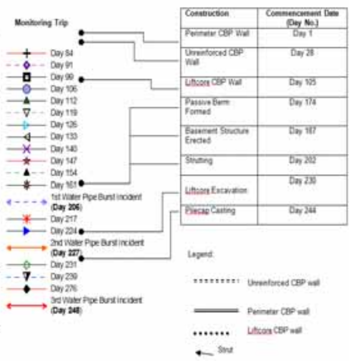
The water pipe burst incident on Day 227 could have weaken the strut corbel connection for Strut F and stressed the CBP walls towards its structural ultimate limit state.

CS2: Important Events Before Collapse

Day 227

Water pipe burst incident on Day 227 which caused the steel corbel for strut F being sheared off as reported.





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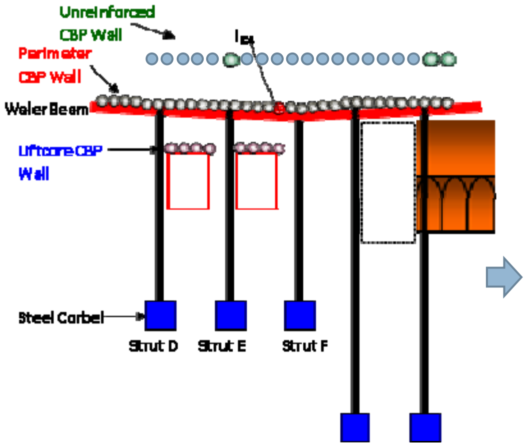
The water pipe burst incident on Day 227 could have weaken the strut corbel connection for Strut F and stressed the CBP walls towards its structural ultimate limit state.

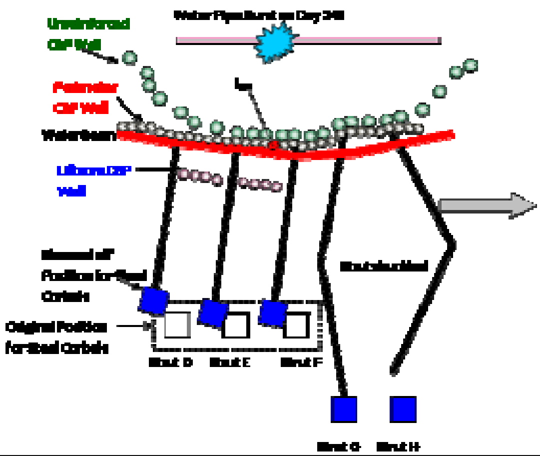
CS2: Important Events Before Collapse

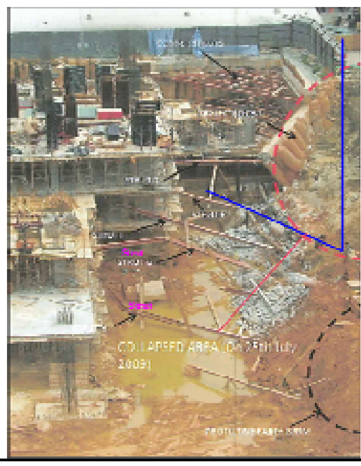
Strut F was reinstated. After installation of struts G and H, temporary passive berm along Gridlines G and H were progressively removed.



CS2: Important Events Before Collapse

The removal of temporary passive berm has caused incremental ground movement that led to another water pipe burst incident on Day 248. This water pipe leakage had triggered CBP wall collapse tragedy on Day 248.





CS2: Video Clip on Wall Failure

CS2: Video Clip on Wall Failure

CS2: Flow of Wall Failure on Day 248

1) Water pipe burst (behind the CBP Wall)
2) Steel corbel connection at Strut F sheared-off
3) Failure of strutting system to re-distribute the failure load to adjacent struts
   - Steel corbel connections at Struts D and E sheared off due to sudden increased in strut force
   - Struts G and H buckled due to sudden increase in strut force
4) Failure of CBP walls due to loss of lateral supports (struts)
5) CBP wall failed rotationally and retained earth at active soil wedge in to the excavation site

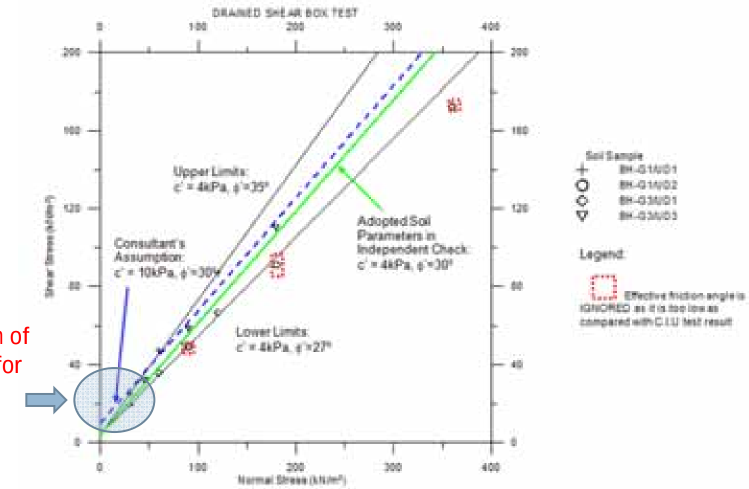
CS2: Why Wall Collapse

Triggering Factor of Wall Collapse: Increase of water pressure due to repetitive water pipe burst incidents happened at the back lane

Causes of Wall Collapse ??

CS2: Causes of Wall Collapse

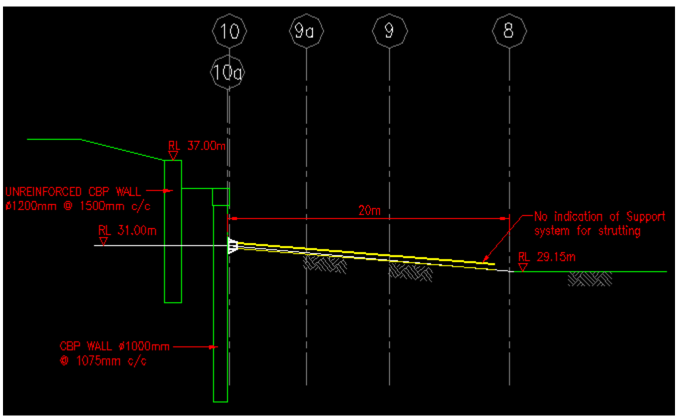
1) Adoption of optimistic cohesion parameter by the consultant



Over-estimation of cohesion for subsoil at shallower depth

CS2: Causes of Wall Collapse

2) Inconsistency of design intent and site execution between consultant and contractor



CS2: Causes of Wall Collapse

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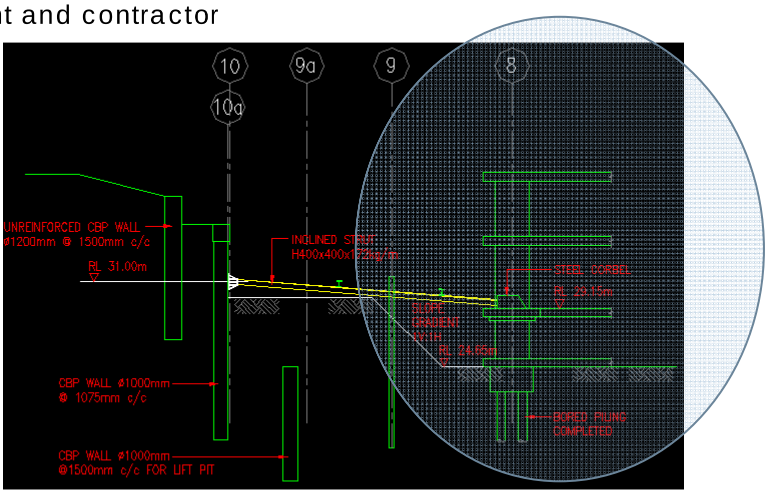
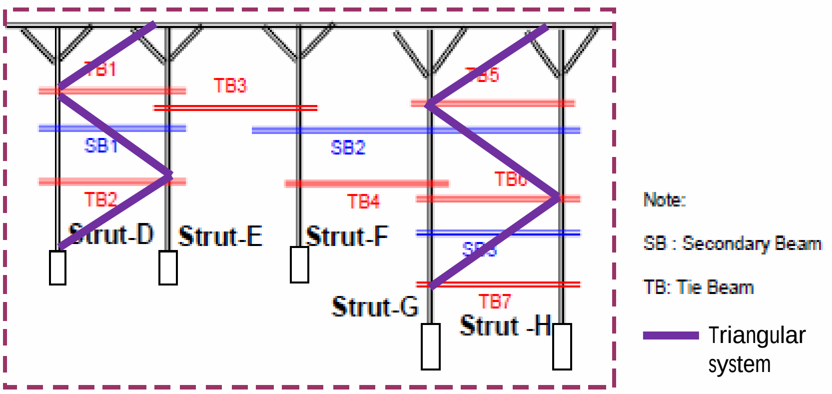


CS2: Causes of Wall Collapse

3) Improper lateral restraint bracing system and non-compliance on hole cutting at steel corbel by strutting sub-contractor and no timely review of the retaining wall and strutting designs.



CS2: Causes of Wall Collapse

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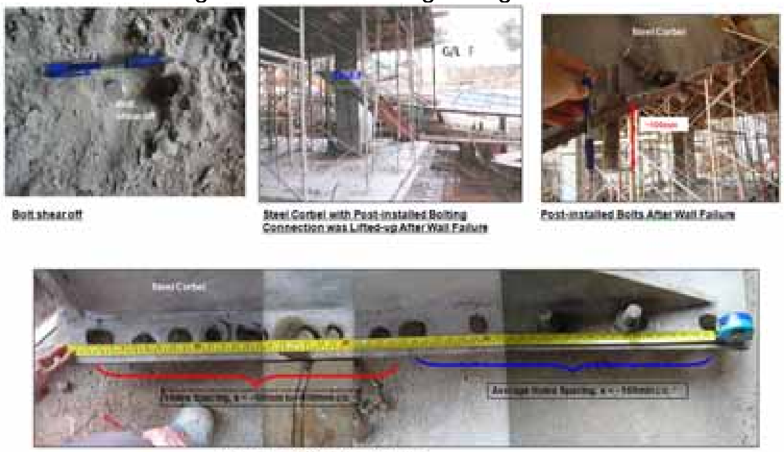


Bolt shear off

Steel Corbel with Post-installed Bolting Connection was Lifted-up After Wall Failure

Post-installed Bolts After Wall Failure

As-built Details of Steel Corbel for Strut-F

CS2: Lesson Learnt & Recommendation

- Timely review on instrumentation monitoring results is important
- Selection of soil parameters shall be done carefully based on sufficient lab testing results and local experiences
- Site supervision team to make sure the consistency between the design intent and site execution
- Pay attention on the connection details and strutting bracing system

CS2: Which connection detail is better?

VS

Failure Investigation of Piled Reinforcement Soil Wall & Excessive Movements of Piled Embankment at Soft Ground, Malaysia

by **Liew Shaw-Shong**

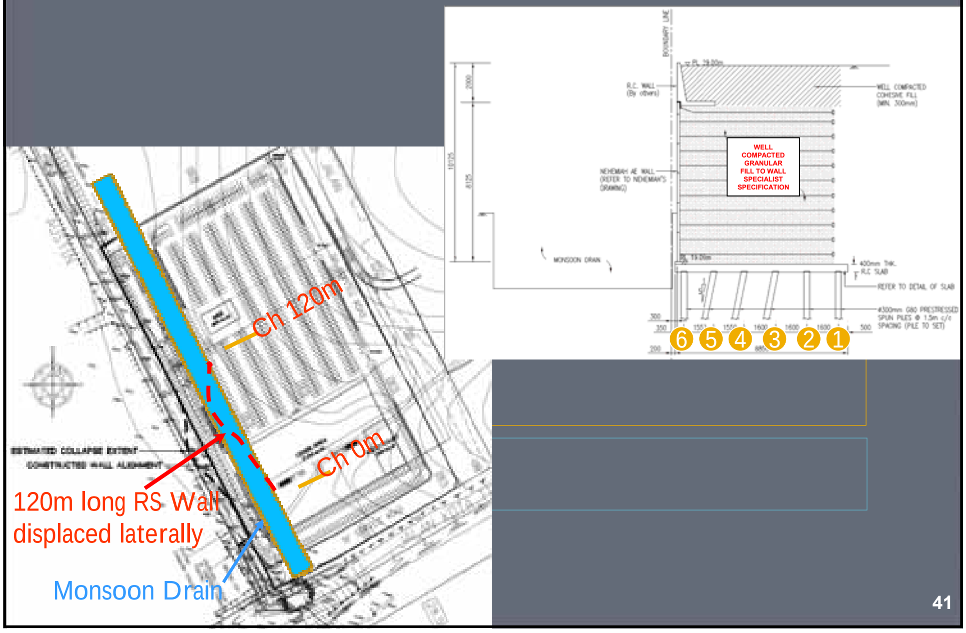
Introduction

- Two Case Studies on Failure of Piled Supported Wall under Extreme Lateral Loading
- Findings in the Forensic Investigation
- Conclusions & Recommendation

Case 1: Case study on Piled Supported Wall Failure

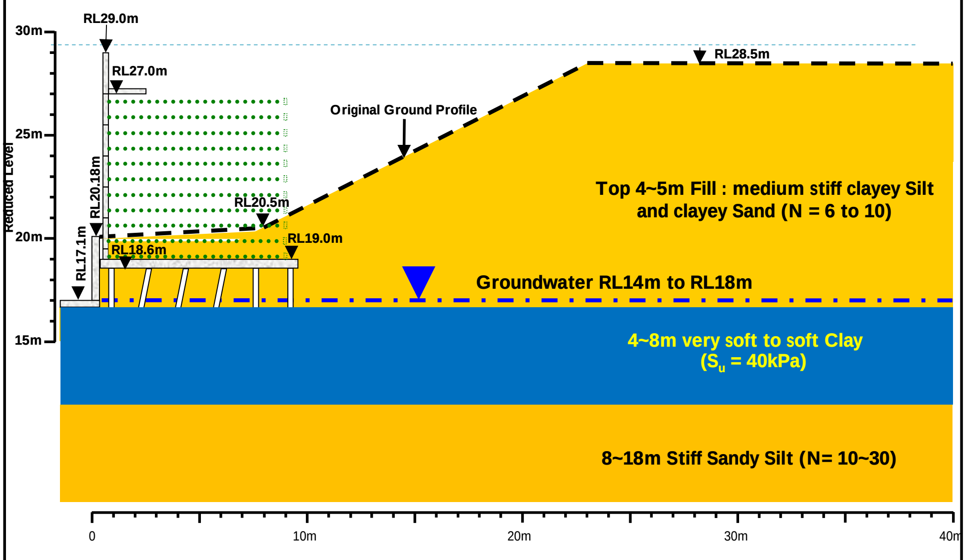
- 8m RS Wall + 2m L-Shaped RC Wall
  - Foundation : Vertical piles + Raked Piles (3 rows each)
  - 400mm thick RC Slab
  - 3~3.5m RC Monsoon Drain in front of Wall
- Failure on 4 Jan 2007 - Intense antecedent rainfall from 10 Dec 06 to 29 Dec 06 & Triggering midnight rainfall (20mm/hr)
  - When 120m long RS Wall reached soffit of L-Shaped RC Wall

Site Layout Plan & RS Wall Sectional View



41

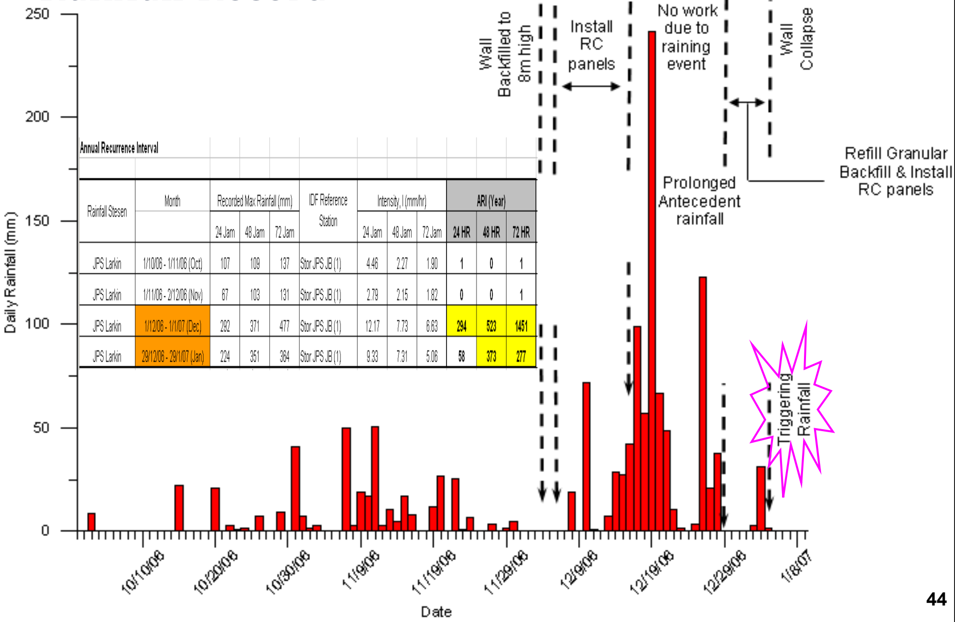
Subsurface Conditions



42

Installation of Piles (mid Oct 06)

Rainfall Record



Annual Recurrence Interval

Rainfall Stesen	Month	Recorded Max Rainfall (mm)			IDF Reference Station	Intensity, I (mm/hr)			ARI (Year)		
		24 Jam	48 Jam	72 Jam		24 Jam	48 Jam	72 Jam	24 HR	48 HR	72 HR
JPS Larkin	1/10/06 - 1/11/06 (Oct)	107	109	137	Stor JPS JB (1)	4.46	2.27	1.90	1	0	1
JPS Larkin	1/11/06 - 2/12/06 (Nov)	67	103	131	Stor JPS JB (1)	2.79	2.15	1.82	0	0	1
JPS Larkin	1/12/06 - 1/1/07 (Dec)	292	371	477	Stor JPS JB (1)	12.17	7.73	6.63	294	523	1451
JPS Larkin	29/12/06 - 29/1/07 (Jan)	224	351	364	Stor JPS JB (1)	9.33	7.31	5.06	58	373	277

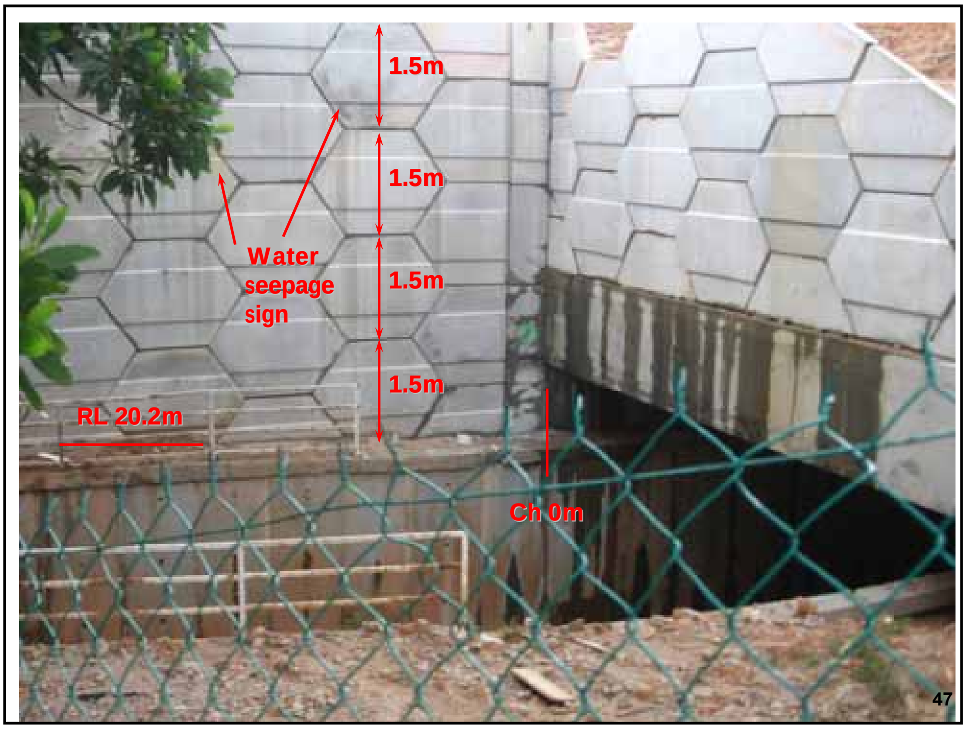
Retention pond full of water

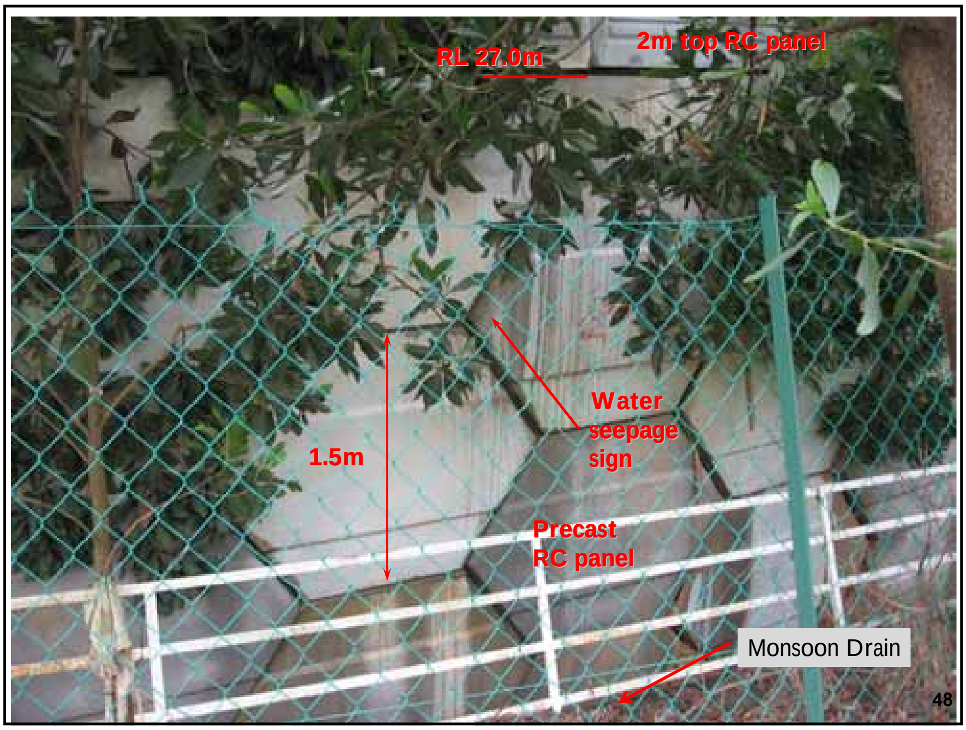
Site Observations

- Panels
  - Wet panels & traces watermark
  - Highest level of observed seeping water below 2m high L-shaped RC wall

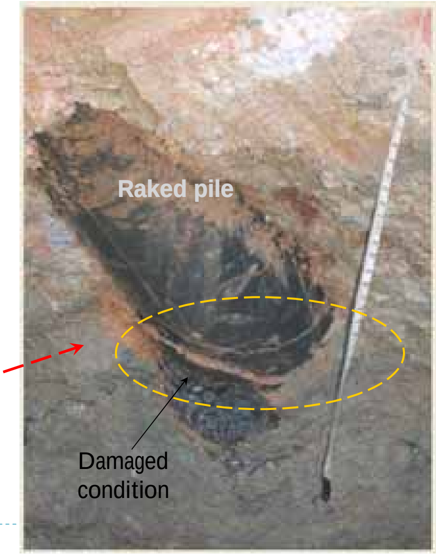
  ∴ Evidence of high water table behind the wall panel
- Pile Foundation
  - Flexural plastic hinge pile damage at 1.75m to 2m below slab soffit level

  ∴ Likely due to excessive lateral load on piles


1.5m
1.5m
Water
seepage
sign
1.5m
1.5m
RL 20.2m
Ch 0m
47

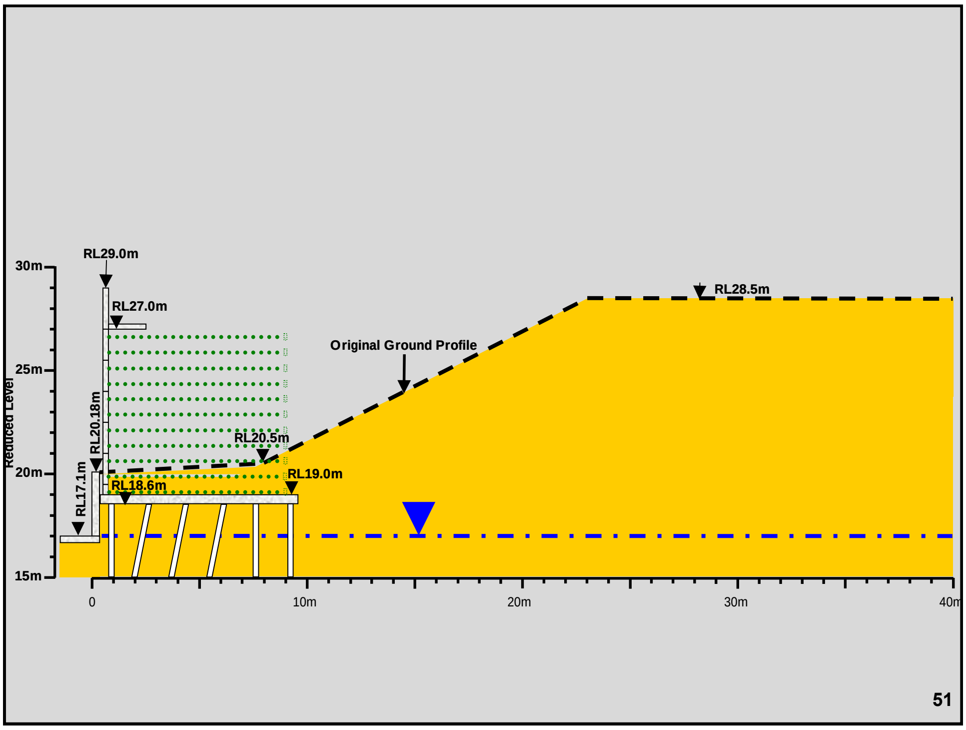

RL 27.0m
2m top RC panel
Water
seepage
sign
1.5m
Precast
RC panel
Monsoon Drain
48

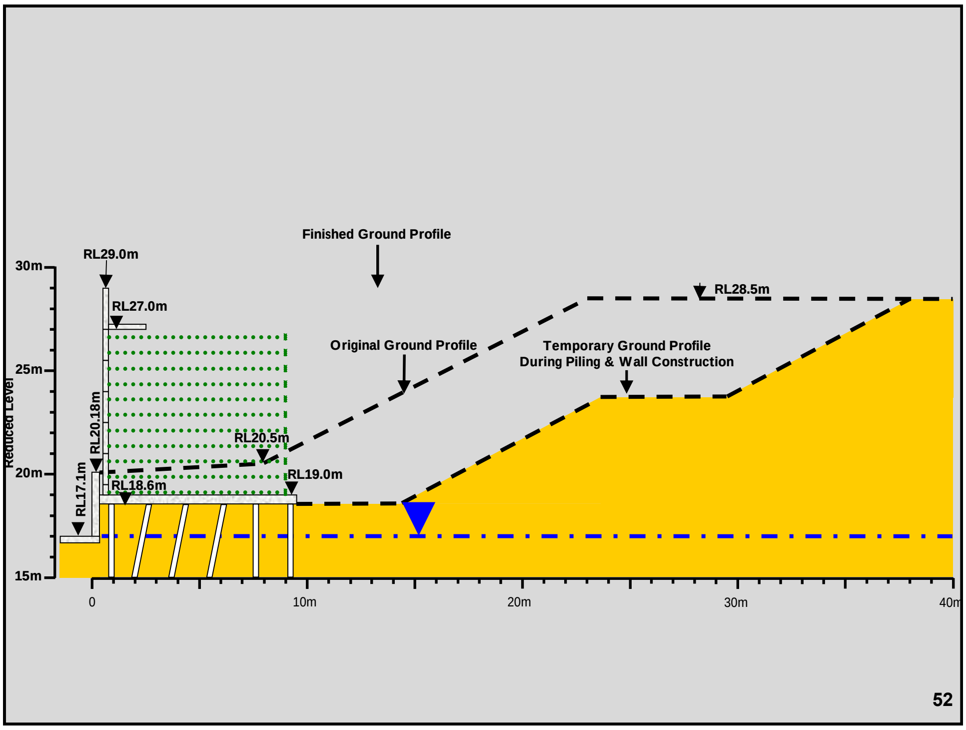
Damaged Foundation Piles

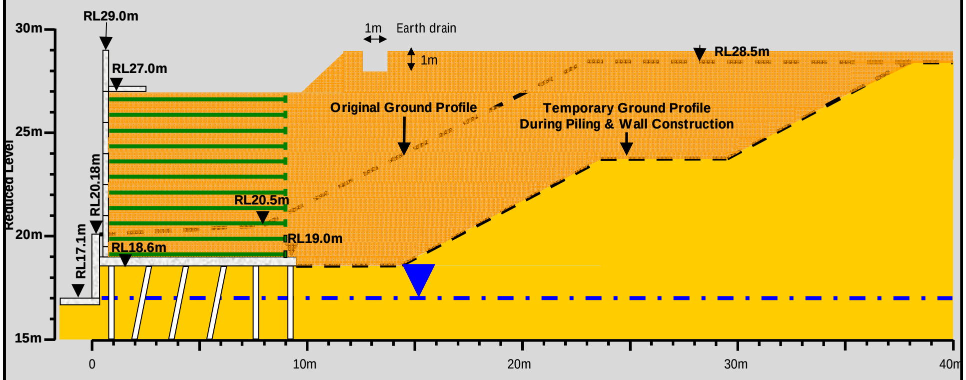


Investigation Approach

- Examine induced Axial & Lateral Forces and Moments on Piles at **Design Condition** & **Failure**
- Lateral earth pressure theory
- PIGLET to compute pile group load distribution
- Check FOS against
  - Pile axial capacity
  - Pile lateral capacity
  - Pile structural adequacy (Moment & Shear)

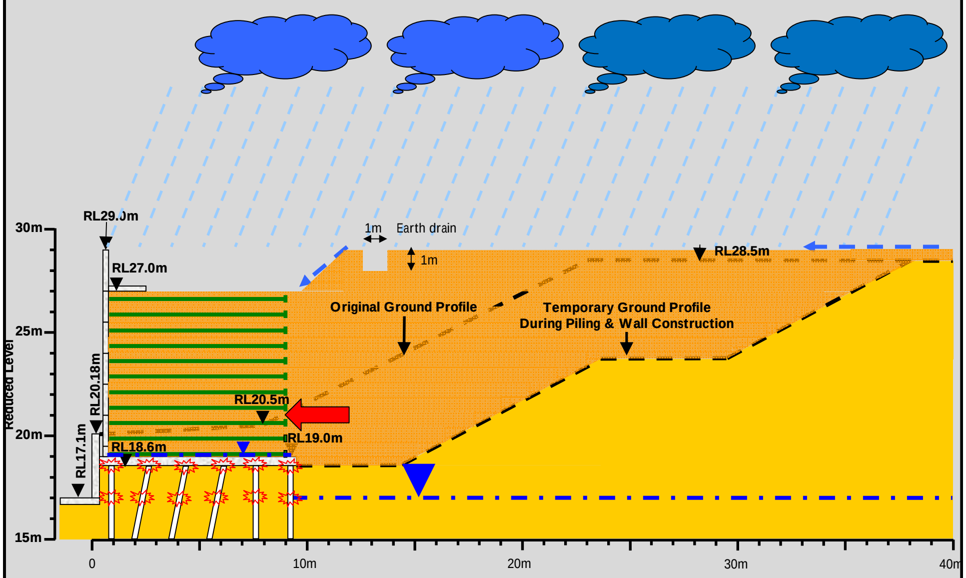

RL29.0m
RL27.0m
RL28.5m
Original Ground Profile
RL20.5m
RL20.18m
RL17.1m
RL18.6m
RL19.0m
Reduced Level
30m
25m
20m
15m
0
10m
20m
30m
40m
51


Finished Ground Profile
RL29.0m
RL27.0m
RL28.5m
Original Ground Profile
Temporary Ground Profile
During Piling & Wall Construction
RL20.5m
RL20.18m
RL17.1m
RL18.6m
RL19.0m
Reduced Level
30m
25m
20m
15m
0
10m
20m
30m
40m
52



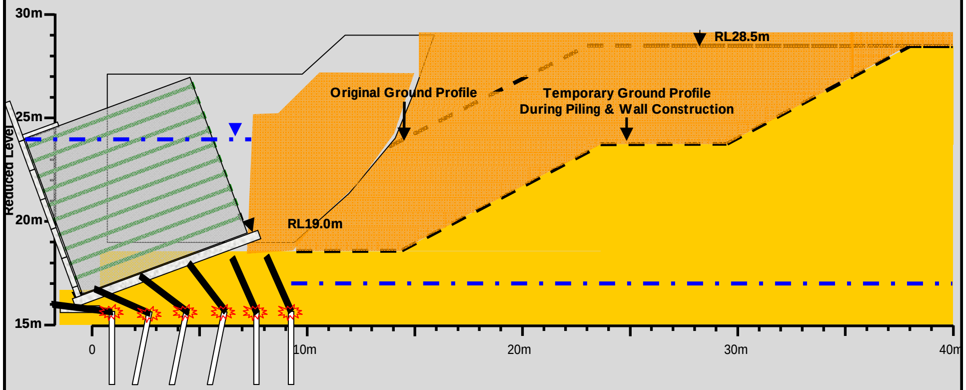
RL29.0m
RL27.0m
1m
Earth drain
1m
RL28.5m
Original Ground Profile
Temporary Ground Profile
During Piling & Wall Construction
RL20.18m
RL20.5m
RL19.0m
RL17.1m
RL18.6m
Reduced Level
30m
25m
20m
15m
0
10m
20m
30m
40m

53

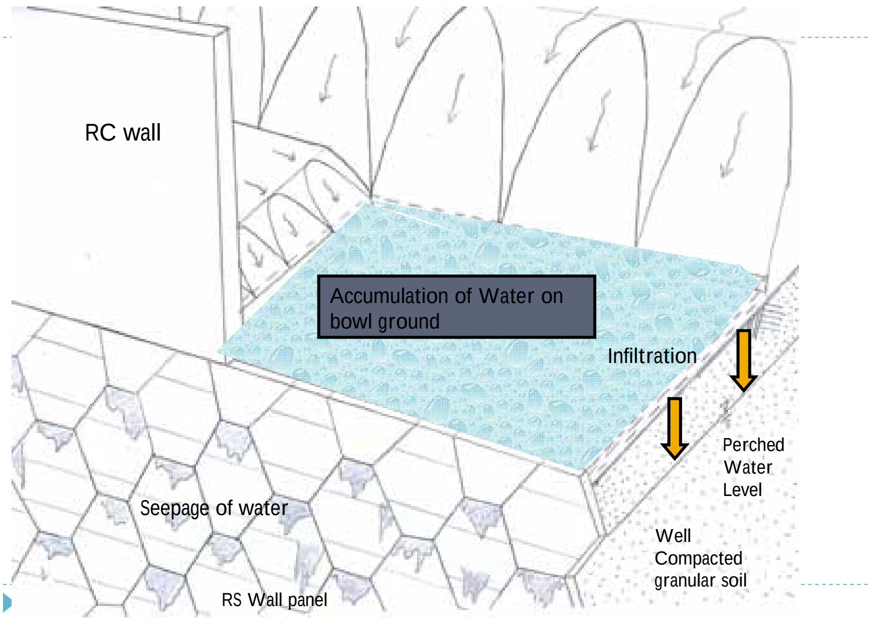


RL29.0m
RL27.0m
1m
Earth drain
1m
RL28.5m
Original Ground Profile
Temporary Ground Profile
During Piling & Wall Construction
RL20.18m
RL20.5m
RL19.0m
RL17.1m
RL18.6m
Reduced Level
30m
25m
20m
15m
0
10m
20m
30m
40m

54



Schematic View of the Rain Water Infiltration



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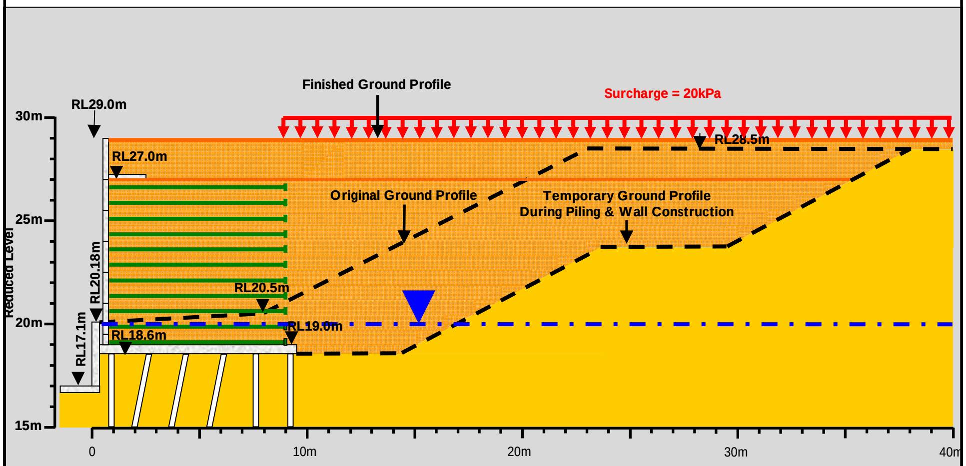
Design Scenario A (GWT at Monsoon Drain)



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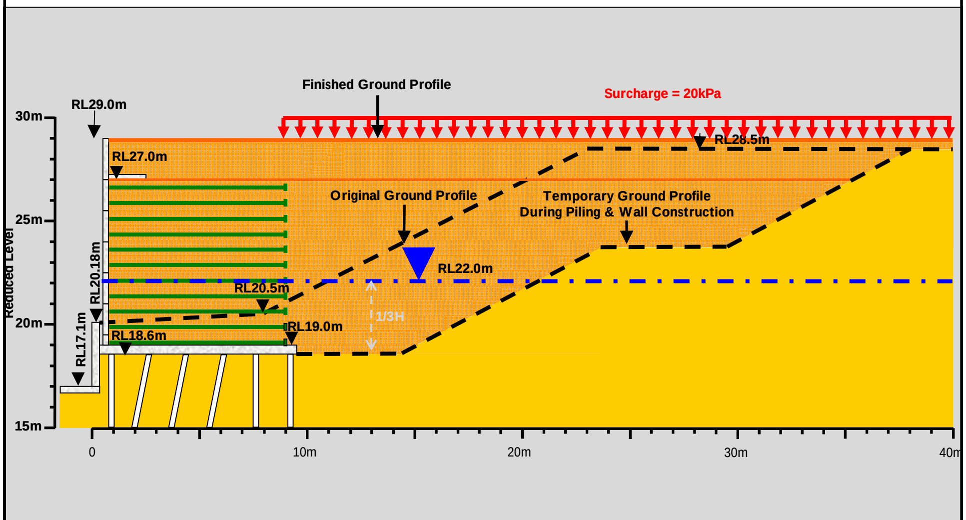
Design Scenario A Results

GWT at Top of Monsoon Drain (RL20.18m)

Pile no.	Axial loads (kN)	Status <840kN	Lateral loads (kN)	Lateral Resistance (kN)	FOS (>2.0)	Moments (kNm)	Ultimate Moment Resistance (kNm)	Load Factor (>1.5)
1	261.40	OK	37.27	86.00	2.3	13.30	62	3.1
2	335.82	OK	39.50	87.00	2.2	14.00	63	3.0
3	469.42	OK	16.82	93.11	5.5	5.98	66	7.4
4	482.78	OK	13.89	93.11	6.7	4.94	66	8.9
5	715.15	OK	16.16	91.00	5.6	5.75	68	7.9
6	558.46	OK	42.14	91.00	2.2	15.00	68	3.0
7	288.96	OK	44.10	86.00	1.9	15.70	62	2.6
8	302.52	OK	30.15	87.00	2.9	10.70	63	3.9
9	459.98	OK	17.14	93.11	5.4	6.09	66	7.2
10	568.37	OK	20.81	93.11	4.5	7.40	66	5.9
11	613.76	OK	10.10	91.00	9.0	2.38	68	19.0
12	608.25	OK	44.16	91.00	2.1	15.70	68	2.9

OK!

Design Scenario B (1/3 GWT)



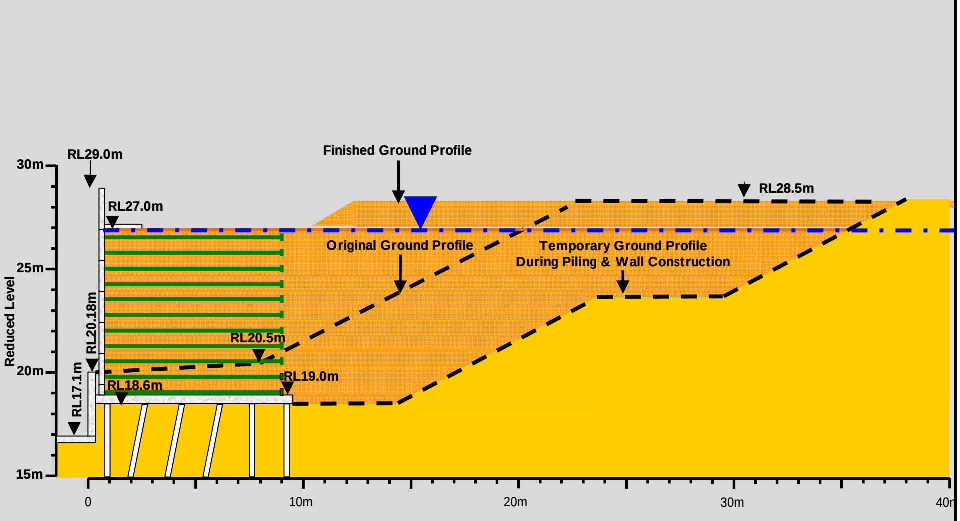
Design Scenario B Results

GWT at 1/3 of Retained Height (RL22.0m)

Pile no.	Axial loads (kN)	Status <840kN	Lateral loads (kN)	Lateral Resistance (kN)	FOS (>2.0)	Moments (kNm)	Ultimate Moment Resistance (kNm)	Load Factor (>1.5)
1	204.98	OK	62.76	86.00	1.4	22.3[illegible]	59	1.8
2	270.28	OK	64.82	87.00	1.3	[illegible].10	62	1.8
3	544.18	OK	35.66	94.34	2.6	12.70	69.5	3.6
4	553.61	OK	29.14	94.00	3.2	10.40	69	4.4
5	823.98	OK	38.75	93.11	[illegible]	13.80	68	3.3
6	434.67	OK	65.72	[illegible].11	1.4	23.40	68	1.9
7	228.29	OK	[illegible].15	86.00	1.2	26.40	60	1.5
8	240.03	OK	48.36	87.00	1.8	17.20	62	2.4
9	532.65	OK	35.57	94.34	2.7	12.70	69.5	3.6
10	64[illegible]	OK	43.20	93.11	2.2	15.40	68	2.9
11	728.00	OK	21.67	94.00	4.3	7.71	69	6.0
12	491.76	OK	70.24	94.00	1.3	25.00	69	1.8

Low Back Calculated Load Factor of Individual Pile ≠ Unsafe Condition

Failure Scenario (GWT at Top Panel)

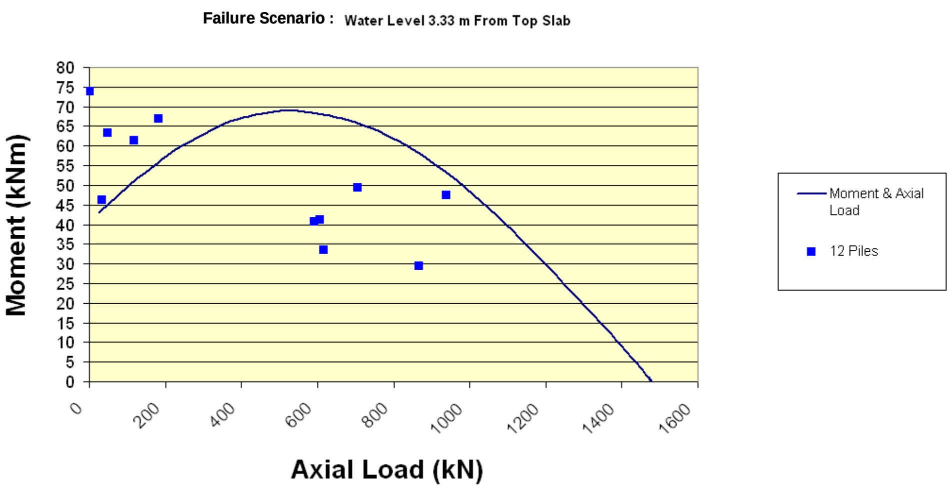


Failure Scenario Results

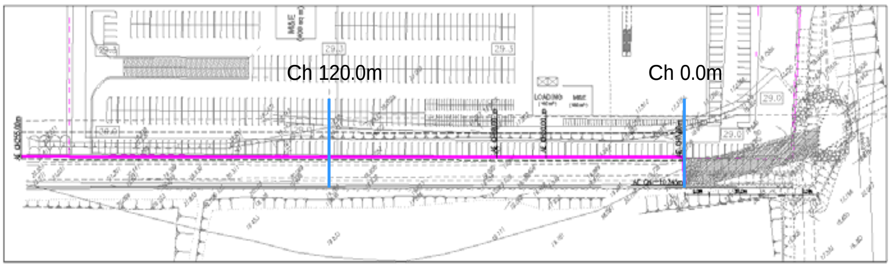
GWT at Top RS Wall Panel (RL27.0m)

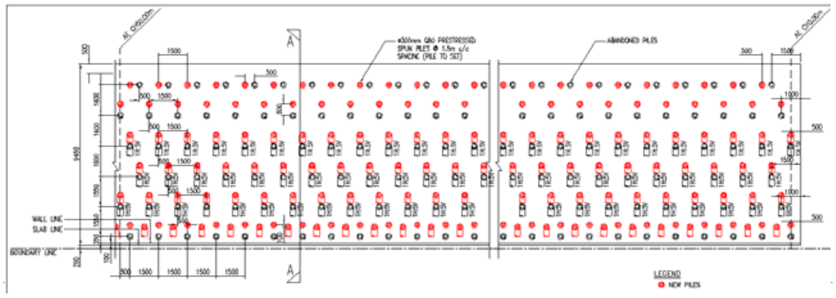
Pile no.	Axial loads (kN)	Status <840kN	Lateral loads (kN)	Lateral Resistance (kN)	FOS (>2.0)	Moments (kNm)	Ultimate Moment Resistance (kNm)	Load Factor (>1.5)
1	-8	OK	110.09	68.53	0.6	39.20	41	0.7
2	47.19	OK	111.38	72.52	0.7	39.60	45	0.8
3	604.08	OK	93.11	94.34	1.0	25.90	68	1.8
4	615.47	OK	93.93	94.00	1.0	21.00	69	2.2
5	937.95	NOT OK	81.91	93.11	1.1	29.70	55	1.2
6	115.81	OK	108.32	72.52	0.7	38.50	45	0.8
7	-1	OK	129.92	68.53	0.5	46.20	41	0.6
8	32.46	OK	81.49	72.52	0.9	29.00	45	1.0
9	589.30	OK	93.11	94.34	1.0	25.60	68	1.8
10	703.97	OK	93.93	93.11	1.0	30.90	69	1.5
11	866.94	NOT OK	79.17	94.00	1.2	18.40	52	1.9
12	180.22	OK	117.71	72.52	0.6	41.90	45	0.7

Unsafe Condition!



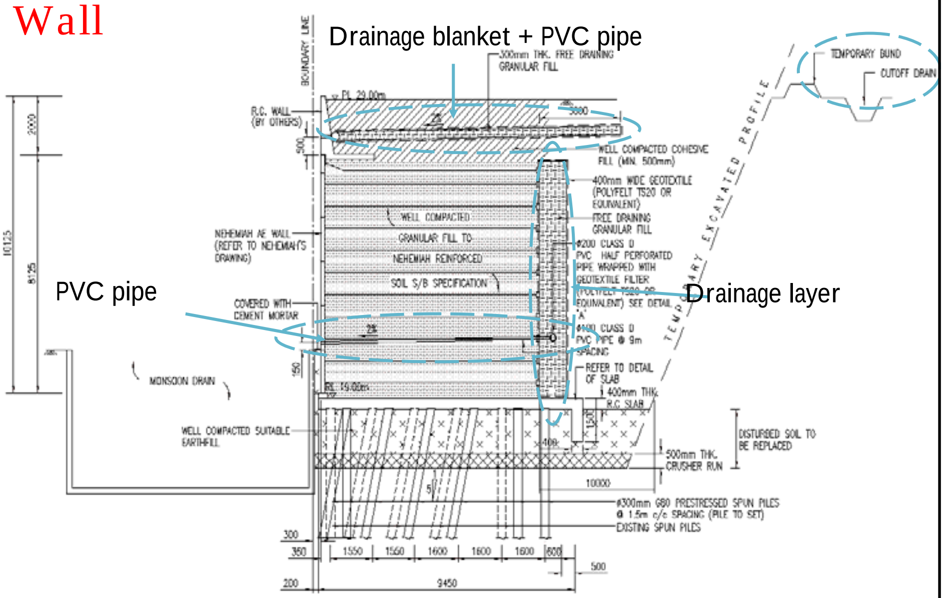
Remedial Works



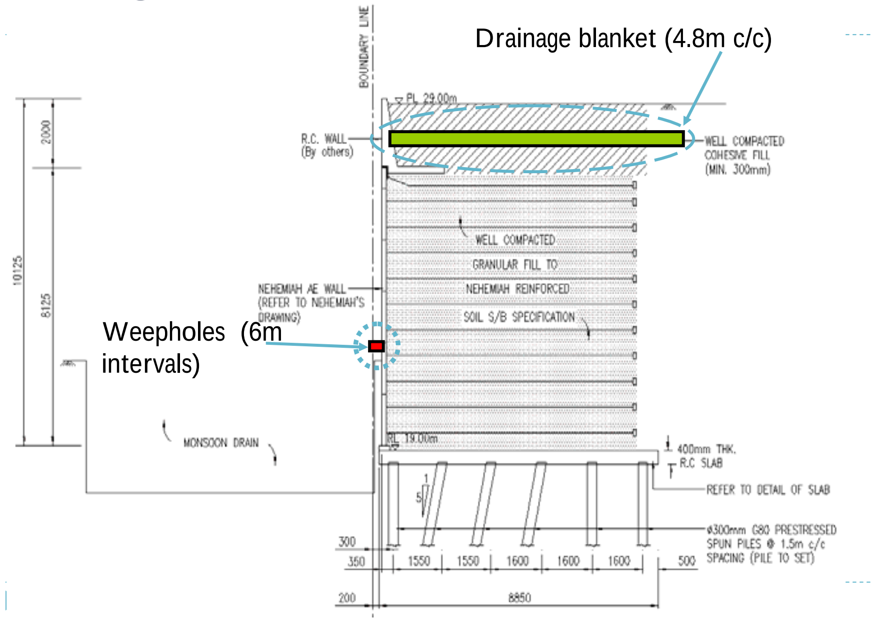


Additional piles (CH 0 m to Ch 50m)

Additional Drainage Control on Re-erected Wall



Drainage control on Intact Wall



Conclusions

- Main causation :
  - Excessive lateral wall force due to high water table rise from prolonged intense rainfall
- Foundation design under service condition is acceptable
- Attention shall be given to brittle behaviour of concrete piles taking lateral load with rapid increase of wall pressure when rise of groundwater table within the wall.

- Need careful evaluation of design robustness of vertical or sub-vertical piles in taking lateral foundation loading
- Solutions :
  - Use more raked piles utilising more robust axial pile strength to resolve lateral imposed loading
  - Extra drainage capacity for temporary drains for large flat retained platform
  - Timely backfilling of suitable fill over granular fill of RS wall

29 December 2006 - Johor was the worst hit. Heavy rain – the highest recorded in 100 years – caused floods in Johor Baru and several major towns.

Lessons Learnt on Stability of a Piled Retaining Wall in Weak Soils

Ir. Liew Shaw-Shong

Content

- Chronological events
- Distress conditions of wall
- Desk study & subsurface conditions
- Forensic investigation (Geotechnical & Structural assessments)
- Probable Causations
- Remedial Solution
- Conclusion

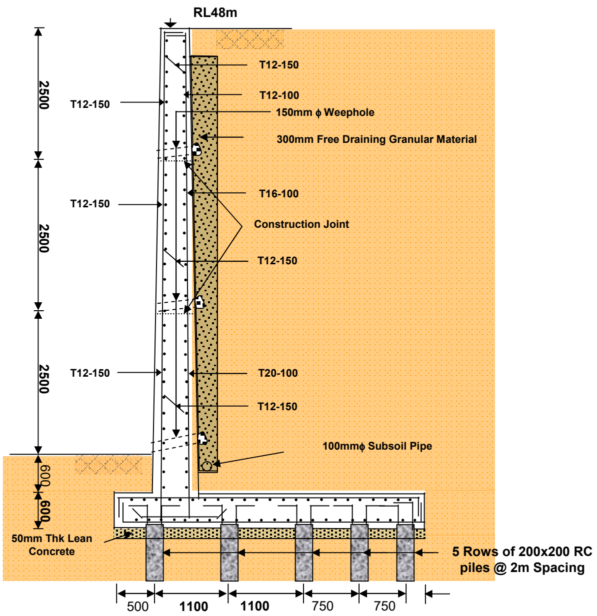
Chronological events

- First SI : Jan 2005 (Within project site)
- Second SI : May 2005 (at wall area)
- Wall Distress : Feb 2006 (After prolonged rain)
- Forensic Investigation : Feb to Mar 2006

Tension Crack & Wall Distresses

Overall View of Site

Cross Section of Wall



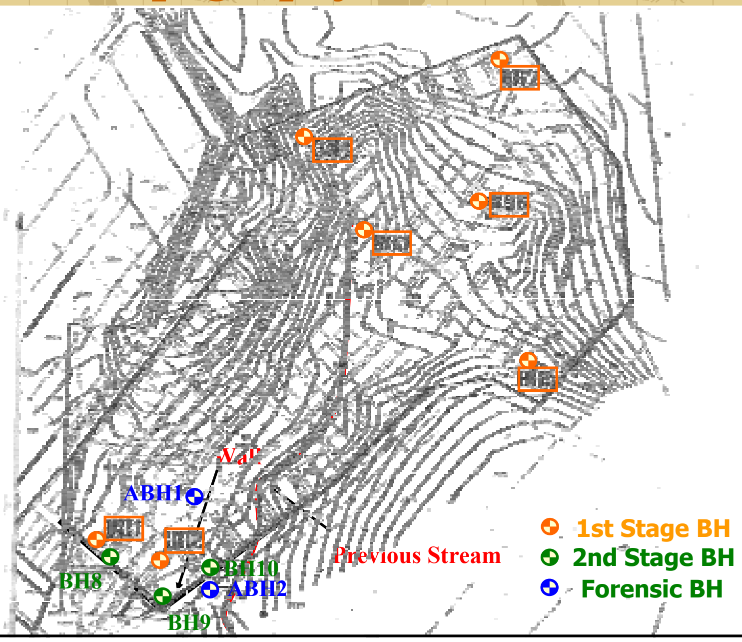
Weephole Drains

Erosion by Weephole Discharge

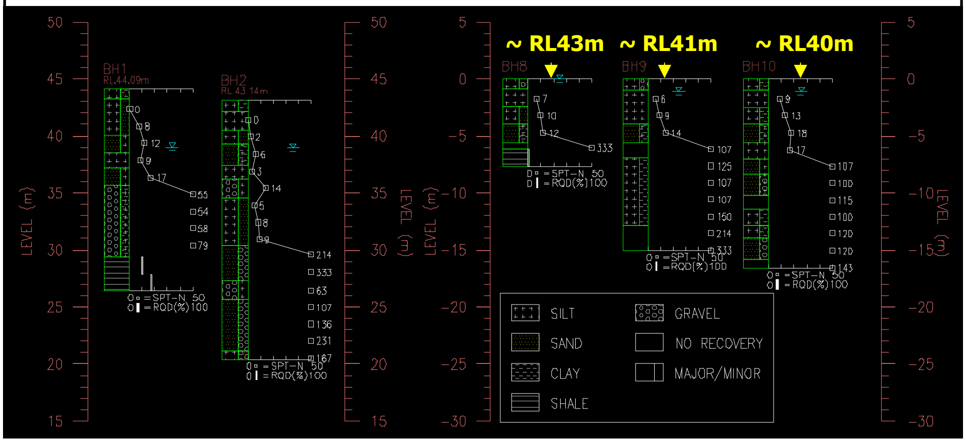
Erosion of Wall Base

Aerial View (Pre-development)

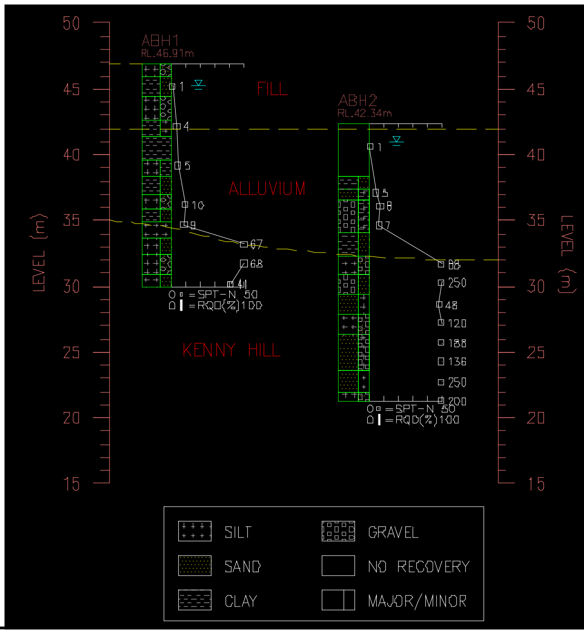
Site Topography & SI Works



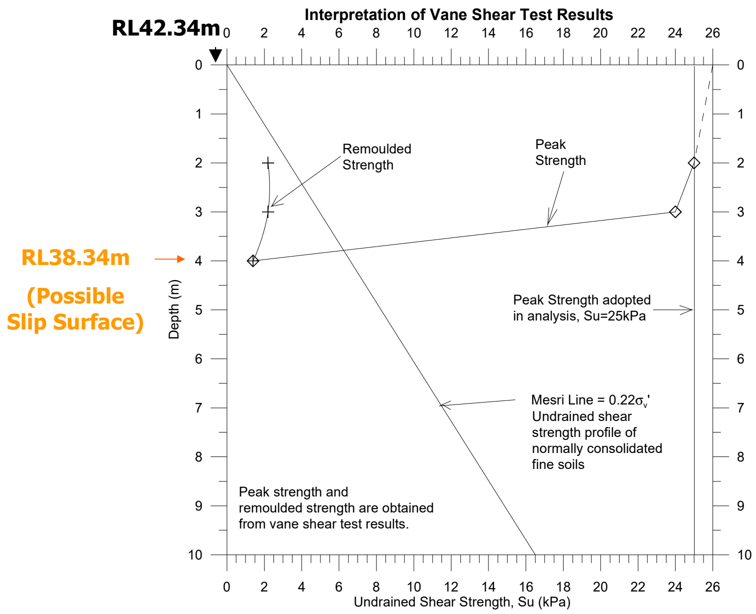
Previous 2-Stage Boreholes



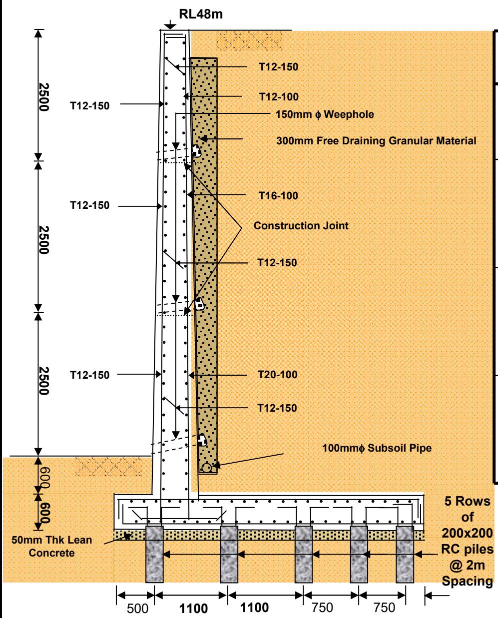
Forensic Boreholes



Vane Shear Test Strength Profile

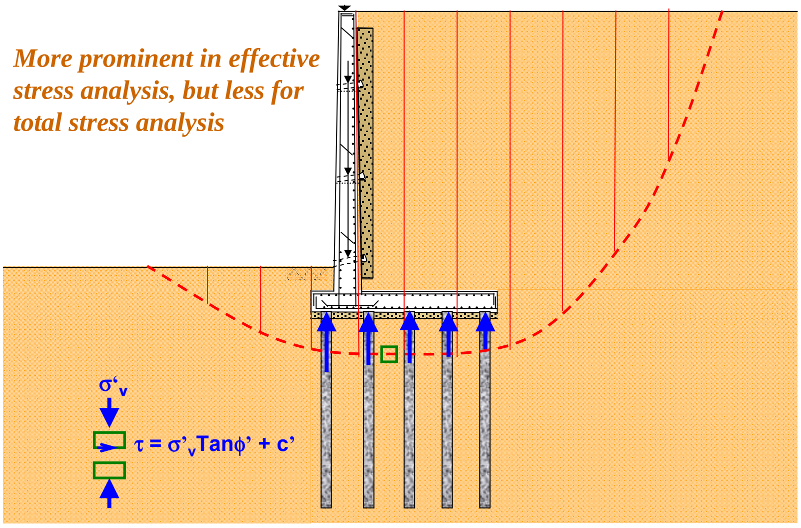


Stability Assessments



FOS Adequacy			
GWT	Over-turning	Sliding	Global Stability
RL45m	✓ 2.9>2.0	✗ 0.97<1.0 (Failure)	✗ 1.13/1.17
RL42.5m	✓ 3.7>2.0	✗ 1.34<1.5	✓/✗ 1.19/1.25
RL40.4m	✓ 3.8>2.0	✗ 1.5	✓/✗ 1.16/1.24

Bearing Capacity is never a concern as pile foundation is designed to take the vertical loading of wall



Pile Integrity Testing

Pile Structural Assessments

- Rankine Pressure
- Brom's Lateral Pile Capacity:
  - Fixed Head : 32kN/pile (Likely the case)
  - Free Head : 20kN/pile
- Ultimate lateral pile capacity reached when RL42.5m<GWT<RL45m

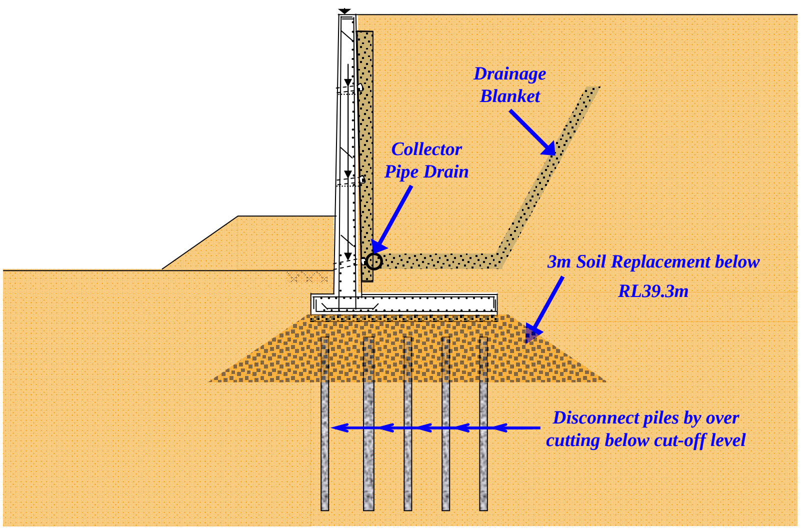
Probable Causes of Wall Distress

- Potential perched water regime in natural valley terrain after raining
- Rise of groundwater increases the lateral force on wall
- Inadequate lateral pile resistance
- Reduction of effective soil strength due to reduction of vertical stress as wall loading carried by piles

Remedial Solution

- Soil Replacement for upper weak soil
- Overcut existing piles below new wall base
- Construct stabilising berm in front of new wall
- Provide subsoil drainage behind wall to control rise of groundwater seepage

Remedial Solution



Conclusion

- Potential perched water regime in natural valley terrain after raining
- Rise of groundwater (inefficient sub-terrain drainage) increases the lateral force on wall
- Inadequate lateral pile resistance
- Reduction of effective soil strength due to reduction of vertical stress as wall loading carried by piles
- Slender vertical piles not suitable for supporting wall on weak & compressible soils (Poor lateral resistance)
- Remedial works : Soil Replacement + Subsoil drainage + Stabilising berm
- Solution : Raked piles in combination of vertical piles (Serviceability limit state)

Thank You