Session 5
Ground Investigation, Field Instrumentation and Monitoring in Hong Kong

[9:00 – 10:30 am, 19 February 2009]

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Objective of this session:

- Ground investigation practice
- Field instrumentation for monitoring of the behaviour of slopes and structures
- Workshop exercise on ground investigation

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Introduction

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Definition of "site investigation" from BS5930:1999

- "….investigation of sites for the purposes of assessing their suitability for the construction of civil engineering and building works and of acquiring knowledge of the characteristics of a site that affect the design and construction of such works and the security of neighbouring land and property………"
- "Ground investigation" taken to mean "ground exploration", often used interchangeably with "site investigation"

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Objectives of Site Investigation (BS 5930)

- Suitability (of sites and environs)
- Design problems
- Construction problems (e.g. constructability)
- Effect of changes (as a result of works)
- Choice of site
- Existing works (e.g. failure investigations)

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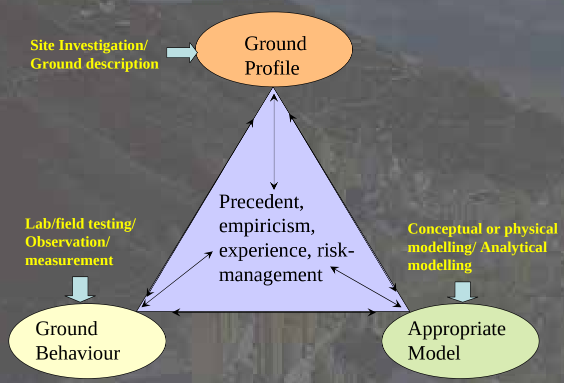

GEOTECHNICAL TRIANGLE
(Morgenstern, 2000)

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Effective GI provides geotechnical information for

- Development of a ground model
- Identification and evaluation of geotechnical hazards
- Geotechnical design of the project

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3-phase approach of Site Investigation (BS 5930)

- Desk Study and site reconnaissance
- Detailed investigations for design
  - main GI supplemented by more GI if necessary in more important areas (Fookes, 1997, 2000)
- Construction Review

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Recommended Procedure for Geotechnical Site Investigations

(International Society for Soil Mechanics & Geotechnical Engineering, March 2005)

1. Detailed desk study (understanding of geological history of the site)
2. Development of a preliminary geological and geotechnical model to assist in formulating the GI programme
3. Preliminary GI for feasibility studies
4. Main detailed GI to refine preliminary ground model and provide input into engineering design and construction methods
5. Allow for supplementary investigation to examine anomalies or uncertainties during the design process

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Recommended Procedure for Geotechnical Site Investigations

(International Society for Soil Mechanics & Geotechnical Engineering, March 2005)

6. Allow for supplementary during construction
7. Allow for presence of a geotechnical professional to be on site during those phases of construction involving ground-related risks
8. Ongoing interpretation of as-built ground conditions and construction monitoring data, to enable comparison with design assumptions and implementation of any necessary changes in construction

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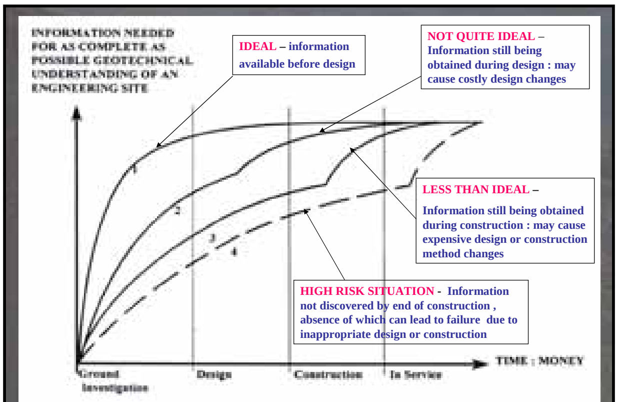

Geotechnical Information acquired during various stages of site investigation (Fookes, 1997)

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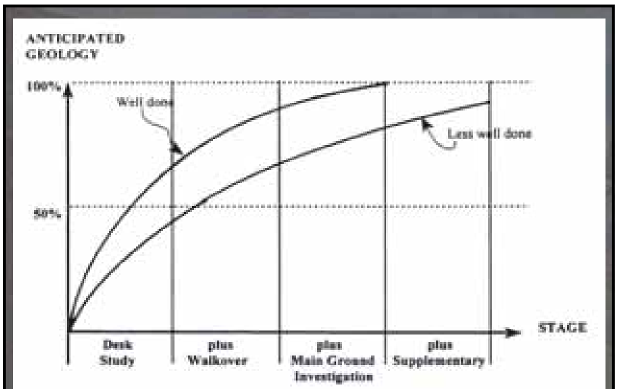

Upper and Lower bounds of Geological Information anticipated during the stages of a site investigation with engineering geology input (Fookes, 1997)

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GI cost in terms of project cost

- Highways Projects 0.1% - 4%
- TDD Projects 0.1% - 3%
- LPM Projects 1% - 20%

How much is enough ?

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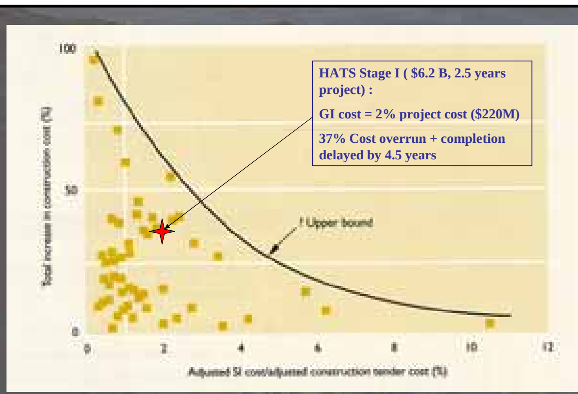

Cost overruns as a function of expenditure on SI for UK highways (Clayton, 2001)

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Public Accounts Committee Report on HATS Stage I 3 June 2004

- "........the Committee asked…whether the Government had misjudged the scope of and methodology for the site investigations….."
- "….agreed that it had under-estimated the complexity of the works and site investigations conducted were not sufficient to reveal the actual ground conditions…….."
- ".....the Administration should ascertain whether:…….(b) the unsatisfactory outcome could have reasonably been foreseen…….."

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Follow-up actions arising from lessons learnt from HATS Stage I (PAC Report)

- Conduct comprehensive site investigations for major works projects involving substantial underground works, with the assistance of geotechnical and tunnelling experts to provide more accurate information about the ground conditions
- Promulgate guidelines for improving site investigations, particularly for tunnel projects
- Improve the methodology for conducting site investigations by adopting new technology

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Role of GEO in Ground Investigation

- Provide GI services to Government Departments through term contracts for
  - Land and Marine GI
  - Geophysical surveys
  - Chemical & Biological testing of sediment planned for marine disposal
- Management of List of Approved Specialist Contractor for GI fieldwork
- Maintain GI standard (through audit of GI contractors, advice to departments and vetting GI supervision requirements)

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Planning

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Definition

- *Site investigation* is the overall process of discovery of information, appraisal of data, assessment and reporting.
- A site investigation should always start with a *desk study*

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Definition

- *Ground investigation (GI)* is the more restrictive phase of specialist intrusive investigation on a site with the associated monitoring, testing and reporting.

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Why is Site Investigation Necessary?

- good design requires an adequate understanding of the nature of the ground
  - distribution of soil & rock
  - properties of soil & rock
  - behaviour during the construction and lifetime of the structure
- UK studies show that 50% of project delays are caused by unforeseen ground conditions
  - half of these delayed by more than a month

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The Elements of Site Investigation

- the Plan-Do-Check-Act Cycle
  - The concept of the PDCA Cycle was originally developed by Walter Shewhart, a pioneering statistician who developed statistical process control in the Bell Laboratories in the US during the 1930's. It is often referred to as "the Shewhart Cycle".
  - It was taken up and promoted very effectively from the 1950s on by the famous Quality Management authority, W. Edwards Deming, and is consequently known by many as `the Deming Wheel'.
  - Peck's "Observational Method" is essentially the same concept

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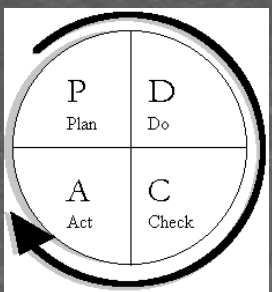
The Elements of Site Investigation



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The Elements of Site Investigation

- PLAN - Desk Study
  - information gathering from available records
    - maps, plans, charts, old photographs, past records
    - aerial photographs
    - geological maps & memoirs
    - existing GI records (extensive records in GIU)
    - utility company records
    - site inspection
    - interviews, contacts etc.
  - see Chapters 4-6 & Appendix A of Geoguide 2

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The Elements of Site Investigation

- DO
  - **topographic / hydrographic study**
  - **ground investigation**
    - phased approach best
    - use geophysics plus limited boreholes initially, to gain an overall appreciation of the site
- CHECK
    - **review the results**
    - **plot cross sections**
    - **identify areas of concern**

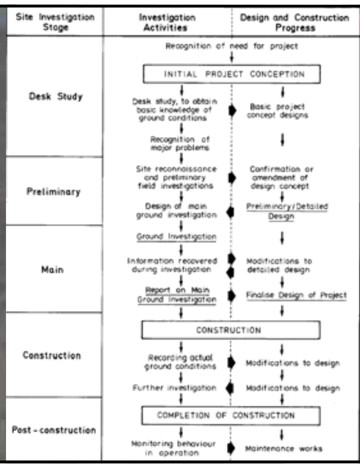
The Elements of Site Investigation

- ACT
    - assess the first phase results and revise the ground model
- PLAN
    - a second phase if necessary
    - more boreholes or vibrocores plus field tests (STPs, CPTs, vane shear etc.) to investigate unusual features
    - be prepared to amend the plan depending on what is revealed

The Elements of Site Investigation

- **GO ROUND AGAIN** as often as necessary
  - in particular –
    - CHECK what is revealed during construction against what was found in the GI and be prepared to
    - ACT - amend the design if necessary

Stages of Site Investigation



The Elements of Site Investigation

- preparation of a geotechnical report
  - factual or interpretative?
  - check the descriptions in the lab report against the descriptions in the borehole records – seldom done

Procuring GI - General

- quality is more important than cost!
- therefore, select GI contractors on reputation and ability.

Procuring GI – Within Government

- full GI service provided by GEO through term contracts – intended for small projects
- project office can invite separate tenders for GI for larger projects; Geotechnical Project Division (GP) of GEO will provide advice
- contractors can only tender if they are on the list of specialist contractors for GI

(does not apply to geophysics or sediment testing)

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GI service provided by GEO

– land GI term contracts	)	
– marine GI term contract	)	by GP
– geophysical survey term contract	)	Division
– sediment testing term contract	)	
– laboratory testing term contracts	)	by S&T Division
– in-house laboratory testing	)	

Note: S&T = Standards & Testing Division, GEO

Term Contract Areas

Current Contracts

current land GI term contracts include:

- **inspection pits, trial pits, trial trenches, slope surface stripping**
- **drilling and sampling**
- **field testing**
  - standard penetration test
  - dynamic probing tests
  - vane shear tests
  - in situ density tests
  - permeability / response tests
  - impression packer / water absorption tests
  - pressuremeter tests
  - inclination and bearing measurements

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Current Contracts

current land GI term contracts also include:

- **drillhole geophysics**
  - acoustic borehole televiewer
  - borehole caliper
  - gamma density probe
  - natural gamma spectrum probe
  - magnetometry
  - time domain reflectometry
- **instrumentation**
  - standpipes / piezometers / piezometer buckets
  - automatic groundwater monitoring
  - inclinometer / inclination and bearing measurements

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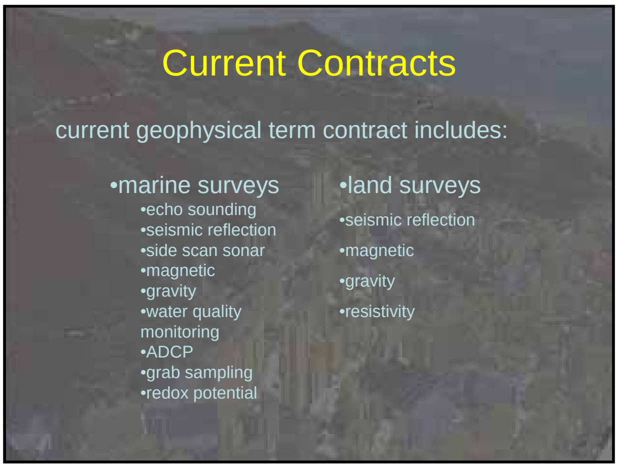
Current Contracts

current marine GI term contract includes:

- **drilling and sampling**)
- **field testing**)
  - standard penetration test) All from floating or
  - cone penetration test) jack-up craft
  - vane shear test) or from
  - permeability tests) scaffolding over
  - impression packer test) shallow water
  - pressuremeter test)
- **vibrocoring**
- **grab sampling**


Current Contracts
current geophysical term contract includes:
•marine surveys
•echo sounding
•seismic reflection
•side scan sonar
•magnetic
•gravity
•water quality monitoring
•ADCP
•grab sampling
•redox potential
•land surveys
•seismic reflection
•magnetic
•gravity
•resistivity


Questions?
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GI Techniques
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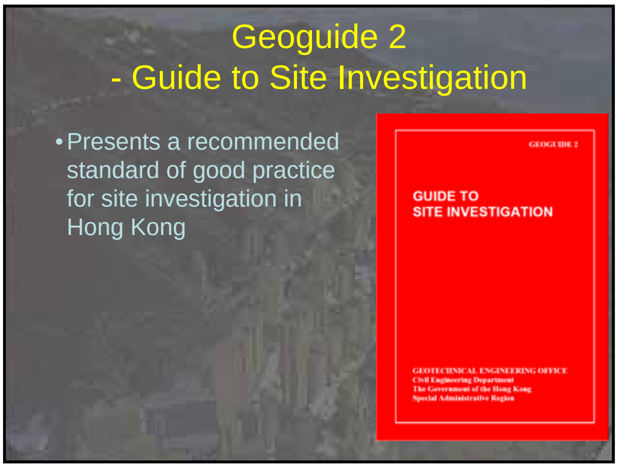
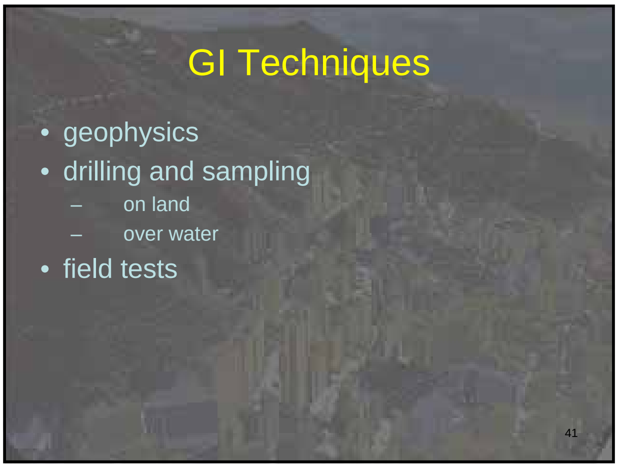

Geoguide 2
- Guide to Site Investigation
•Presents a recommended standard of good practice for site investigation in Hong Kong
GEOGUIDE 2
GUIDE TO
SITE INVESTIGATION
GEOTECHNICAL ENGINEERING OFFICE
Civil Engineering Department
The Government of the Hong Kong
Special Administrative Region


GI Techniques
• geophysics
• drilling and sampling
– on land
– over water
• field tests
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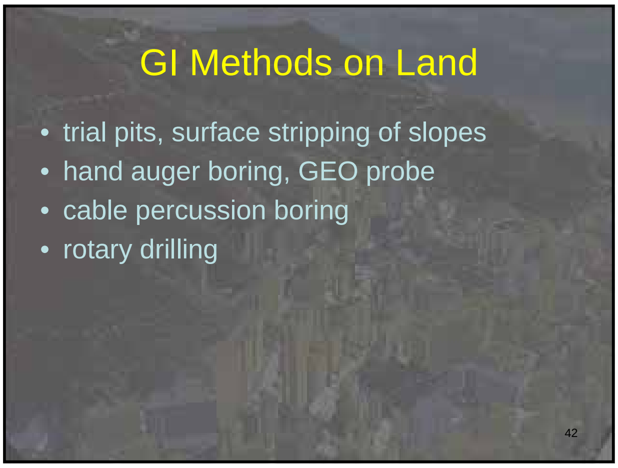
GI Methods on Land
• trial pits, surface stripping of slopes
• hand auger boring, GEO probe
• cable percussion boring
• rotary drilling
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Cable Percussion Boring

- extensively used in areas of soft soils (e.g. UK)
- fast, cheap
- light equipment
  - tripod rig, winch
  - bailer (shell), clay cutter, chisel
- don't use on slopes or behind retaining walls

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Cable percussion (shell & auger) boring

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Rotary Drilling

- open hole drilling
- core drilling
  - double tube
  - triple tube

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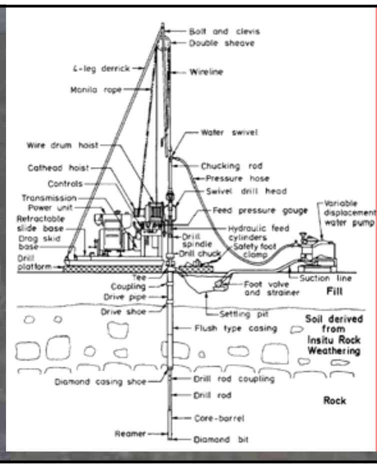
Rotary Drilling Rig



Open Hole Drilling

- useful only to advance a hole to the depth at which sampling, field testing or installation of instrumentation is to begin
- yields little information on the material being drilled
- wash-boring normally used instead but can be dangerous

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Core Drilling

- annular cutting bit
- core retained in the barrel and is retrieved
- success depends on the skill of the operator, particularly in weak or fractured rock
- choice of drill bit and core barrel affects recovery

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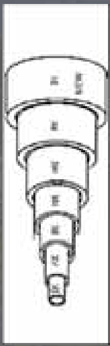
Casing of Boreholes

- casing is usually required for land boreholes and always required for marine boreholes
- usually use H-size (101mm ID)
- telescoping required if borehole is deep – therefore deep holes are much more expensive
- start with P size (140mm ID) for deeper holes



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Drilling Fluid

- water
- drilling mud – bentonite or polymer
- air-foam

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Sampling

- block samples
- jar samples
- SPT liner samples
- piston samples
- driven samples
- 'Mazier' samples
  - see Geoguide 2, tables 8 & 9 for quality classification

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Material Type	Typical Composition of Materials	Sampling Procedure	Expected Quality Class
Soils derived from insitu rock weathering	Composition of soils varies depending on the nature of parent rock material. Soils derived from granitic rock are usually silty and clayey sands; soils derived from volcanic rock are usually sandy and clayey silts.	Block sample from dry excavation	1
		Large diameter triple-tube core-barrel (102mm diameter cores) with retractor shoe, air-foam flush	1
		Triple-tube core-barrel (≥ 76mm diameter cores) with retractor shoe	1/2
		U100 sampler	2/4
		SPT split barrel sampler with or without liner	3/4
		Bulk samples and jar samples from dry open excavation	3/4
		Light percussion shell and chisel for boulders	5
Colluvium	Fresh or variably decomposed rock fragments (boulders, cobbles and gravels) within a matrix of varying proportions of sand, silt and clay	The sampling procedures for soils derived from insitu rock weathering apply.	
Alluvial and marine deposits	The following materials can be found : (a) Granular soils (sands, silty sands or sandy silts)	Piston sampler or compressed air sand sampler	2/3
		U100 sampler (with core-catcher)	4
		SPT split barrel sampler	4
		Light percussion shell	5
	(b) Very soft to soft cohesive soils (sandy clays, silty clays or clays)	Piston sampler	1
		Thin-walled sampler	1/2
		U100 sampler	2/3
		Delft continuous sampler	2/3
		Light percussion clay cutter (dry boreholes) or shell (wet boreholes)	4/5
	(c) Firm to very stiff cohesive soils	Triple-tube core-barrel with retractor shoe	1/2
		U100 sampler	2/3
		Light percussion clay cutter	5
	(d) Cohesive and granular soils containing boulders, cobbles or gravel	The sampling procedures for soils derived from insitu rock weathering apply.	
Fill	Variable material, which can include compacted or uncompacted soil, rock fragments and building debris mixtures	See sampling procedures for relevant soil type and composition under "Alluvial and Marine Deposits" above.	
Rock	All rock types found in Hong Kong, including boulders in colluvium	Diamond core drilling with double or triple-tube core-barrel. The latter generally causes less disturbance and gives better core recovery, especially in highly fractured or jointed rocks.	N/A

Notes : (1) The typical composition of materials should only be taken as a general guide.
(2) The quality classes are defined in Table 9.
(3) The expected quality classes given should only be taken as a guide, as sample quality is highly dependent on workmanship and on the compactness (or consistency) and grading of the soil.

Geoguide 2 – Table 8

Expected sample quality from different sampling procedures for Hong Kong materials

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Sample Quality	Soil Properties that Can Be Reliably Determined
Class 1	Classification, moisture content, density, strength, deformation and consolidation characteristics
Class 2	Classification, moisture content, density
Class 3	Classification, moisture content
Class 4	Classification
Class 5	None (approximate sequence of materials only)

Notes : (1) Large diameter class 1 and class 2 samples are often sufficient to allow the 'fabric' of the soil to be examined. Sometimes this may also be done using class 3 and class 4 samples.
(2) Remoulded properties can be obtained using class 1 to class 4 samples.
(3) Table taken from BS 5930 (BSI, 1981a).

Geoguide 2 – Table 9

Soil sample quality classification

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Piston Samples

- for sampling of soft clay / silt
- 76mm or 100 mm Ø sampler
- 1 m long steel sampling tube with cutting edge
- Class 1 samples

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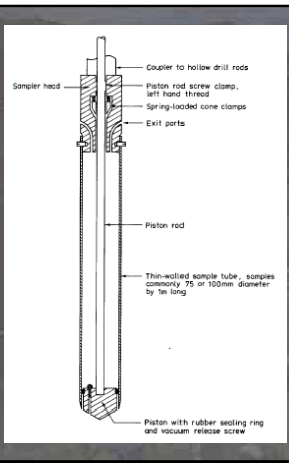


Piston sampler

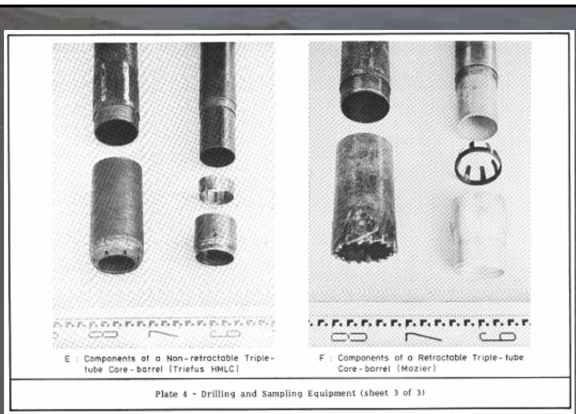
Driven Samplers

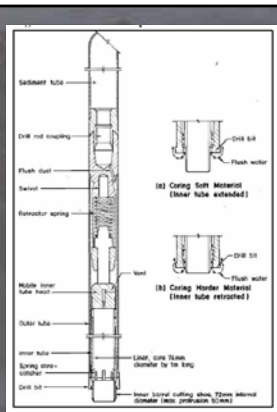
- for sampling firm & stiff clay / silt & sand
- U76 or U100 open drive sample tubes
- 450 mm long steel sampling tube with cutting shoe
- can be coupled to give 900mm long samples
- Class 2-3 samples

U76/U100 sampler

Core Samples

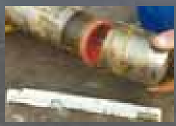
- core samples taken by rotary drilling in weathered in-situ rock or soil
- double tube core-barrel or retractable triple-tube core-barrel fitted with PVC or transparent liner
- min. 74 mm internal Ø, 1 m long
- compatible with the commonly-used laboratory triaxial testing apparatus





Geoguide 2
Figure 18

Retractable triple tube core barrel (Mazier)



Core Barrels

Potential problems

- depth of hole
  - cleaning hole is important
    - flush thoroughly
    - flush through core barrel before coring
  - measure the depth after flushing
    - measure with tape
    - check casing depth
    - check drill string length

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Potential problems

- sampling difficult material
  - colluvium
  - saprolite
- continuous sampling or SPT and Mazier at alternate 2m centres?

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Field Testing

- SPT (Standard Penetration Test)
- vane shear test
- permeability test
- pressuremeter test
- impression packer survey
- CPT (Cone Penetration Test)

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SPT

- deceptively simple
- correlations well established
- supervision required in order to avoid problems
  - high blow counts allowed in Hong Kong cause equipment damage
  - loose connections => energy loss => wrong results

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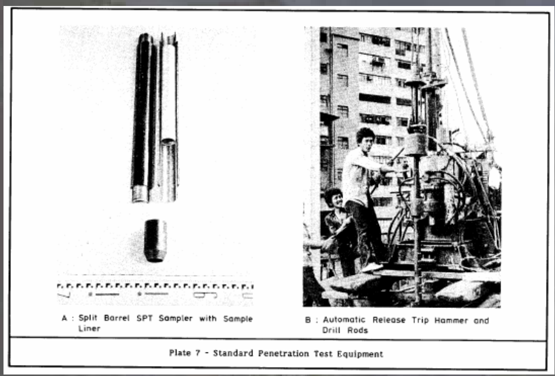
Standard Penetration Testing



SPT Equipment

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Vane Shear Test

- for saturated cohesive soil with C_u < 75kPa
- used in marine mud in Hong Kong
- if soil is homogeneous, values of shear strength are more valid than lab test values
- can be misleading if soil is laminated or contains shell fragments

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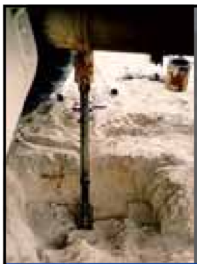
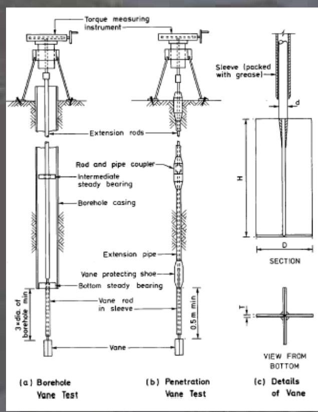
Vane Shear Test Equipment





Vane Shear Test

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Cone Penetration Test

- CPT apparatus consists of a thrust and reaction system, and an electric cone penetrometer
  - heavy reaction frame sits on seabed
  - cone advanced at steady penetration rate (20 mm/s) until refusal
  - electric cone measures tip resistance, sleeve friction and pore water pressure simultaneously
  - rapid profiling of sediment strata
  - determine broad sediment type and strength characteristics

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Cone Penetration Test (CPT) reaction frame

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Electric Cone Penetrometer

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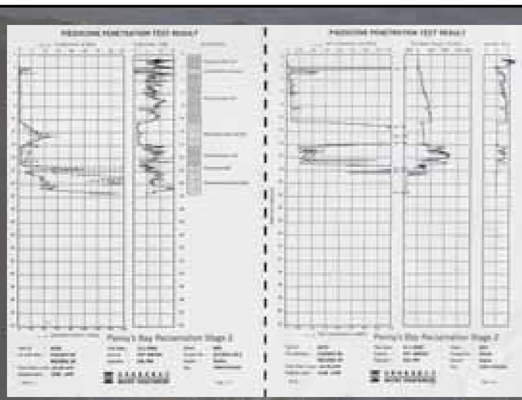

Cone Penetrometer Test record

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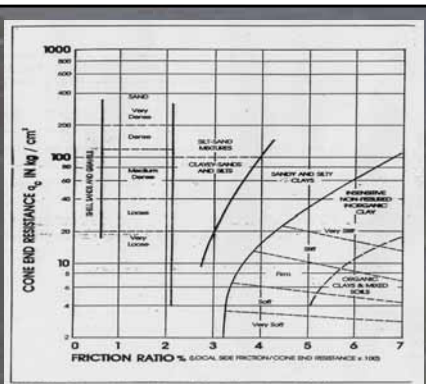

Guide for determining soil type (after Schmertman 1969).

Chart for determining soil type

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Questions?

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BREAK

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Marine GI

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Projects that require Marine GI:

- reclamation areas
- construction of marine structures, e.g. piers, bridges, seawalls
- marine disposal facilities
- installation of submarine tunnels & pipelines
- widening / deepening of drainage / navigation channel

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Working Platform

- regular (floating) marine craft
- jack-up marine craft (10m > water depth >1m)
- scaffold platform erected over shallow water (water depth < 1m)

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Regular Marine Craft (Anchored Barge)

- floating craft with anchorage system
  - need to deal with tidal variation, current and waves
  - drilling rig incorporates a heave-compensating mechanism to prevent wave/swell-induced motion
  - auxiliary vessel required to handle anchors
  - can be used in any depth within HK waters

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A floating marine craft (anchored barge)

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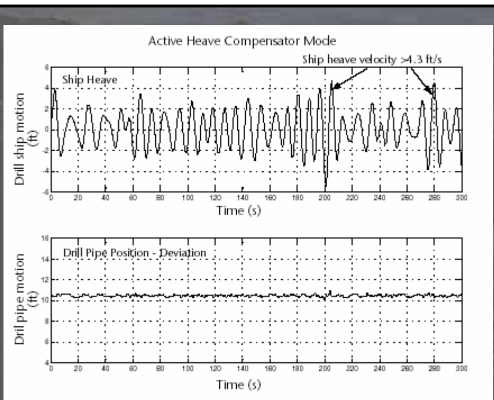

Heave compensation

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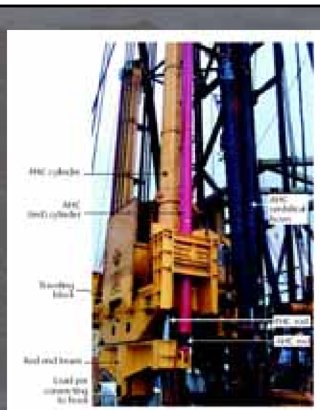

Heave compensator on an oil drilling ship

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Jack-up Marine Craft

- platform fitted with retractable legs
  - floated into position and jacked out of water
  - no problem of heave
  - used for near-shore investigation
  - capable of carrying out works in water depth from 1m to 10m

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Jack-up barge being floated into position

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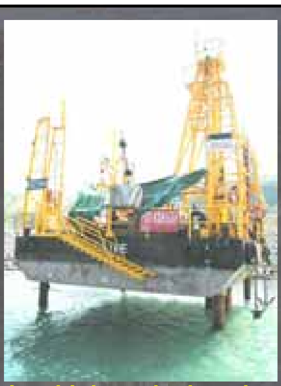

Jack-up rig with legs deployed and raised above water level

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Lifting a jack-up barge across the bridge over Kai Tak Nullah

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Vibrocore Sampling

- a sample of a continuous vertical profile of sediment taken in soft soil (Marine Deposit, Alluvium etc.) by vibration
- 100 / 76 mm Ø, 6m length
- vibrocore barrel fitted with a rigid plastic liner with a piston to form a vacuum over the retained sample
- a basket core retainer fitted at the bottom of the tube to assist in the recovery of samples
- samples taken up to 12 m depth without casing

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Vibrocore tube and vibrator

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Vibrocore tube

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Removal of cutting shoe

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Removal of piston

93

Vibrocore sample in PVC liner - 6m per run

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Grab Sampling

- samples sea-bed sediment
  - collects 2 litres of sediment in each operation
  - samples placed in waterproof plastic bags or containers and stored at 4ºC before testing
  - for testing for sea-bed contaminants or as reference sediment for comparison

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Grab sampler

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Issue of Works Order

- subject to:
  - resolution of land matters
  - receipt of Marine Department notice
  - provision of details of supervisory staff
  - confirmation of funding arrangement

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Questions?

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Field instrumentation

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Planning a Monitoring Operation

1 GROUND BEHAVIOUR WARNING LEVELS AND CONTINGENCY ACTION	2 GENERAL MONITORING PLAN	3 DETAILED MONITORING PLAN
PROJECT DEFINITION Geometry; geology; groundwater; stress; construction programme ↓ GROUND BEHAVIOUR Mechanism; critical locations; magnitudes; rates ↓ CONTINGENCY PLANNING Decisions on hazard warning levels; action plans if warning levels exceeded	TERMS OF REFERENCE Monitoring objectives; budget ↓ WHAT TO MEASURE Displacement; water; pressure; load ↓ WHERE TO MEASURE Identify key locations and depths; establish priorities ↓ WHEN TO MEASURE Project duration; frequency of readings; frequency of reports	PERSONNEL No. of persons; allocation of responsibilities; liaison and reporting channels ↓ INSTRUMENTS Selection; calibration; detailed layout ↓ INSTALLATION Define installation locations, times and procedures ↓ MONITORING Define detailed monitoring programme ↓ DATA PROCESSING Draft & print data sheets and graphs; set up computation procedures ↓ REPORTING Define reporting requirements; timing; contents; responsibilities

Slope stability monitoring, instrumentation and equipment selection

- Groundwater levels and pore pressures
  - Measurement of groundwater levels
  - Measurement of pore pressures
  - Open hydraulic (Casagrande) piezometers
  - Closed hydraulic piezometers
  - Pneumatic piezometers
  - Electrical piezometers
  - Measurement of pore suctions
  - Location of piezometers

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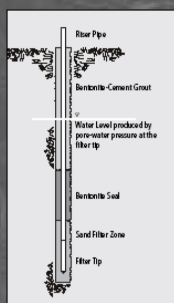
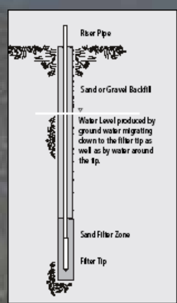
Standpipe Piezometer

Water Level Indicator



Water level in standpipe (Casagrande) piezometer is produced by pore-water pressure at the filter tip.



Water level in observation well is produced by the intake of the entire borehole.

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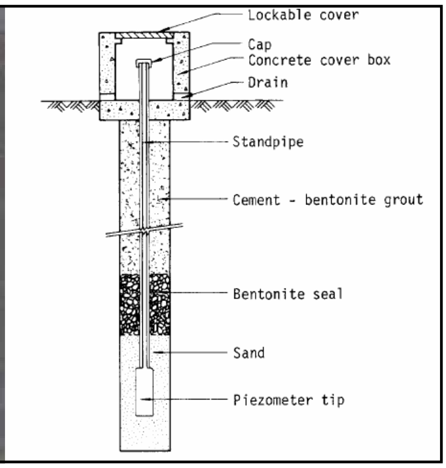
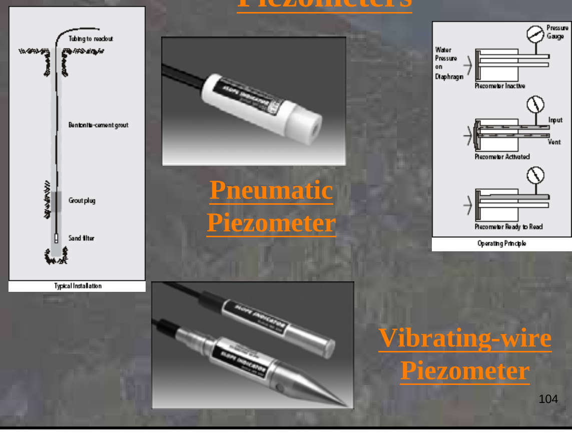
Open Hydraulic Piezometer



Piezometers



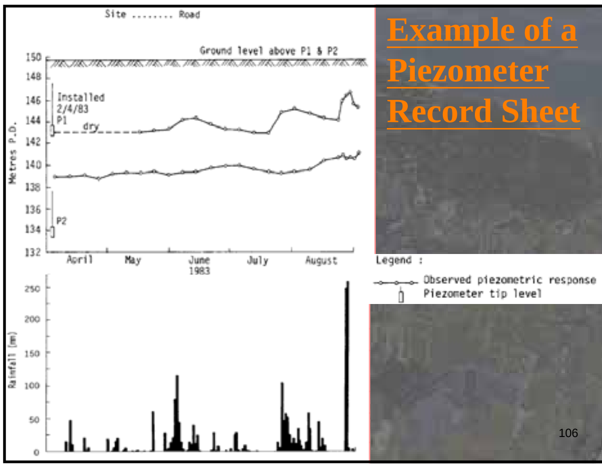
Pneumatic Piezometer

Vibrating-wire Piezometer

Piezometer Types

Type	Range	Response	Deairing	Remote Reading	Long Term Reliability	Other: Advantages	Other: Disadvantages
Open Hydraulic (Casagrande)	[illegible]	Slow	Self deairing	[illegible]	Very good	[illegible]	[illegible]
Closed Hydraulic [illegible]	Any positive pressure	Moderate	Can be deaired	Yes	[illegible]	[illegible]	[illegible]
Closed Hydraulic [illegible]	[illegible]	Moderate	Can be deaired	Yes	As above	[illegible]	[illegible]
Pneumatic	Any positive pressure	Rapid	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Electric vibrating-wire type	Any positive pressure	Rapid	As above	[illegible]	[illegible]		[illegible]
Electric resistance type	Any positive pressure	Rapid	As above	[illegible]	Poor		As above
Tensiometer	[illegible]	[illegible]	Can be deaired	Yes	Good	[illegible]	[illegible]
Psychrometer	[illegible]	Variable	Not relevant	[illegible]	[illegible]		[illegible]

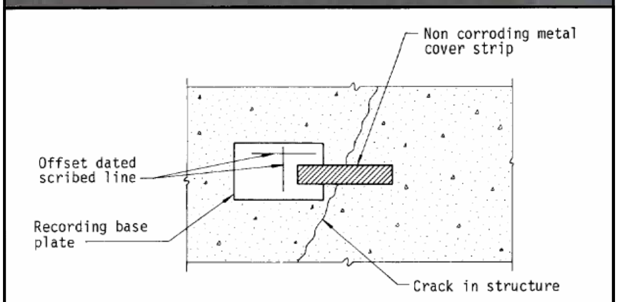
Example of a Piezometer Record Sheet

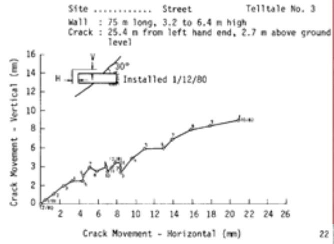


Slope stability monitoring, instrumentation and equipment selection

- Surface movements
  - Significance of movements
  - Structural cracking
  - Rock and soil slopes
  - Surveying
  - Photogrammetry

Tell-tale





Example of a Tell-tale Record

Slope stability monitoring, instrumentation and equipment selection

- Subsurface movements
  - Inclinometers
  - Slip indicators
  - Extensometers
  - Settlement gauges
- Loads and stresses
  - Load cells for rockbolts and anchors
  - Earth pressure cells

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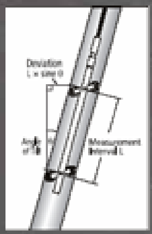
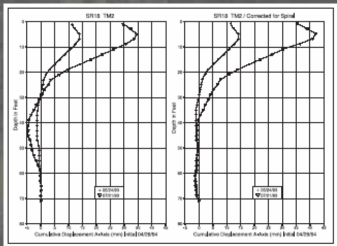
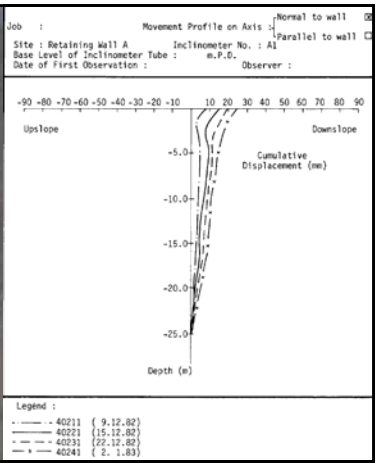
Inclinometer





Displacement graphs generated by DigiPro software. Spiral corrections were applied to graph on right.

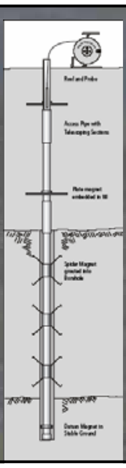
Example of an Inclinometer Record Sheet



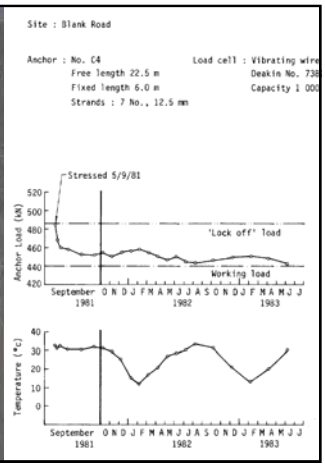
Magnet Extensometer

MAGNET EXTENSOMETER

The magnet extensometer provides multi-point measurements of settlement or heave along the axis of inclinometer casing or access pipe. The resulting data indicate the magnitude of settlement at various depths as well as the total amount of settlement. Readings are obtained with a portable readout.



Example of an Anchor Load Record Sheet



Load Cells

Type	Long Term Reliability	Remote Reading	Other: Advantages	Other: Disadvantages	Recommendation
Hydraulic Load Cell	Good	Not with dial gauge, possible with linear displacement transducer	Simple to operate	System fails if load cell or hydraulic tubes leak. Gauge needs to be connected permanently	Most suitable for long term monitoring if a transducer is used
Hydraulic Jack	Good except pressure gauges subject to corrosion	No, access required to measure	Simple hydraulic system	Not continuous reading. Jack must be pressurised until anchor head begins to move. Difficult to just lift head, large movements often occur	Not very suitable for long term regular monitoring. […] jack suitable for occasional testing
Photoelastic	Good	No	Cheap, simple to install, easily replaced	Reading requires practice. Limited to low loads	Suitable for […] and small anchors
Electrical (vibrating-wire type)	Moderate (up to 10 years)	Yes	Remote reading not affected by environment	Fairly expensive. Calibration may drift but recalibration possible	Most suitable where remote reading required
Electrical (resistance type)	Poor	No (a few metres is possible)	Simple, easy to read	As above. Stain gauges very susceptible to corrosion	Not suitable for long term use

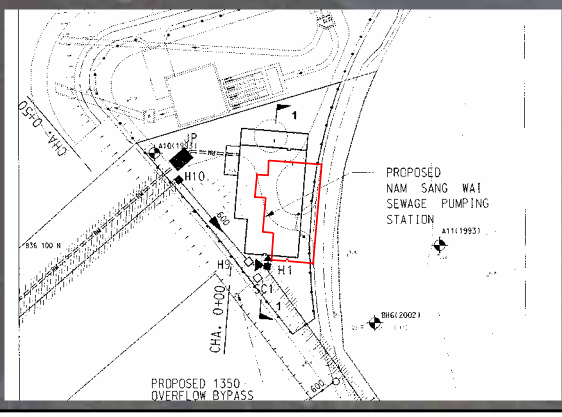
Questions?

Workshop Exercise on Ground Investigation

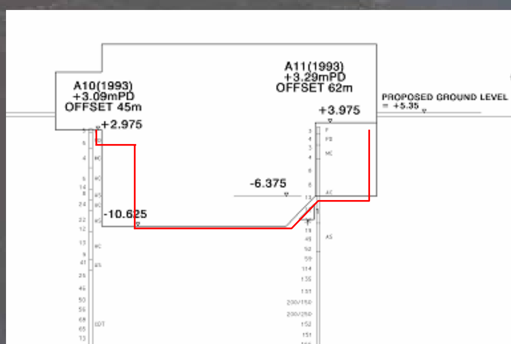
Activity:

Preparation of GI Plan for the Proposed Nam Sang Wai Sewage Pumping Station

Location Plan



Cross-Section 1-1



Existing Information

- The dimension of the Lower Section is approx. 25m x 23m.
- The general geology is 5.5m thick of Fill underlain by 2-2.5m thick of Marine Clay, 5-6m thick alluvial Clay and completely to highly decomposed bedrock.
- Ground water table is about 3.4m below existing ground level.

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Task

- To prepare a GI plan to collect sufficient information for the design of the foundation and basement excavation works.

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Requirements

1. Locations of the proposed investigation stations
2. Drilling and sampling requirements
3. Field Testing requirements
4. Field Installation requirements

Time Allowed = 20 minutes

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Thank You

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