Singapore Geology
And Its Impact on Underground Construction Works

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Content

➢ Singapore geology

➢ Some characteristics of Singapore soils and rocks

➢ Construction methods
  ✓ Deep excavations
  ✓ Tunnelling

➢ Construction challenges
  ✓ Deep excavations
  ✓ Tunnelling

➢ Conclusions
Major Geological Formations in Singapore

- Bukit Timah Granite Formation
- Jurong Formation
- Kallang Formation
- Old Alluvium Formation
Existence of corestones/boulders depends on the minerals of the original rock and the weathering agents.

Size of corestones/boulders vary.
Bukit Timah Formation

- Surface weathered to residual soil (mainly sandy clayey silt); depth to bedrock varies from 3m to up to 70m with an average depth of 30m

- There is often, but not always, corestone/boulder encountered within GVI to GV

- Average uniaxial compressive strength of intact rock is about 190 MPa but could be as high as 400MPa

- There are 4 to 5 joint sets ranging from sub horizontal to sub vertical. Dominant joint set is sub vertical

- Interface between soil and rock is highly variable within short distance and the change in strength of soil to that of rock is very drastic

- There is often, but not always, a zone (typically 0.5 to 2m thick) of permeable \((1 \times 10^{-5}\) to \(10^{-6}\) m/s) GIV to GV immediately overlying the rock grades
Jurong Formation

- Origin was dated late Triassic to possibly early Jurassic and overlies the Granite. It exists mostly at western and southern parts of Singapore.

- Seven sedimentary facies, including one that is characterised by limestone, are recognised within the formation.

- Further geological activity in early Tertiary, late Tertiary and early Pleistocene caused beds of Jurong Formation variably folded and faulted; 3 major thrust faults and numerous small scale faults.
Due to folding/faulting, the sequence of rock vary significantly.

Highly weathered rock could be below less weathered rock.
Jurong Formation

- Consists of a variety of sedimentary rocks: sandstone, siltstone, mudstone, limestone etc.
- Degree of weathering depends on rock types, e.g. sandstone more resistive to weathering than mudstone.
- Strength of rock depends on rock type and weathering stage.
- Residual soils are mainly silty clay.
Jurong Formation - Limestone
Jurong Formation - Limestone

Unweathered Stage
(Stage I)

Initial Weathering Stage
(Stage II)

Intermediate Weathering Stage
(Stage III)

Late Weathering Stage
(Stage IV)

Last Weathering Stage
(Stage V)

Residual Stage
(Stage VI)
Jurong Formation - Limestone
Jurong Formation - Limestone

Borehole Logs along Gridline D – PSA’s 3rd Container Terminal at Pasir Panjang
Jurong Formation - Limestone

PSA 3RD TERMINAL AT PASIR PANJANG

EXISTING GROUND LEVEL
Concrete level Vs Concrete volume in a bored pile construction – a bridge project at the Pandan Reservoir
Jurong Formation - Limestone

Borehole (cavity filled with mortar) | Additional holes to check infill

Investigation of cavity during bored piling works at PSA’s 3rd Container Terminal Pasir Panjang
Jurong Formation - Limestone

Could it be like this?

Or this?
Fort Canning Boulder Bed (FCBB)

- FCBB is a colluvial deposit of slipped material of Rimau Facies of JF triggered by seismic activity.

- It was probably laid down in late Cretaceous, but could be anytime between JF deposited and OA was first deposited.
Fort Canning Boulder Bed (FCBB)

- Comprising generally lens-shaped or rounded fresh sandstone boulders ranging 1 to 9m in a hard, multi-coloured, mainly red and white silty clay

- The content of boulders in the FCBB varies at different locations from 10% to 40% with an average of 20%
Fort Canning Boulder Bed (FCBB)

- Exist in CBD district of Downtown Singapore
- Exist above JF but below OA/Kallang
In late Tertiary, a downwarp occurred and the resulting trough was back-filled with a coarse sand-gravel unit referred to as the Old Alluvium.

The base of OA is below base level associated with Pleistocene low sea levels, and its top associated with minimum high sea level of 70m.
Old Alluvium Formation

OLD ALLUVIUM - GEOLOGICAL SETTING

BUKIT TIMAH GRANITE

BEDOK - TAMPINES

granite-wash
subrounded quartz pebbles
mud
muddy gravelly sand

Nee Soon Fault

Pleistocene drainage

Ama Keng Fault
Nee Soon Fault

OA
Old Alluvium Formation

- Exits mostly at eastern parts of Singapore

- Generally it overlies on Granite. Granite ridges found beneath OA at some areas

- However, it was laid down against Sajahat formation in the north near Punggol, Jurong formation in Sungei Buloh Besar, FCBB in CBD area

- Depth up to 195m
Old Alluvium Formation

- Medium dense to very dense clayey/silty coarse sand and fine gravel and lenses of silt and clay
- Surface weathered and much of cementation lost as a result
- Potential existence of high permeable sand lenses
Old Alluvium Formation

- Appears in cohesive and granular layers and its behaviour varies accordingly.
Old Alluvium Formation

- OA has pockets of sand, confined aquifers and beds of permeable cemented sands.

- Pebble within OA are dominantly quartz (generally more angular) but rhyolite, chert and argillite pebbles (rounded) are also found.
Zone of cementation are found but cemented rock disintegrates after few days of exposure.

However some areas of cemented OA have been exposed for several years and yet remained cemented.
Youngest deposit; Alluvial, littoral and inshore marine sediments have been laid down from late Pleistocene to Holocene period.

- Could be up to 55m deep; generally low lying and seldom recognised more than 4m above sea level.

- Includes marine clay, fluvial clay, fluvial sand, and estuarine Kallang Formation.
Kallang Formation

**HORIZONTAL & VERTICAL DISTRIBUTION OF THE KALLANG FORMATION MEMBERS**


**DEPOSITION OF THE KALLANG FORMATION MEMBERS**
Kallang Formation

- Marine clay / estuarine is very soft and highly compressible whereas fluvial clay is stiff.
- Where Kallang is thick, marine clay could appear in two layers: upper and lower layers separated by fluvial deposits.
- Loose fluvial sand (F1) is highly permeable.
- Large consolidation settlement could be expected due to additional loads or water drawdown.
- Reclamation was carried out in several phases over the years
- Cut OA material was used in earlier phases and imported sands are used in later phases of reclamation
- Marine clay underneath is still under going consolidation
- Abandoned and buried structures exist within reclamation fill
Construction Methods
Slope Excavation

- Seldom adopted in Singapore due to site constraints
- Not appropriate in sandy soils or fractured rocks
- Steeper slopes could be achieved with soil nails/ rock dowels
Braced Excavation
Braced Excavation

1. Waling member
2. Strut member
3. Brace member
4. Corner piece
5. Brace piece
6. Cover plate
7. Kirin jack
8. Jack cover
9. Auxiliary piece
10. Adjustable brace piece
11. Soil pressure gauge
12. Cross section piece
13. Cross section bolt. nut
14. Tightening bolt. nut
15. Strut bracket
16. Waling bracket
Choices of Retaining Systems

- **Types of temporary Retaining Wall systems**
  - Sheetpile/ Soldier Pile/ Steel Pipe Pile
  - Contiguous Bored Pile/ Secant Pile
  - Diaphragm Wall

- **Types of bracing systems**
  - Strutting
  - Soil Nails/Ground Anchor

- **Types of Ground Improvement**
  - Jet Grouting
  - Deep Soil Mixing
  - Ras Jet Method
  - Chemico-Lime Piles
NET PRESSURE ON WALL (i.e. active – passive)
Sheet Pile + Soldier Pile Wall

Theoretical Internal Face of Sheet Pile Wall

Coordinates at Corners between Sheet Pile Walls

Sheet Pile

Soldier Pile
Contiguous Bored Pile Wall / Secant Pile Wall

Contiguous Bored Pile (CBP)

Secant pile wall
Beam mounted jet grout rigs working adjacent to Race Course Road
Diaphragm Wall Excavation
- Bugis Station

EXISTING BUILDING

GROUND LEVEL

103.20

PILE

1.6
m

3.7
m

2.2
m

2.0
m

1.7
m

1.5
m

2.5
m

CHEMICO-LIME PILES

1.0M TO 1.2M THICK DIAPHRAGM WALLS

10M TO 14M INTO OLD ALLUVIUM

UPPER MARINE CLAY

FLUVIAL SAND

LOWER MARINE CLAY

FLUVIAL SAND

OLD ALLUVIUM
Types of Retaining Systems

- Types of wall system depends on many factors:
  - Depth of excavation
  - Type of soil profile and ground water level
  - Sensitivity of surrounding buildings and services
  - Space constraints
  - Cost
Choice of wall type

– Diaphragm wall
  • Typically used in deep Kallang formation
  • Used in site constraints areas
  • Not preferred where rock socketing required in Granite

– Contiguous bored pile wall
  • Typically used in stiff to hard cohesive soils/rock
  • Possible soil flow through gaps if not treated adequately

– Secant bored pile wall
  • Typically used in OA, Jurong and Granite

– Soldier pile-sheet pile wall
  • Generally adopted for shallower excavation for entrances
Choice of Ground Improvement

- Choice of ground improvement
  - Jet grout piles (JGP) or Deep soil mix piles (DSM)
    - Used to control basal heave in deep Kallang formation
  - Cross walls
    - Used in place of JGP/DSM
    - Very effective to limit the ERSS wall deflections
Submerged Excavation

MRT Phase 1 tunnel construction at Marina Bay
Submerged Excavation

Stage 1
1-1 Drive sheet piles.
1-2 Excavate approx. 1.5m and install S1.
1-3 Excavate approx. 6.5m and install S2 and bracing between S1 and S2.

Stage 2
2-1 Flood the cofferdam to the top level.
2-2 Excavate under water using grabs, water jets and air lifting.
2-3 Install bored piles using R C D method.

Stage 3
3-1 Place min.300mm thk sand levelling layer.
3-2 Install pressure relief pipes.
3-3 Install pressure plates and place compressible void formers where required
3-4 Cast tremie concrete slab.
3-5 Dewater cofferdam.

MRT Phase 1 tunnel construction at Marina Bay
Shaft Excavation

Jurong Island Cavern Project
Semi-circular Cofferdam Excavation

Excavation at Esplanade
Semi-circular Cofferdam Excavation

Adopted construction sequence at Esplanade
Semi-circular Cofferdam Excavation

Various Construction stages at Esplanade
Circular Cofferdam Excavation

The Sail, Marina Bay Triple cell
3x32m diameter for 9.5m depth excavation

Manjung, Malaysia Twin cell
59m/56m diameter for 16.5m depth excavation
Circular Cofferdam Excavation

Marina Bay Sands Development

Layout of Basement Excavation
Circular Cofferdam Excavation

Basement Excavation
Hotel, MICE, Casino, Theatre

Basement Excavation
Museum
Mechanised Tunnelling: Excavation of ground with a rotating cutterhead which is pushed against tunnel face by thrust cylinders.

- Pressurised closed face Tunnel Boring Method (TBM)
  - EPB TBMs and Slurry TBMs
- Open face TBMs

Non Mechanised Tunnelling: NATM/ Mined Tunnels
EPBM Vs Slurry TBM

- EPBM maintains control over settlement by controlling the face pressure in the cutter head chamber by adjusting the rate of muck extraction to the TBM advance.

- Slurry machine maintains control over settlement by controlling slurry pressure by slurry flow and density.
EPBMs are well suited in low permeable and plastic soils but they have problems in handling mixed face of rock and granular soils

Slurry TBMs have problems in handling clayey soils
EPBM Vs Slurry TBM

- EPBM has difficulty to maintain face pressure when it encounter very permeable interface between rock and soil of Granite

- Slurry TBMs – Adopted in significant mixed face of soil/rock granite interface

- EPB TBMs – Adopted in Kallang, Jurong, Old Alluvium as well as residual soils and completely weathered Granite
NATM Tunnel – Fort Canning Tunnel

ELEVATION OF SPRAYED CONCRETE LINING (SCL) TUNNEL

Artocarpus Spp Tree (Tree 64)
NATM Tunnel – Fort Canning Tunnel
Mined Tunnel - Pipe Box Method
Construction Challenges
Nicoll Highway ERSS Collapse

Before collapse

After collapse on 20th April 2004

Ground condition
Type of ERSS wall
Depth of excavation
Width of excavation
No of strut layers
JGP layers
No continuous walers

– Very deep Kallang formation (up to 40m)
– Diaphragm wall (1.0m thick)
– 33m
– 20m
– 10
– 1.5m & 2.6m thick
COI that investigated the collapse concluded that the failure was contributed by several factors including technical and administrative issues.

Two major design deficiencies identified by COI are:
- Under-design of diaphragm wall using Method A
- Under-design of waler connections in strutting system
Inadequate wall penetration

- Contour of top of OA – buried valley
- Adequate borehole investigation along the wall
Diaphragm wall trench instability

Mostly occurred:
- In layers of sand
- During or after desanding

Possible causes:
- High external water level
- Lower level of slurry
- Lower density of slurry
- Surcharge

Mitigation measures:
- Prior grouting
Potential gaps in walls due to:
- Existing utilities
- Defects in wall installation
- Type of wall

Potential issues:
- Ground loss behind walls
- Water drawdown behind walls
Soil and Water flow through gaps in ERSS

- During drilling for ground anchor installation, if adequate precautions are not taken, potential loss of sand and water through the borehole.

- If soft clay exists below or above sandy soils, potential large ground settlement could be expected behind the ERSS wall.
Water drawdown due to under drainage
Limestone below the shaft excavation
Challenges in construction of ERSS walls and excavations

- Inadequate ERSS wall penetration
  - Uncertainty in ground information

- Trench instability – damage to adjacent property
  - Prior grouting near critical structures

- Difficulty of diaphragm walling in Granite
  - Rock socketting & encountering corestones/boulders

- Flow through gaps in walls
  - Utility gaps & CBP piles without any grouting in-between piles

- Consolidation settlements - Ground water drawdown
  - Due to under drainage/leakage through walls (utility gaps or defects)

- Potential flooding of excavations
  - Karst limestone or sandy soils such as F1 underneath excavations
Risks faced during EPBM tunnelling

• Sinkholes during TBM launching & docking
  – This risk is eradicated in CCL & DTL projects through prior ground treatment

• Wear of machines & tools
  – Very abrasive Granite, Jurong & Old Alluvium
  – delay due to interventions for tool changes

• Face instability
  – mixed interface of Granite/Jurong/OA with Kallang Formation
  – loose sandy soils (F1)
Loss of Ground during Launching
Wear of Screw and Tools
Face instability during EPBM tunnelling

- DTL3 Tunnelling underneath Upper Changi Road East
- Loss of ground due to Kallang formation soils close or at tunnel face
Ground loss during CCL3 tunnelling through weathered granite with Kallang soils underneath Kuo Chuan School
Face instability during EPBM tunnelling

Mitigation measures:
- prior grouting of soft soils
- tight tunnelling control
- good excavation management system

CCL5 tunnelling underneath Telok Blangah Road within Jurong formation and Kallang soils
Blockage during EPBM tunnelling

Bukit Panjang Bound Soil Profile

Expo Bound Soil Profile
Frequent encounters with boulders of Bukit Timah Granite caused blockage.

**Preventive Measures**

- Clayshock pumped through TBM ports.
- Grouting from surface implemented.
- Removal of boulders under compressed air.
Issues faced during Slurry TBM tunnelling

• Sinkholes
  – tunnelling through soil/rock interface
  – appropriate face pressure application
  – good excavation management system

• Slurry blow-out
  – blockages between excavation and plenum chambers
  – old boreholes which are not grouted
  – geotechnical instrumentation close to tunnels

• Damages to cutters and tools
  – impact forces during tunnelling through mixed ground
  – wear of pipes at sharp corners
Tunnelling through mix ground conditions

Problems faced:
- Face instability
- Cutter tool damage
Sinkholes during tunnelling using Slurry TBM
Slurry blowout at ground surface
Blockage in excavation chamber
Slurry pipe leakages
Conclusions

- Major infrastructure route in Singapore generally run through all major geological formations.

- Various ERSS types were adopted in the cut and cover excavation works depending on the ground condition.

- Slurry TBM are chosen typically for tunnelling through rock and mixed face conditions in Bukit Timah Granite whereas EPBM type TBM are generally adopted for all other ground conditions.

- Some of the geotechnical challenges encountered during the constructions are highlighted together with adopted mitigation measures.
Thank You
Surface Geology along the Circle Line
Geology along the Circle Line

GEOLOGICAL FORMATION:
- FILL
- KALLANG FORMATION
- JURONG FORMATION
- BUKIT TIMAH GRANITE
- OLD ALLUVIUM

LEGEND:
- TUNNEL AND RAIL (INNER TRACK)
- TUNNEL AND RAIL (STACK) (OUTER TRACK)
- CIVIL CONTRACT NUMBER

VERTICAL SCALE: 1:2000
HORIZONTAL SCALE: 1:800000