INTRODUCTION

- Deep basement construction
  - Urban areas for parking space
  - Infrastructures, e.g. KVMRT

- Risk associated with deep basement construction high!

- Proper Design and Construction Control = IMPORTANT
FAILURES of DEEP EXCAVATION
FAILURES of DEEP EXCAVATION

SOIL PARAMETERS
SOIL PARAMETERS

- Some important soil parameters related to retaining wall and support system design:
  - Shear strength parameters ($s_u$, $\phi'$ & $c'$)
  - Soil permeability
  - Soil stiffness

Shear strength parameters ($\phi'$ and $c'$)
- Commonly obtained from CIU for effective stress strength parameters
- Commonly obtained using in-situ test methods (e.g. field vane shear test) for total stress strength parameters, $s_u$
- Finite element analysis – requires proper understanding of the constitutive soil models
SOIL PARAMETERS

- Soil permeability
  - Important in order to choose modelling in drained or undrained condition
  - In-situ tests (rising, falling or constant head) recommended
  - Values obtained from tests should always be compared to published values (e.g. BS8004)

<table>
<thead>
<tr>
<th>Drainage Type</th>
<th>Good</th>
<th>Poor</th>
<th>Practically impossible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of soil</td>
<td>Clean gravels</td>
<td>Clean sands and sand gravel mixtures</td>
<td>Very fine sands, silts and clay silts terminate</td>
</tr>
<tr>
<td></td>
<td>Unfissured clays and well mixed clay soils containing more than 10% clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dedicated and fissured clays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recommended method of determining k</td>
<td>Pumping tests in situ</td>
<td>Flow from parameter file</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Constant head permeability tests</td>
<td>Equilibrium, Non-equilibrium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Estimation from grading curves</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BS8004: 1986
SOIL PARAMETERS

- Soil stiffness
  - Important parameters for retaining wall design
    BUT difficult to obtain reliably
  - In Malaysia, sometimes based on empirical correlations
  - Laboratory tests unreliable and values obtained significantly smaller than appropriate values for retaining wall design
  - Designer should be aware of small-strain nature of retaining wall design
SOIL PARAMETERS

- Soil stiffness
  - Seismic tests or seismic piezocone appears promising
  - **Basis of empirical correlations should be understood** – e.g. local soil conditions, constitutive model used, etc.
  - Example, correlations in Kenny Hill formation using hardening soil model of PLAXIS software

Field and laboratory methods to evaluate shear wave velocity
<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Maximum small-strain shear modulus, $G_0$ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft clays</td>
<td>2,750 to 13,750</td>
</tr>
<tr>
<td>Firm clays</td>
<td>6,900 to 34,500</td>
</tr>
<tr>
<td>Silty sands</td>
<td>27,600 to 138,000</td>
</tr>
<tr>
<td>Dense sands and gravels</td>
<td>69,000 to 345,000</td>
</tr>
</tbody>
</table>

Typical values of maximum small-strain shear modulus

\[ G_0 = 15,560 \ (N_60)^{0.68} \]
\[ G_0 = 1,634 (q_c)^{0.25} (\sigma'_{vo})^{0.375} \]
\[ \gamma_{0.7} = \frac{0.385}{4G_0} (2c(1 + \cos \vartheta) + \sigma'(1 + K_o) \sin \vartheta) \]
DESIGN OF RETAINING WALLS

DESIGN CONSIDERATIONS

- Overall stability
- Basal heave failure
- Hydraulic failure
- Axial stability
- Finite element analysis
- Ground movement associated with excavation
OVERALL STABILITY

- To ensure sufficient **wall embedment**
  - Overturning of wall and overall slope stability
  - Adequate factors of safety (e.g. 1.4 for high-risk-to-life structures)

EUROCODE 7
DESIGN CONSIDERATIONS

- Overall stability
- **Basal heave failure**
- Hydraulic failure
- Axial stability
- Finite element analysis
- Ground movement associated with excavation

BASAL HEAVE FAILURE

- Critical for deep excavation in **soft ground**
- **Analogous to bearing capacity failure**, only in reverse
- Available methods:
  - Terzaghi (1943) – shallow and wide excavations
  - Bjerrum & Eide (1956) – deep and narrow and excavations
  - **Moment equilibrium** - adequate for routine design
Required factor of safety for moment equilibrium method

- **1.2** (Kohsaka & Ishizuka, 1995)
- Vertical shear resistance along retained ground shallower than the excavation is ignored

Note:
The required FOS is 1.2 where the vertical shear resistance along the retained ground shallower than the excavation is ignored. (Kohsaka & Ishizuka, 1995.)
DESIGN CONSIDERATIONS

- Overall stability
- Basal heave failure
- **Hydraulic failure**
- Axial stability
- Finite element analysis
- Ground movement associated with excavation

HYDRAULIC FAILURE

- Base instability caused by piping
  - Seepage due to high groundwater level

- Available methods
  - Terzaghi’s method
  - Critical hydraulic gradient method
## HYDRAULIC FAILURE CHECKS

<table>
<thead>
<tr>
<th>Terzaghi’s method</th>
<th>Critical hydraulic method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diagram</strong></td>
<td></td>
</tr>
<tr>
<td>$w = \gamma' L$</td>
<td>$h_w$ difference of water head</td>
</tr>
<tr>
<td>$\gamma_s$</td>
<td>$L_s$ permeation length</td>
</tr>
<tr>
<td>$u = \frac{1}{2} \gamma' h_w$</td>
<td>$t$ length of stream line</td>
</tr>
<tr>
<td>$\gamma_u$</td>
<td>$G_s$ specific gravity of soil particle</td>
</tr>
<tr>
<td>$\gamma_w$</td>
<td>$e$ void ratio</td>
</tr>
<tr>
<td><strong>Equation</strong></td>
<td></td>
</tr>
<tr>
<td>$FOS = \frac{w}{u} = \frac{2 \gamma' L_s}{\gamma_w h_w}$</td>
<td>$FOS = i_s / i = \frac{G_s - 1}{1 + e} \frac{L_s}{h_w} = \frac{\gamma_u}{\gamma_w h_w}$</td>
</tr>
<tr>
<td>$FOS \geq 1.2$ (temporary works)</td>
<td>$FOS \geq 2.0$ (permanent works)</td>
</tr>
</tbody>
</table>

### HYDRAULIC FAILURE

- **Terzaghi’s method** recommended
  - Based on latest research by Tanaka & Verruijt (1999)
  - Factor of safety required – **1.2 to 1.5**
HEAVING DUE TO ARTESIAN PRESSURE

\[ FOS = \frac{W}{u} \quad FOS \geq 1.2 \]

\( w = \) overburden pressure
\( (w = \gamma h) \)
\( \gamma = \) bulk unit weight of soil

\( u = \) pore water pressure
\( (u = \gamma_u h_w) \)

- Clayey Soils
- Sandy Soils

HYDRAULIC FAILURE

- Heaving due to artesian pressure
  - Factor of safety – 1.0 to 1.2
  - Smaller FOS sufficient as it did not consider shear strength or adhesion strength of the ground and retaining wall
DESIGN CONSIDERATIONS

- Overall stability
- Basal heave failure
- Hydraulic failure
- Axial stability
- Finite element analysis
- Ground movement associated with excavation

AXIAL STABILITY

- Simple check but is often overlooked

- Factor of safety required – 2.0
Soil-structure interaction important for deep basement retaining wall design

Commercial finite element software easily available and very user friendly (e.g. PLAXIS, CRISP, etc.)

Understanding and proper use important!!!
GEOMETRICAL DATA

- Provision for over-excavation
  - for cantilever walls - 10% of the wall height above excavation level, limited to a maximum of 0.5m
  - for a supported walls - 10% of the distance between the lowest support and the excavation level, limited to a maximum of 0.5m
- Can be reduced when excavation surface can be controlled reliably throughout the excavation works

GEOMETRICAL DATA

- Water levels
  - Flood level should be taken into consideration for flood prone areas
- Surcharge
  - Minimum surcharge of 10kPa – for construction loads and unforeseen circumstances
CONSTITUTIVE SOIL MODELS

- Various constitutive soil models, e.g. Mohr-Coulomb, Cam Clay, Hardening Soil, Soft Soil, etc.
  - Proper understanding and limitations of each model important!
  - Incorrect use of soil models in Nicoll Highway!
FEM ANALYSIS OF LIMIT STATE

- **Eurocodes** have replaced British Standards

- Current design of retaining wall for deep basement mostly based on “**working state design**”
Three (3) schemes to perform limit states design using FEM:

(A) Perform all the calculations with design (factored) values of ground and action parameters

(B) Simulate the whole stress history using ground parameters at characteristic levels
    - check the safety at the relevant stages

(C) Simulate the whole stress history using ground parameters at characteristic levels and multiplying these values by the load factor (which then in fact acts as a model factor on the effects of actions).

Important to evaluate limit state:

- Part of the reason for factors of safety is to cover human error
- Limit state analyses investigate unrealistic states, especially in the Ultimate Limit State (ULS) analysis

To ensure that limit state is sufficiently unlikely to occur
Latest: 3-D FEM for complicated project

GROUND MOVEMENT ASSOCIATED WITH EXCAVATION
GROUND MOVEMENT

- Deep excavation include a substantial component of **horizontal strain**

- **Damage estimation** should include both angular distortion and horizontal strain
GROUND MOVEMENT INDUCED BY DEEP EXCAVATION

Settlement

47
### Damage criteria by Boscardin & Cording, 1989

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>ANGULAR DISTORTION, $\beta \times 10^{-3}$</th>
<th>HORIZONTAL STRAIN, $\varepsilon_h \times 10^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>$&lt; \sim 1.1$</td>
<td>$&gt; 0.5$</td>
</tr>
<tr>
<td>Very slight</td>
<td>$\sim 1.1 &lt; \beta &lt; \sim 1.6$</td>
<td>$0.5 &lt; \varepsilon_h &lt; 0.75$</td>
</tr>
<tr>
<td>Slight</td>
<td>$\sim 1.6 &lt; \beta &lt; \sim 3.3$</td>
<td>$0.75 &lt; \varepsilon_h &lt; 1.5$</td>
</tr>
<tr>
<td>Moderate</td>
<td>$\sim 3.3 &lt; \beta &lt; \sim 6.7$</td>
<td>$1.5 &lt; \varepsilon_h &lt; 3.0$</td>
</tr>
<tr>
<td>Severe</td>
<td>$&gt; \sim 6.7$</td>
<td>$&gt; 3.0$</td>
</tr>
</tbody>
</table>
Before excavation

After excavation

$L = \text{length of building}$

$\Delta \beta = \Delta / L$

$\epsilon_h = h / L$

E.g.

Building length = 10m

Allowable lateral movement = 15mm

($\epsilon_h = 1.5 \times 10^{-3}$)

Instrumentation

Monitoring

Prepared: Ir. Chow Chee Meng
Types of Instruments

- **Deformation/Movement**
  - Inclinometer
  - Extensometer
  - Ground Movement Marker
  - Tiltmeter
  - Crackmeter

- **Water/Earth Pressure**
  - Piezometer, Observation Well
  - Earth Pressure Cell

- **Load/Stress/Strain**
  - Strain Gauges
  - Load Cell

- **Thermal**
  - Thermal Coupler

- **Flow**
  - V-Notch Gauge

- **Vibration**
  - Accelerometer
Instruments (e.g. settlement/displacement markers, tiltmeters, vibration monitoring, standpipes, etc. at neighbouring buildings)
Some Common Mistakes

- Inclinometer needs to be terminated in stable stratum

- Important to establish base readings

- Important to establish objective of monitoring (e.g. observational method, safety requirements, etc.)
## MONITORING TRIGGER LEVELS

### General Monitoring Trigger Levels

<table>
<thead>
<tr>
<th>Feature to Be Monitored</th>
<th>Instrument / Parameter to Be Monitored</th>
<th>Alert</th>
<th>Action</th>
<th>Alarm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heritage Structures/Buildings</td>
<td>Building Settlement (mm)</td>
<td>5</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Distortion Angle (1:1000)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structures/Buildings on Deep Foundation</td>
<td>Building Settlement (mm)</td>
<td>7</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Distortion Angle (1:750)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structures/Building on Shallow Foundation</td>
<td>Building Settlement (mm)</td>
<td>12</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Distortion Angle (1:750)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing Building/Structures</td>
<td>Air Overpressure</td>
<td>100dBL</td>
<td>120dBL</td>
<td>130dBL</td>
</tr>
<tr>
<td>Groundwater Drawdown (Not Piezometric Head)</td>
<td>Stabilometer/Piezometer Stabilometer</td>
<td>1000mm with reference to baseline reading</td>
<td>1500mm with reference to baseline reading</td>
<td>2000mm with reference to baseline reading</td>
</tr>
</tbody>
</table>

Note: The above values are subject to adjustment after completion of building condition survey works.

### Monitoring Trigger Levels

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Alert</th>
<th>Action</th>
<th>Alarm</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN(W)-101, IN(W)-102</td>
<td>40mm</td>
<td>50mm</td>
<td>75mm</td>
</tr>
<tr>
<td>IN(W)-103, IN(W)-104</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(W)-105, IN(W)-111</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(S)-101, IN(S)-102</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(S)-103, IN(S)-108</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(S)-110</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(W)-107</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(W)-108, IN(W)-110</td>
<td>25mm</td>
<td>50mm</td>
<td>75mm</td>
</tr>
<tr>
<td>IN(S)-105, IN(S)-106</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(S)-107</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(W)-112, IN(W)-113</td>
<td>50mm</td>
<td>65mm</td>
<td>75mm</td>
</tr>
<tr>
<td>IN(S)-104, IN(S)-109</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(W)-203, IN(W)-204</td>
<td>25mm</td>
<td>50mm</td>
<td>75mm</td>
</tr>
<tr>
<td>IN(S)-203, IN(S)-204</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(W)-204</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(S)-201</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(W)-201</td>
<td>25mm</td>
<td>50mm</td>
<td>75mm</td>
</tr>
<tr>
<td>IN(S)-202</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IN(W)-202</td>
<td>25mm</td>
<td>50mm</td>
<td>75mm</td>
</tr>
</tbody>
</table>
**ALERT LEVEL**

- Notify the supervising consultant immediately and increase frequency of monitoring to daily.
- Within 24 hours of detecting that an alert level has been reached, submit a brief report describing the work being undertaken in the vicinity of the instrument.
- Propose a suitable plan of action such as the installation of additional instruments and/or increase the monitoring frequency.
- Within 7 days, submit a report to review the instrument responses including differential deformations, assessment of the effects on the monitored elements in light of relevant construction activities and prediction of further movements based on the trends in the monitoring data up to date.
- Within 7 days, submit a detailed plan of action to the supervising consultant describing the measures to be taken in the event of an action or alarm trigger level being attained.
- Make preparations for implementing the action and alarm trigger actions in accordance with the agreed detailed plan of action.

**ACTION LEVEL**

- Notify the supervising consultant immediately and increase frequency of monitoring to twice daily.
- Undertake a joint inspection of the works with the supervising consultant.
- Implement the action level trigger actions as appropriate so that the alarm level is not reached in accordance with the detailed plan of action.
- Within 48 hours of exceeding an action level, devise and submit an emergency plan describing the measures to be taken in the event of an alarm trigger level being attained.
- Meet with the supervising consultant to discuss instrument response and review the effectiveness of the trigger level actions.
- Within 7 days, submit an updated report to review the instrument responses including differential deformations, assessment of the effects on the monitored elements in the light of relevant construction activities and prediction of further movements based on the trends in the monitoring data up to date.
ALARM LEVEL

- Suspend all works within 50m of the instrument and increase the frequency of monitoring to twice daily.
- Notify the supervising consultant immediately.
- Undertake a joint inspection of the works with the supervising consultant.
- Implement emergency trigger action based on the emergency plan reviewed without objection by the supervising consultant.
- Within 3 days, provide a complete report to examine the construction method and review the deformation and ground response history and trigger actions adopted related to the construction activities. The works can only be recommenced after a remedial proposal has been agreed with the supervising consultant.

MONITORING TRIGGER LEVELS

- Example for inclinometer:
  - **Alert**: 0.8*Maximum predicted lateral movement using moderately conservative parameters
  - **Action**: 0.9*Maximum predicted lateral movement using moderately conservative parameters
  - **Alarm**: 1.0*Maximum predicted lateral movement using moderately conservative parameters

To be developed based on specific project/site requirements depending on factors such as risk to public safety, nature of the works, site control measures, etc.
Case History 1:
Deep Excavation for Berjaya Times Square
Berjaya Times Square

- Berjaya Times Square
  South-East Asia’s Deepest Basement
- Excavated depth
  24.5m - 28.5m (6-levels basement)
- Retaining wall
  1.2m thick diaphragm walls
- Support system
  Prestressed Ground Anchors
FINITE ELEMENT MODELLING
Berjaya Times Square

- **Hardening Soil Model** of PLAXIS able to model the problem sufficiently accurate

- From FEM back-analysis, the correlations between soil stiffness ($E'$) and SPT ‘N’ as follows:
  - $E' = 2000 \times SPT'N'(kN/m^2)$
  - $E'_{ur} = 3 \times E' = 6000 \times SPT'N'(kN/m^2)$
Case History 2: Hydraulic Failure @ Penang

The Site

[Image of excavation site with double sheet pile with strutting]
100 Years Ago

Coastal Line
(about 100 years ago)

River
(about 100 years ago)

SITE

Subsoil Profile

BH-4

BH-3

BH-1

Very soft
silty CLAY

Soft clay
silty CLAY

Medium dense
silty SAND

Very soft
silty CLAY

Soft clay
silty CLAY

Medium dense
silty SAND

Very soft
silty CLAY

Soft clay
silty CLAY

Medium dense
silty SAND

Dense fine
SAND

Dense fine
SAND

Dense fine
SAND
Original Design

The Site after Failure

Ponding of water gushed in.
Cracks of Houses

Settlement of Ground
Remedial Works

Case History 3:
Deep Excavation for Three (3) Underground Stations for KVMRT

– Sungai Buloh to Kajang Line (Line 1)
Locations of the MRT Underground Stations

Geology of Kuala Lumpur

All three underground stations in KL Limestone Formation (with Karstic Features)
Karstic Features of Kuala Lumpur Limestone Formation

Typical Karstic Feature:
Typical Karstic Feature:

CAVERN/CAVITY EXPOSED AFTER EXCAVATION
Typical Excavation Section for Underground Station

(Note: Rock slope strengthening indicated is provisional only. Actual locations and extent of rock slope strengthening are determined after geological mapping works and kinematic analysis.)

Subsoil

<table>
<thead>
<tr>
<th>Material type</th>
<th>Silty Sand</th>
<th>Limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average depth</td>
<td>5m</td>
<td>5m below</td>
</tr>
<tr>
<td>Unit weight</td>
<td>18 kN/m³</td>
<td>24 kN/m³</td>
</tr>
<tr>
<td>SPT N</td>
<td>2 - 4</td>
<td>-</td>
</tr>
<tr>
<td>RQD</td>
<td>-</td>
<td>0 – 100%</td>
</tr>
<tr>
<td>Average UCS</td>
<td>-</td>
<td>50 MPa</td>
</tr>
<tr>
<td>Effective shear strength</td>
<td>( c' = 1 \text{kPa} )</td>
<td>( c' = 400 \text{kPa} )</td>
</tr>
<tr>
<td>Elastic Modulus, ( E' ) (kPa)</td>
<td>4000 - 12000</td>
<td>1.0E6 – 1.0E7</td>
</tr>
<tr>
<td>Hydraulic conductivity, ( k )</td>
<td>1.0E-5 m/s</td>
<td>0 – 31 Lugeon</td>
</tr>
</tbody>
</table>
Table 1. Overlapping of secant pile wall.

<table>
<thead>
<tr>
<th>Pile diameter</th>
<th>Length&lt;8m</th>
<th>Length&lt;15m</th>
<th>Length&lt;25m</th>
</tr>
</thead>
<tbody>
<tr>
<td>880mm</td>
<td>130mm</td>
<td>170mm</td>
<td>-</td>
</tr>
<tr>
<td>1000mm</td>
<td>150mm</td>
<td>200mm</td>
<td>340mm</td>
</tr>
<tr>
<td>1180mm</td>
<td>170mm</td>
<td>230mm</td>
<td>360mm</td>
</tr>
<tr>
<td>1500mm</td>
<td>225mm</td>
<td>260mm</td>
<td>380mm</td>
</tr>
</tbody>
</table>

Temporary Ground Anchor Support System

<table>
<thead>
<tr>
<th>Description</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working loads (kN)</td>
<td>212; 424; 636; 848</td>
</tr>
<tr>
<td>No. of strand</td>
<td>2; 4; 6; 8</td>
</tr>
<tr>
<td>Strand diameter</td>
<td>15.24mm</td>
</tr>
<tr>
<td>Breaking load</td>
<td>260.7 kN</td>
</tr>
<tr>
<td>Factor of safety</td>
<td>1.6</td>
</tr>
<tr>
<td>Strand U-turn radius</td>
<td>47.5mm</td>
</tr>
<tr>
<td>Reduction factor</td>
<td>0.65</td>
</tr>
<tr>
<td>Drill hole diameter</td>
<td>175mm</td>
</tr>
<tr>
<td>Allowable bond stress</td>
<td>400 kPa (limestone)</td>
</tr>
<tr>
<td>Free length</td>
<td>Varies (until bedrock)</td>
</tr>
<tr>
<td></td>
<td>3; 3; 4.5; 6</td>
</tr>
</tbody>
</table>
Curtain & Base Grouting to seal the Limestone Karstic Features

Table 3: Holding pressure for fissure grouting:

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Holding pressure (Bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 10</td>
<td>2 to 4</td>
</tr>
<tr>
<td>10 to 20</td>
<td>6 to 8</td>
</tr>
<tr>
<td>20 to 30</td>
<td>10 to 12</td>
</tr>
<tr>
<td>30 to 50</td>
<td>14 to 16</td>
</tr>
<tr>
<td>40 to 50</td>
<td>18 to 20</td>
</tr>
<tr>
<td>&gt;50</td>
<td>&gt;22</td>
</tr>
</tbody>
</table>

Note: Termination criteria shall be satisfied with flow rate less than 2 litres per minute or gross volume reaches 10m³ for every grouting zone in 5m depth.

Typical Curtain & Base Grouting Holes Layout
Construction Sequence

1. Removing Mud & Settling of Slurry
2. Setting of Blasted Area
3. Setting of Rock Face
4. Setting of Rock Face

Construction Sequence (con’t)

5. Setting of Rock Face
6. Setting of Rock Face
7. Setting of Rock Face
8. Setting of Rock Face
Exposed Vertical Rock Face of the Excavation

Maluri Portal (excavation in progress)

Table 2: Partial load factors

<table>
<thead>
<tr>
<th>Load case</th>
<th>EL</th>
<th>DG</th>
<th>LL</th>
<th>TL</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working condition</td>
<td>1.4</td>
<td>1.4</td>
<td>1.6</td>
<td>1.2</td>
<td>NA</td>
</tr>
<tr>
<td>Accidental impact</td>
<td>1.05</td>
<td>1.03</td>
<td>0.5</td>
<td>NA</td>
<td>1.0</td>
</tr>
<tr>
<td>Uplift failure</td>
<td>1.05</td>
<td>1.03</td>
<td>0.5</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Note:
- EL – Earth pressure and groundwater
- DL – Dead load
- LL – Live load
- TL – Temperature effect
- IL – Accidental impact load
- NA – Not applicable
Steel Decking for the Traffic diversion above @ Maluri

Maximum 25m deep

TRX Station (Excavation in Progress)

Maximum 45m deep
Conchrane Station (Excavation Stage)

January 2013

Conchrane Station (Launching of 2nd TBM)

Maximum 35m deep
Case History 4: Excavation Support for TBM Retrieval Shaft using Deep Soil Mixing Technique

Paper by:
Ir. Yee Yew Weng (Keller) & Ir. Tan Yean Chin
International Conference & Exhibition on Tunnelling & Underground Space (ICETUS2015) 3-5 March 2015 Kuala Lumpur

Location Plan – Taman Maluri South Portal, KL

- The Maluri South Portal Structure acted as shaft for retrieval of two Tunnel Boring Machines
- Excavation of 15.0 m depth
- Retaining Wall required
Retaining Wall is required

Cross-Section and Subsoil Profile

Retaining Structure System Selection

- Gravity block - No steel reinforcements
- Gravity block – No struts or anchors

In addition, economy, time & “green” advantages:

- No Rock Socket
- No removal of Spoil
- No Transportation of Concrete to site
- Less storage space for steel and fabrication yard
- Low noise
- Faster
- Cheaper
Deep Soil Mixing (DSM)

- Very Soft Clay / Slime
  - $Cu = 5 \text{ to } 10 \text{ kPa}$
- Hard Element
  - $Cu = 100 \text{ to } 2000 \text{ kPa}$

- The mechanical mixing of in-situ soils with cement
- Increase in shear strength, stiffness and reduced permeability

Deep Soil Mixing Tool
Typical Construction Sequence

1. Mechanical Cutting
2. Mechanical Mixing
3. Full Completed DSM Column

The process

DSM Gravity Block

Water table = 1.30m EBL
Existing ground level
Soil
DSM Column

Lake stone

Final excavation level = 5.00m BGL

East Wall
North Wall
West Wall
Tunnel East
Tunnel West
Design

- Wall Overturning Stability
- Wall Sliding Resistance
- Vertical Load Support
- Inter-locking bond between column elements
- TBM Operational Requirements

### DSM Wall Dimensions

<table>
<thead>
<tr>
<th>Wall Location</th>
<th>Depth to Rock (m)</th>
<th>Width of DSM Block (m)</th>
<th>Column Dia (m)</th>
<th>Column Interlock (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North (TBM drive)</td>
<td>4.0 to 10.0</td>
<td>16.7</td>
<td>1.0</td>
<td>0.12</td>
</tr>
<tr>
<td>East</td>
<td>5.0 to 7.0</td>
<td>9.7</td>
<td>1.0</td>
<td>0.12</td>
</tr>
<tr>
<td>West</td>
<td>5.0 to 7.0</td>
<td>8.8</td>
<td>1.0</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Good contact between lime stone and DSM
Wall movement was 10mm to 15mm (less than 0.15% wall height)

Max ground subsidence of 2mm to 6mm was observed.

West tunnel TBM breakout – April 8th, 2014

East tunnel TBM breakout – April 24th, 2014

DSM wall standing for 2 years and no visual signs of distress or degradation.
Klang Valley Mass Rapid Transit (KVMRT)
Underground Section

VD TBM 1 BREAKTHROUGH

Location: Maluri South Portal
Date: 8 April 2014

THANK YOU

Q & A

Y.C. TAN
G&P Geotechnics Sdn Bhd
www.gnpgroup.com.my
11 April 2016