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

- Natural Resources (Materials)
- Site Selection
- Forensic Investigation
- Construction Verification
- Development Project
- Study

Project Cycle

Ground Investigation

Common Problems & Trend

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

**Why doing GI?**
It is regarded 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).

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**WITHOUT SI, GROUND IS AN HAZARD**

Sink hole triggers dramatic Florida viaduct collapse

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

The reinforced concrete pier almost completely disappeared.

Source: [http://www.sptimes.com/2004/04/16/Tampabay/At_site_ofCollapse__shtml](http://www.sptimes.com/2004/04/16/Tampabay/At_site_ofCollapse__shtml)
WITHOUT SI, GROUND IS AN HAZARD

Light saves man in sinkhole scare

7:30 PM. When Lew Danley steadied his legs and saw an enormous sinkhole at Jam Road yesterday, he nearly fainted on the spot.

The idea at his home in Budhi Murti New Village, was missing... but to a slide.

The manhole, measuring 2.5m by 7m, was the first to occur in the area since last October, according to Mr. Lee. He said he would have fallen into the sinkhole if not for the 3m-wide, 2m-long, 2m-deep sinkhole, which was always on watch.

He also said he cannot leave his home because his neighbors have been casing at the house.

The sinkhole was discovered on May 13 and measured 2m by 2m.

The manhole, which is 10m by 10m, will be the first to occur in the area since last October, according to Mr. Lee. The sinkhole was discovered on May 13 and measured 2m by 2m.

Deep trouble: There are about 200 people living at the back of the village, which is a large and very deep dry season, which has existed for over 10 years.
WITH SI, GROUND CAN BE A HAZARD

UNDER THE MUD VOLCANO
It began with a burst of steam and a spurt of mud. But the gloopi 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 geologists Richard Davies believes caused the disaster.

1. Driller exploring for gas bored 3,000 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, cavities formed and collapsed, causing faults.

Source: National Geographic (Jan 2008)

GOD CREATION & HUMAN CREATION
Geotechnical Engineering

- Fluid Control Systems (e.g. dams)
- Structural Support Systems (e.g. foundations)
- Surface Geo-structures (e.g. embankments, landfills)
- Underground Geo-structures (e.g. tunnels)
- Ground Improvement (e.g. densification, remediation)
- Construction
- Site Exploration
- Ground Movements
- Materials
- Geochemistry
- Hydrology
- Rock Mechanics
- Soil Mechanics
- Fracture Mechanics
- Public Policy
- Risk Management
- Mechanical Engineering
- Contract Law

Modified from Morgenstern (2000)
Captain, no worry! We are still far from it.

How GI cost

Consequence

How GI shall be done?
Codes & Standards
Stage 1 of GI

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

Stage 2 of GI

- Field Supervision
- Sampling, In-situ Testing, Geophysical Survey
- Monitoring
- Laboratory Testing
- Work Certification
Stage 3 of GI

- Factual Data Compilation
- Interpretation & Reporting
- Report Preparation

“Without Site Investigation, Ground is a Hazard”

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

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: 2 probing per critical section

- **Vertical Extent**
  - Foundation: 3x8% stress bulb 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 waterproofing 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 affect
- In-situ stress

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

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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 - (brief overview of ground conditions)
- Detailed GI - Arch/Let area for more information
- GI in Construction/Verification - Areas not covered in previous GI/Detailing 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

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

- 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
  - Mazer 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


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
Sampler

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

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

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>During</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress relief</td>
<td>Stress relief</td>
<td>Stress relief</td>
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</tr>
<tr>
<td>Swelling</td>
<td>Remoulding</td>
<td>Moisture migration</td>
<td></td>
</tr>
<tr>
<td>Compaction</td>
<td>Displacement</td>
<td>Extrusion</td>
<td></td>
</tr>
<tr>
<td>Displacement</td>
<td>Shattering</td>
<td>Moisture loss</td>
<td></td>
</tr>
<tr>
<td>Base heave</td>
<td>Stone at cutting shoe</td>
<td>Heating</td>
<td></td>
</tr>
<tr>
<td>Piping</td>
<td>Mixing or segregation</td>
<td>Vibration</td>
<td></td>
</tr>
<tr>
<td>Caving</td>
<td>Poor recovery</td>
<td>Contamination</td>
<td></td>
</tr>
</tbody>
</table>


Sample Disturbance

• Poor recovery
  o Longer rest period for sample swelling
  o Slight over-sampling
  o Use of sample retainer

• Sample contamination
Sample Quality Classification

<table>
<thead>
<tr>
<th>Sample Quality</th>
<th>Soil Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Classification</td>
</tr>
<tr>
<td>Class 1</td>
<td>✓</td>
</tr>
<tr>
<td>Class 2</td>
<td>✓</td>
</tr>
<tr>
<td>Class 3</td>
<td>✓</td>
</tr>
<tr>
<td>Class 4</td>
<td>✓</td>
</tr>
<tr>
<td>Class 5</td>
<td>X</td>
</tr>
</tbody>
</table>

BS 5930 (1981)

In-situ Tests

Piezocone (CPTu)
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

<table>
<thead>
<tr>
<th>Test</th>
<th>Stress</th>
<th>Strength</th>
<th>Stiffness</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPT</td>
<td>G</td>
<td>C</td>
<td>R</td>
<td>G</td>
</tr>
<tr>
<td>CPT/CPTu</td>
<td>G, C</td>
<td>G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMT</td>
<td>G, C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Borehole PMT</td>
<td>C</td>
<td>G, R</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PLT</td>
<td>C</td>
<td>G, R</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>VST</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seismic</td>
<td></td>
<td></td>
<td></td>
<td>G, C, R</td>
</tr>
<tr>
<td>SBPMT</td>
<td>G, C</td>
<td>G, C</td>
<td></td>
<td>G, C</td>
</tr>
<tr>
<td>Falling/Rising Head Test</td>
<td></td>
<td></td>
<td></td>
<td>G</td>
</tr>
<tr>
<td>Constant Head Test</td>
<td></td>
<td></td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Packer Test</td>
<td></td>
<td></td>
<td></td>
<td>R</td>
</tr>
</tbody>
</table>


\[ \begin{align*}
\text{K}_0 & = \text{granular}, \quad \text{C} = \text{cohesive}, \quad \text{R} = \text{Rock}
\end{align*} \]

### Summary on the Common Types of Ground Investigation, Field Tests, Sampling & Laboratory Tests

<table>
<thead>
<tr>
<th>Description</th>
<th>Types of Ground Investigation</th>
<th>Field Test</th>
<th>Laboratory Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Self ground invasion</td>
<td>m</td>
<td>m</td>
<td>m</td>
</tr>
<tr>
<td>2) Shallow foundation clay</td>
<td>m</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>3) Pile Foundation</td>
<td>m</td>
<td>m</td>
<td>m</td>
</tr>
<tr>
<td>4) Slope Cut Fill</td>
<td>m</td>
<td>m</td>
<td>m</td>
</tr>
</tbody>
</table>

Legend: JK = JKH Probe, HA = Hand Auger, TP = Triaxial Test, BM = Bentonite, FZ = Flextome, GS = Geophysical Survey.
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

- BS1377
- P11: In-situ (classification test)
- P5: Compaction index test
- P6: Chemical & physical test
- P7: Unconfined compression test
- P8: Consolidation & permeability test
- P9: Hydraulic cell & swell test
Table Top Geotechnical Centrifuge

4000 kg Compact Geotechnical Centrifuge

Vertical orientation for high speed running

A World First - The G-max Modular CGC

Fig 1: Drum ring channel with 2 soil compartment boxes

Fig 2: Basin rotor table with 2 evoluing soil string boxes

Source: Life Style Magazine - EDGE
Ground Characterisation

Focus of Geological Model

- Stratification
- Historical Geological Processes
- Weathering
- Hydrogeology
- Geological Structures
- Geomorphology

Geological Mapping

Mapping of:
- Geological features (Structural settings)
- Weathering profile
- Outcrop exposure
- Seepage conditions

- Geomorphology
- Lithology
- Stratification
- Sequence of geological actions & history
Ground Characterisation

Focus of Geotechnical Model

- Subsurface Profile
- Strength
- Stiffness
- Permeability
- Material Type
- Chemical Characteristics

GEOTECHNICAL MODEL
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

We are connecting the bridge deck at the same level successfully!
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

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

\[ \sigma'_1 = \sigma'_3 + \sigma'_u \left( m \left( \frac{\sigma'_3}{\sigma'_u} \right) + s \right) \]
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)
  - 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
References


References

Site Investigation Steering Group, "Without Site Investigation, Ground is a Hazard”, Part 3, Site Investigation in Construction, Thomas Telford Ltd.
THANKYOU

SITE RECONNAISSANCE
Case Study 1 - Geotechnical Review

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

General Subsoil Profile

Blocks 1, 3, 17 (P. 2C), Blocks 1, 2 (P. 2D)
General Subsoil Profile

- Fill
- Compressible Soft Clay
- Firm to Stiff Soil
- Blocks 4 & 5 (P. 2C)

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
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
Monitoring Results

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