Tunnelling Asia' 2023

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ASSOCIATION INTERNATIONALE DES TUNNELS ET DE L'ESPACE SOUTERRAIN
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Design Concepts, Optimisation and Challenges of an Underground Metro Interchange Station in Mixed Ground Conditions

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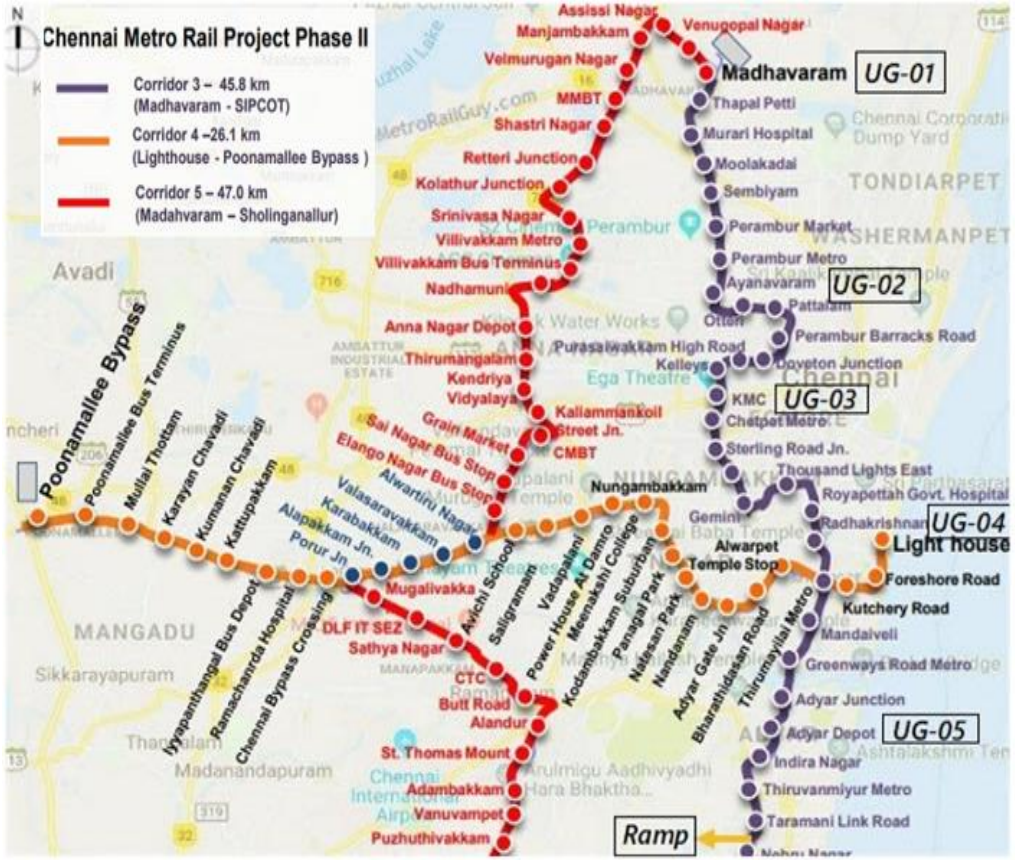
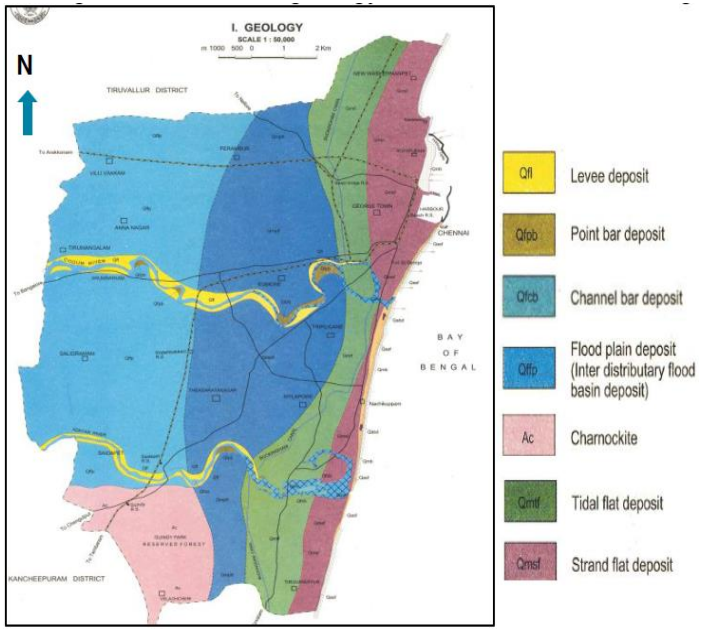
Outline of the Case Study presentation

- Chennai Metro Phase II Corridor 3: Overview and challenges
- Station Description
- Geotechnical Conditions of Thirumayilai station
- Model of the Case Study
- Construction Stage Analysis
- Service Stage Analysis
- Stability Analysis
- Discussion on Analysis and Results
- Conclusions
- References

Chennai Metro Phase II Corridor 3 Location and Geology

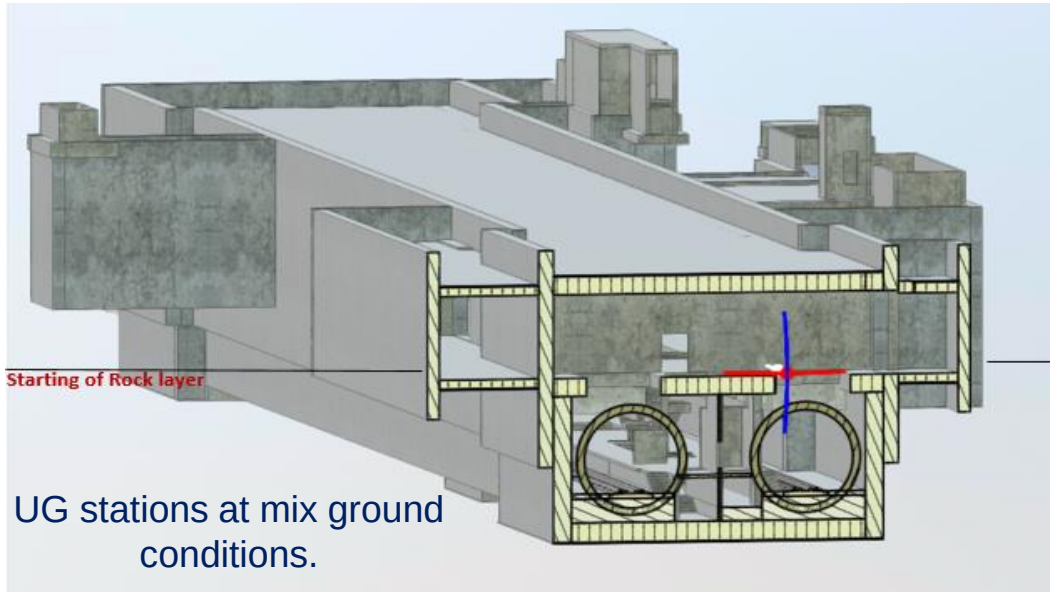
- The current study focusses on the Design and construction of Thirumayilai underground station which is interchange station of corridor 4 and corridor 3 of Chennai Metro Rail Limited (CMRL) Phase II project.



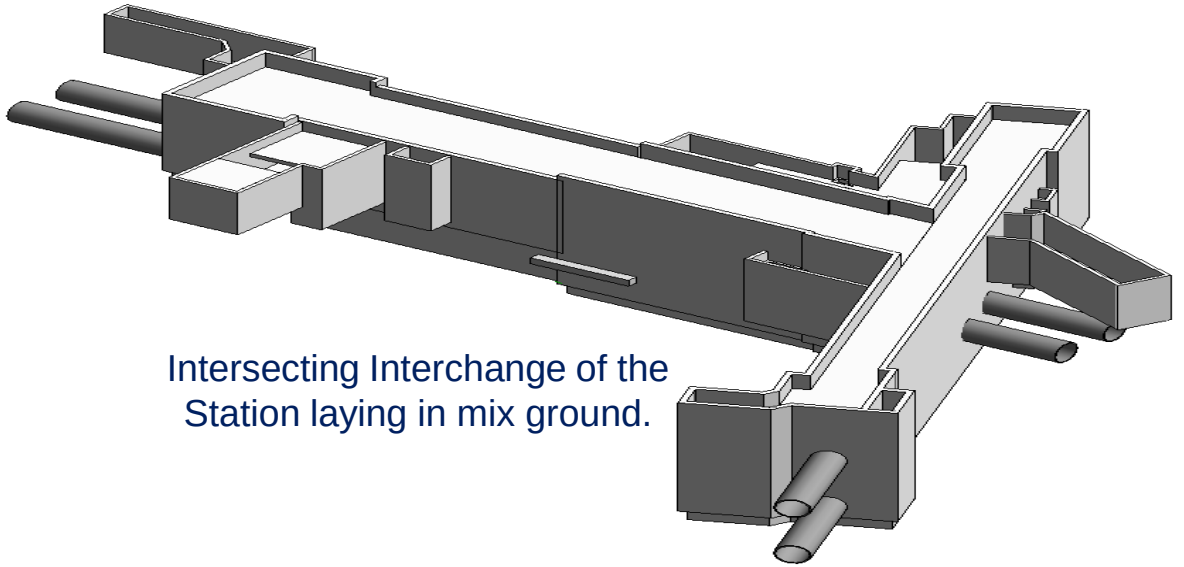


Geology of study area: Chennai city and southern part.

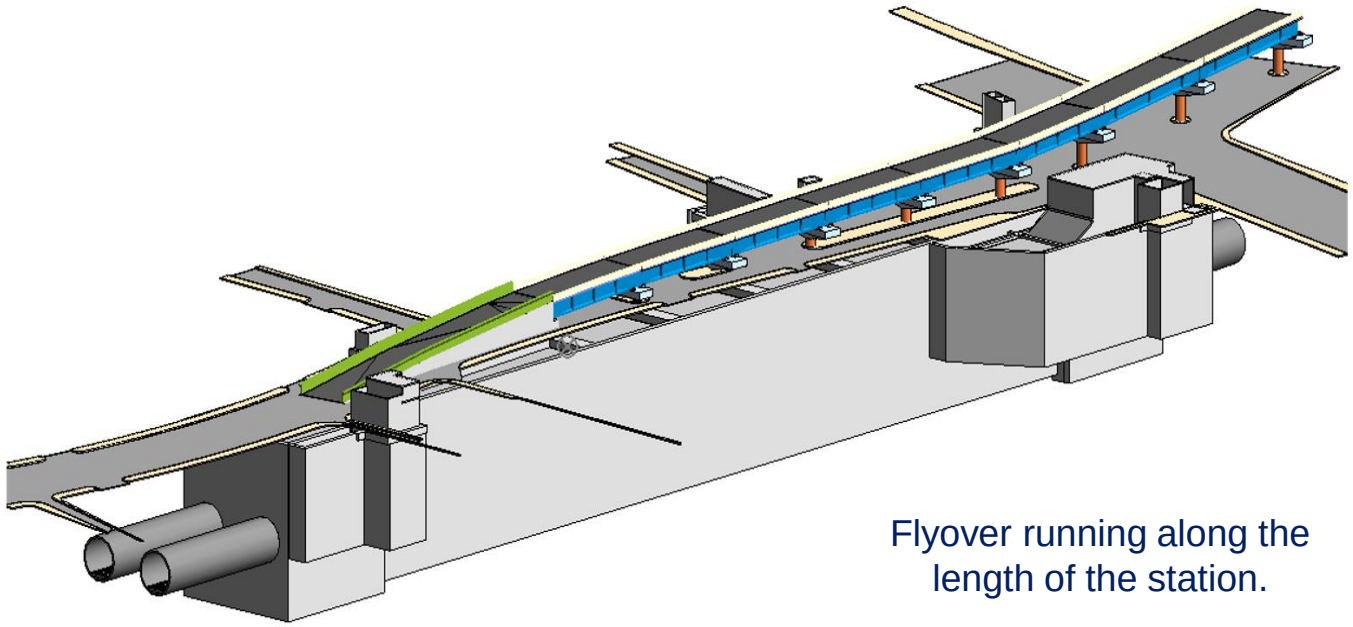
Chennai Metro Phase II Corridor 3 - Various types of Challenging Features



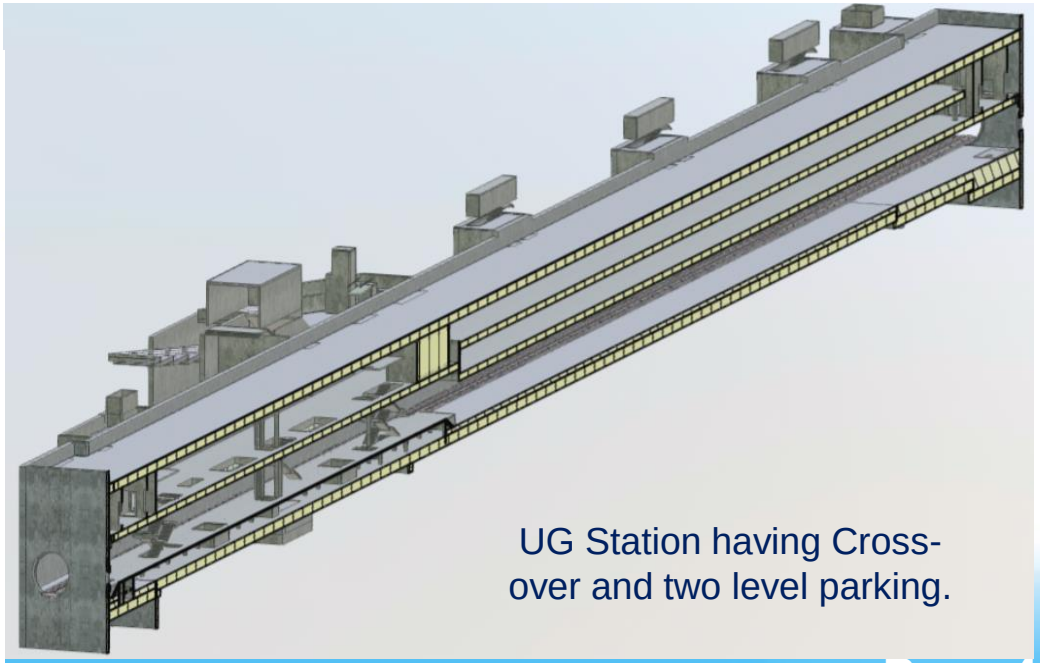
UG stations at mix ground conditions.



Intersecting Interchange of the Station laying in mix ground.



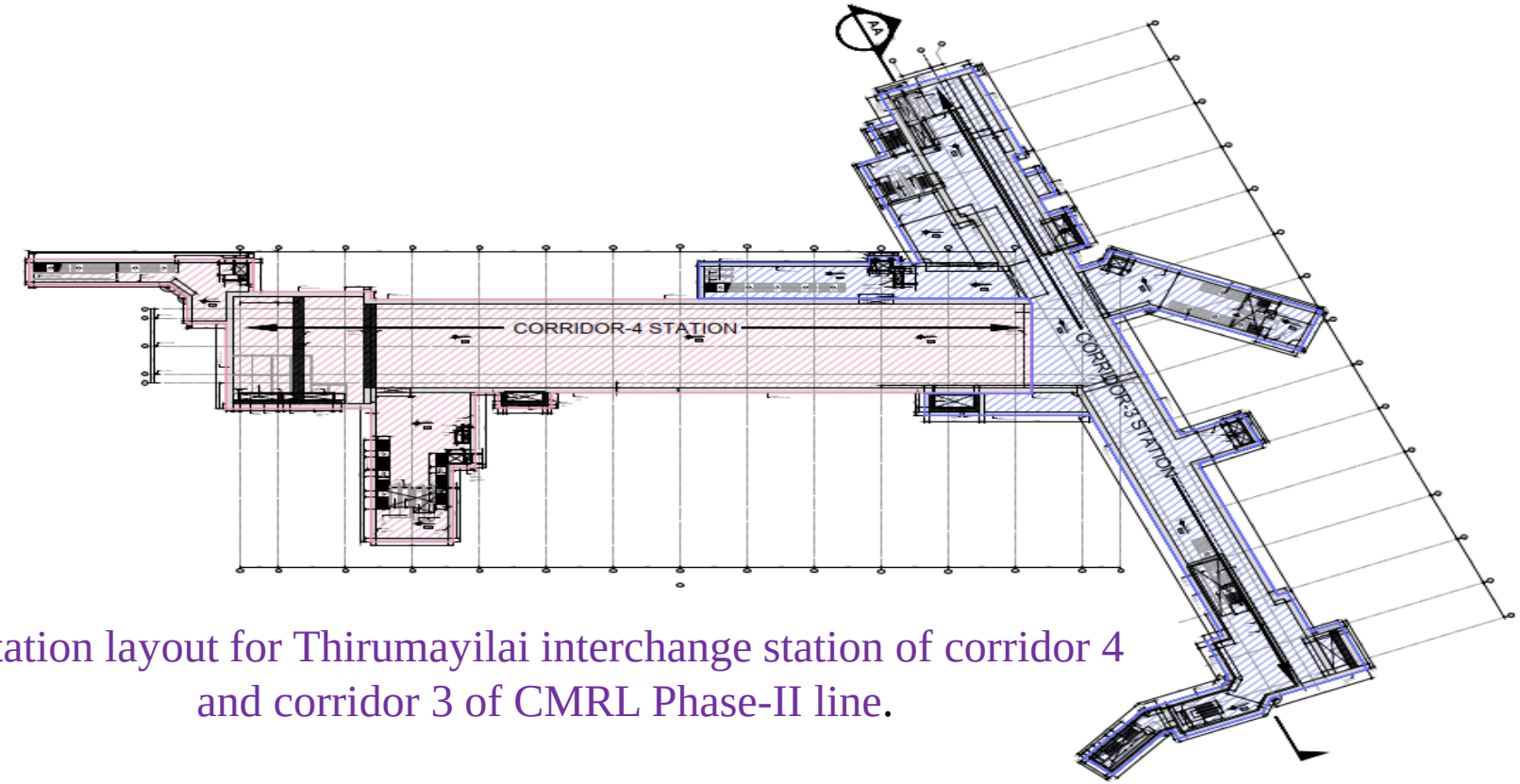
Flyover running along the length of the station.



UG Station having Cross-over and two level parking.

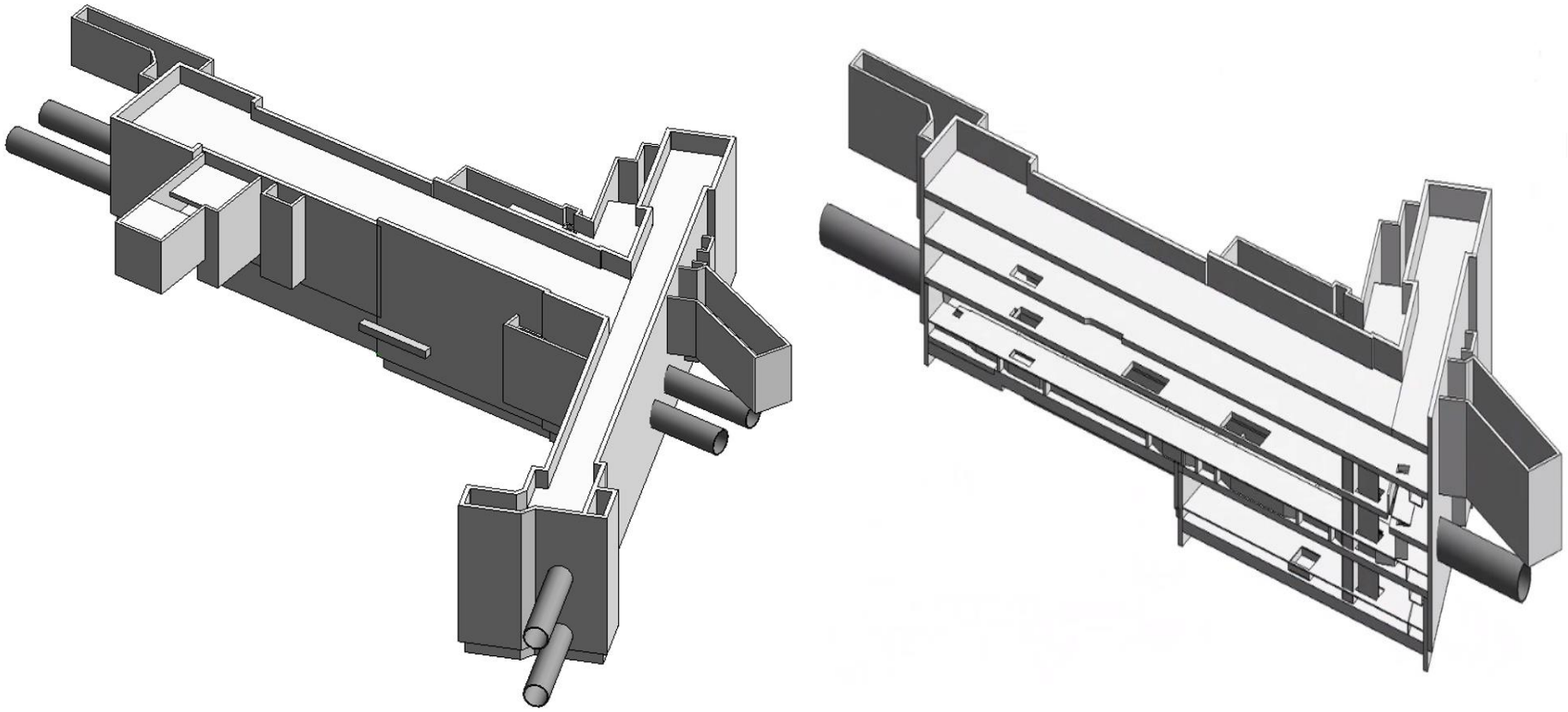
Station Description

- Thirumayilai Interchange Station is a four-level underground structure having Commercial level, Upper Platform level, Island platform level, Lower platform level and one level Entry/Exits. It comprises of an island station (Corridor C4) and a stacked station (Corridor C3) There are three intermediate levels to connect the island station and the stacked station.



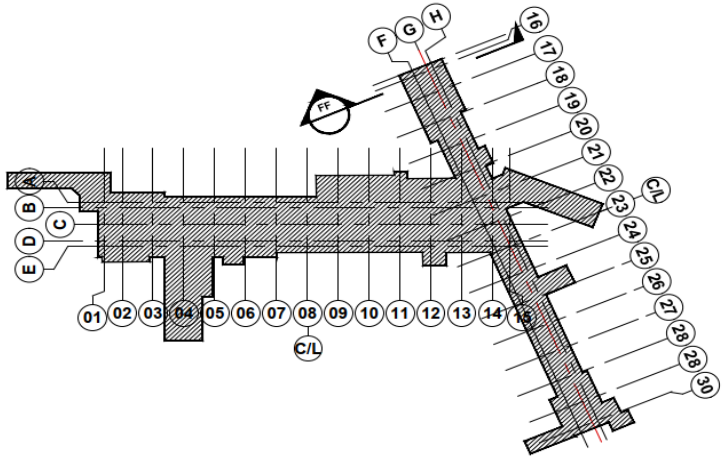
Station layout for Thirumayilai interchange station of corridor 4 and corridor 3 of CMRL Phase-II line.

Station Description….Continued

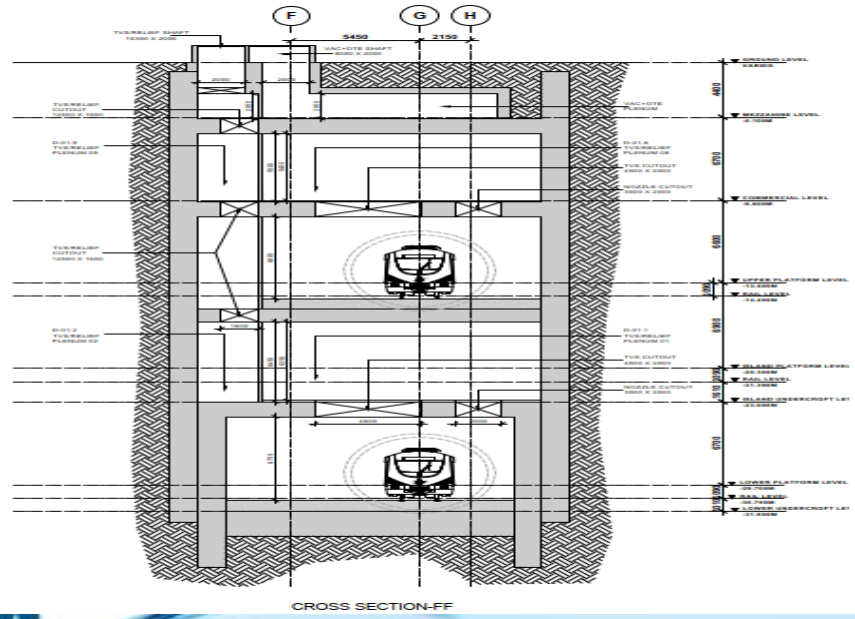


Three-dimensional (3D) view of the entire station box for Thirumayilai station with long section of interchange area

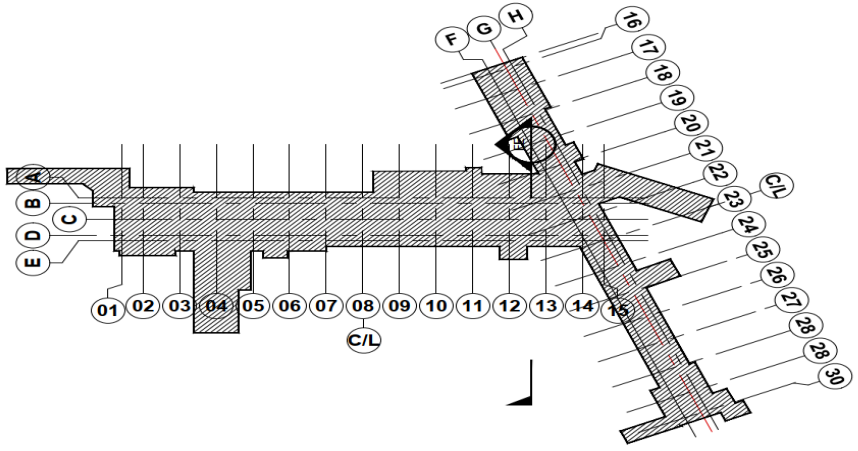
Station Description….Continued



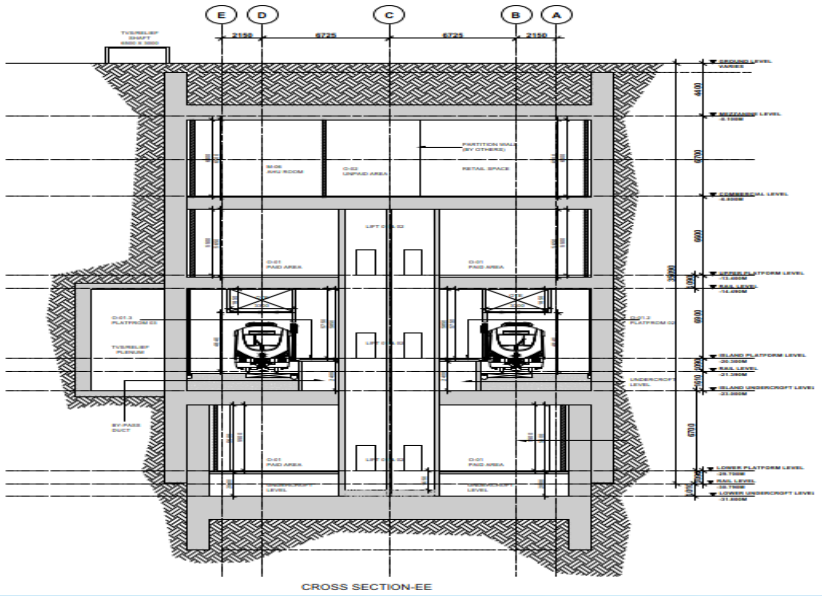
KEY PLAN



Cross Section of Corridor 3 Station



KEY PLAN



Cross Section of Corridor 3 and Interchange area

GEOLOGICAL AND GEOTECHNICAL CONDITIONS

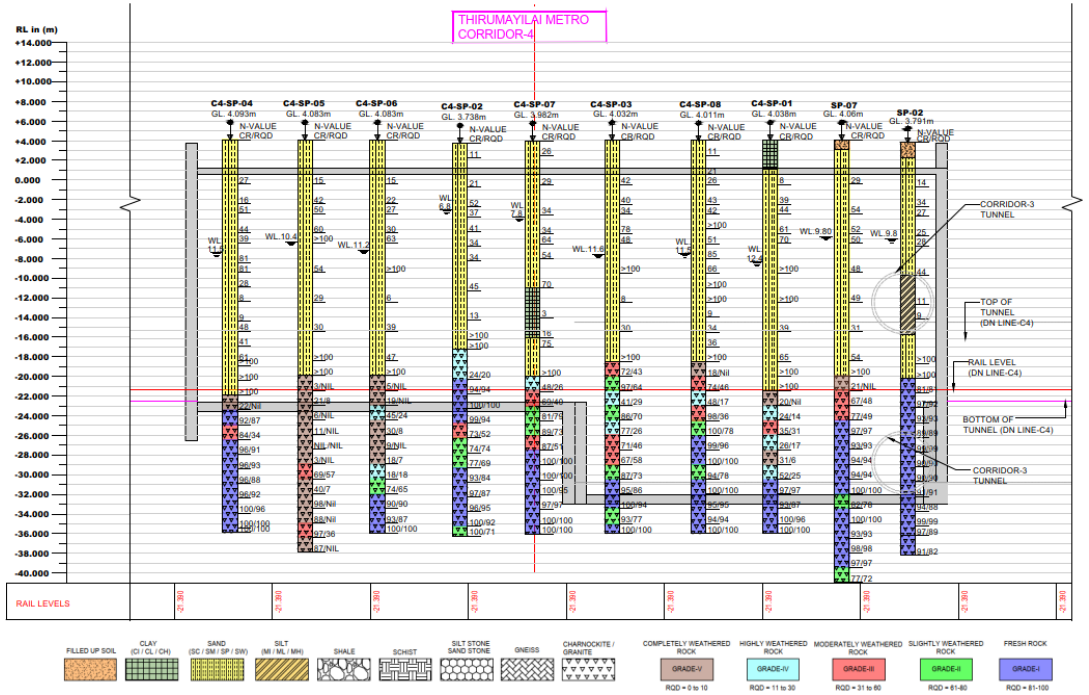
- The city is classified into three regions based on geology i.e. **sandy areas** found along the riverbanks and the coasts, **clayey areas** covering most of the city and **hard-rock areas** found in some central parts and south parts of the city.

- For the Thirumayilai station, the subsurface strata at the site consists of cohesionless soils and weathered rock.

Depth wise Geotechnical parameters for Thirumayilai station.

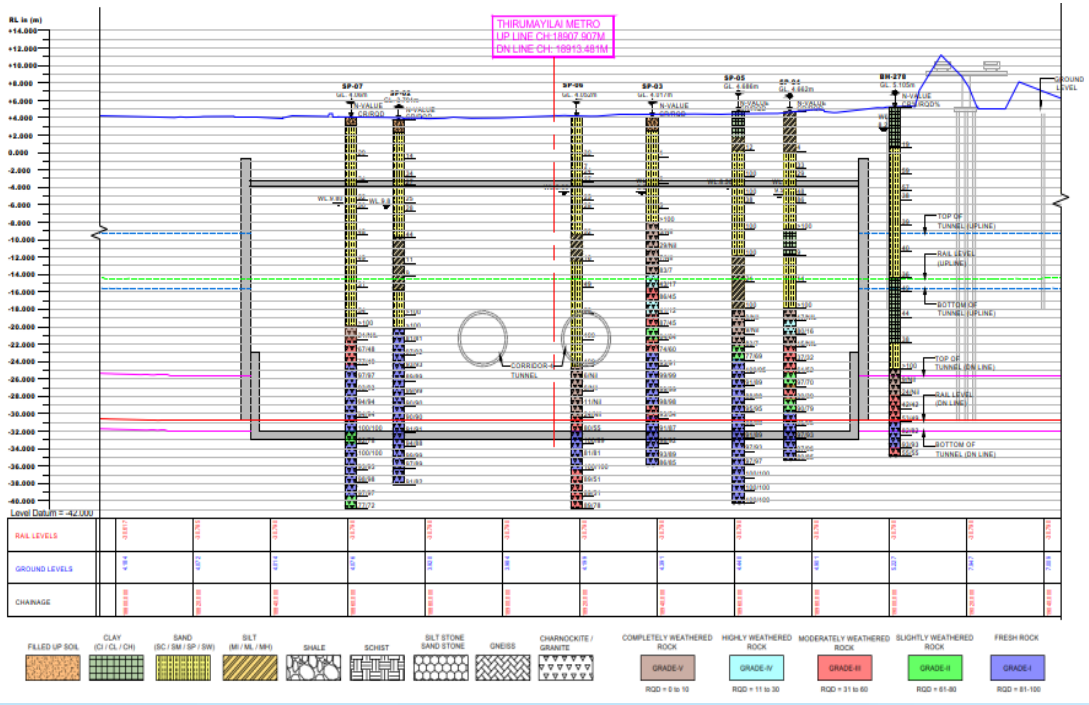
Soil Type	Depth m	SPT	C' kPa	Φ' deg	Y kN/m3	E' kPa	E_m MPa	ν
Loose silty sand	0 – 6.2	8	-	28	18.0	12000	-	0.3
Medium silty sand	6.2 – 10.7	26	-	32	19.0	39000	-	0.3
Dense silty sand	10.7 – 28.7	50	-	34	20.0	75000	-	0.3
Charnockite G(V)	28.7 – 34.7	-	69	48	22.0	-	277	0.2
Charnockite G(III)	34.7 – 45.0	-	219	65	24.0	-	3391	0.15

GEOLOGICAL AND GEOTECHNICAL CONDITIONS….Continued



Geotechnical profile's longitudinal section with superimposed station box outline for Thirumayilai Island station (corridor 4) with interchange area.

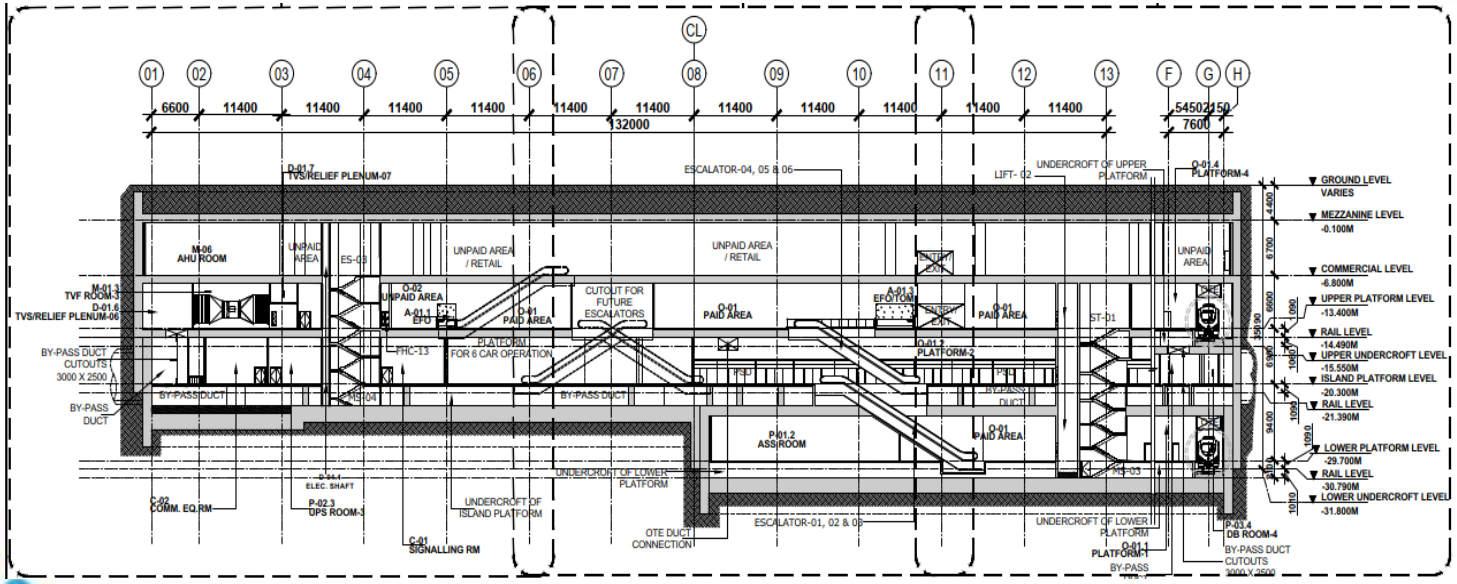
Geotechnical profile's longitudinal section with superimposed station box outline for Thirumayilai Stacked station (corridor 3).



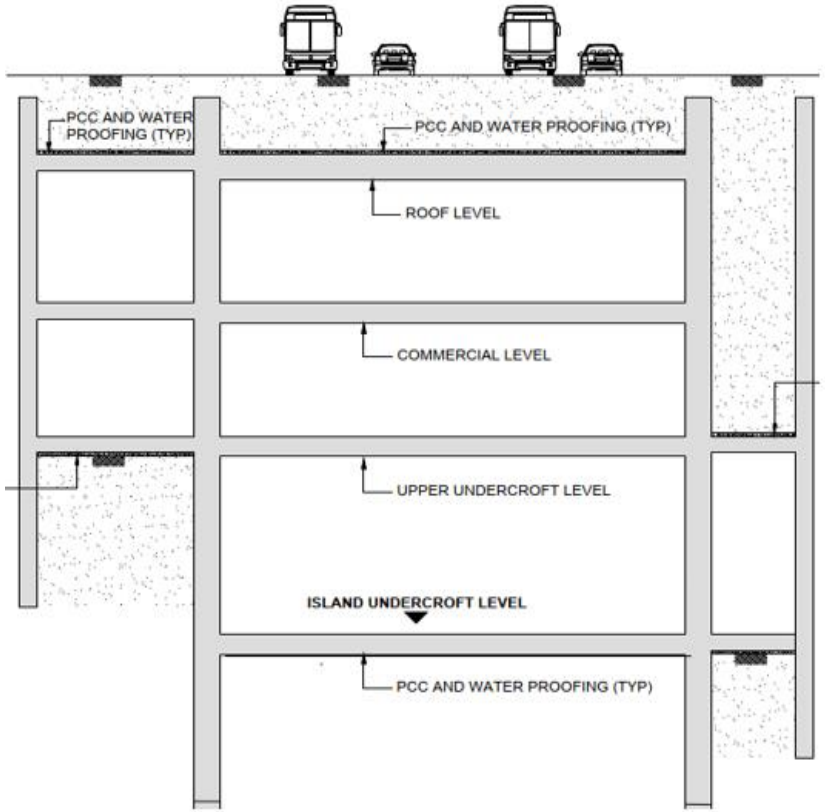
Model of the Case Study

➢ Due to varying rock layer along the station alignment the following conditions are considered:

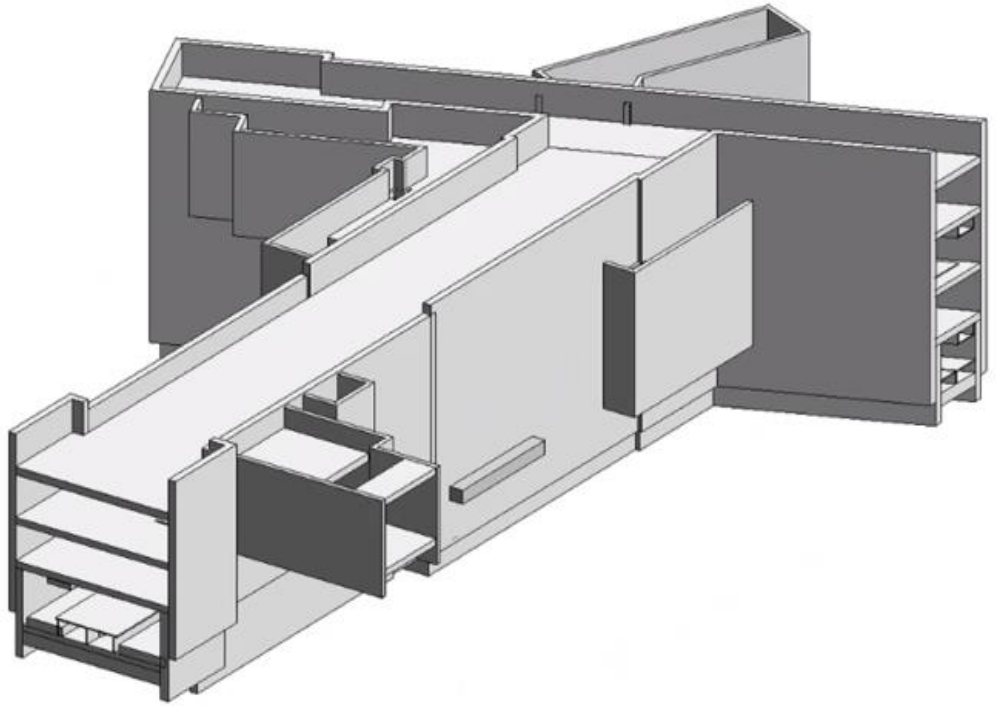
- **Case-1** (rock layer at or below Island Undercroft level slab): Diaphragm wall (D-Wall) with typical embedment of 3m for GIV or better rock and embedment of 5m for GV rock is required.
- **Case-2** (rock layer below Island Undercroft level slab but above Lower undercroft level slab): Diaphragm wall terminates above Lower Undercroft level slab. Diaphragm walls with shear pins embedded in rock strata is adopted.



Model of the Case Study….Continued



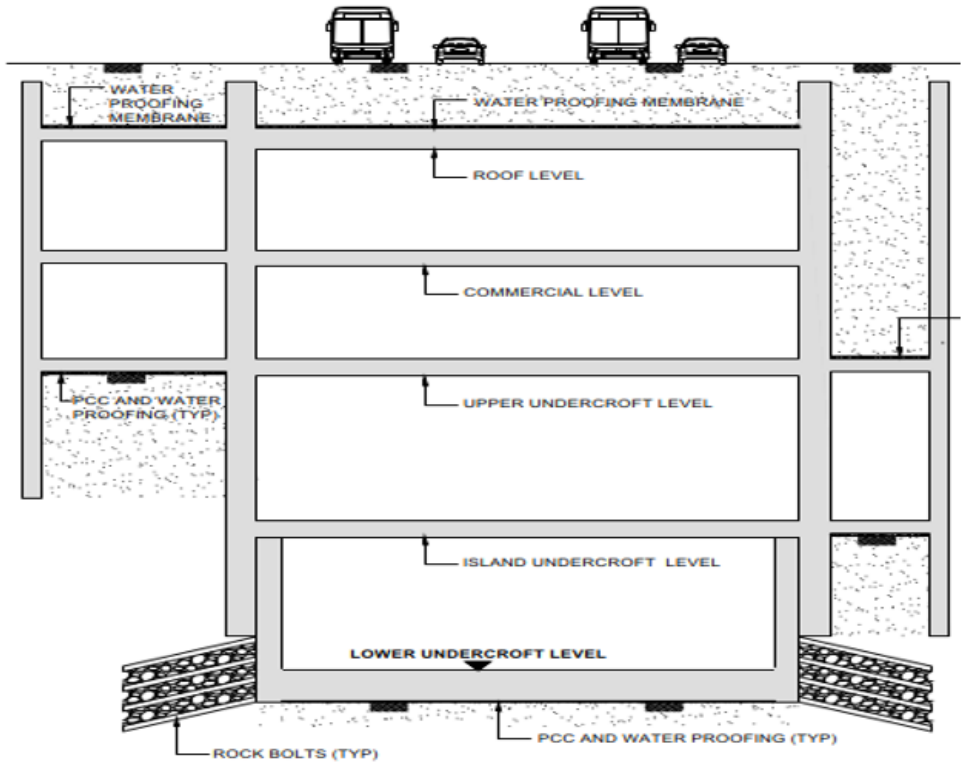
A. Typical Cross Section of Island station



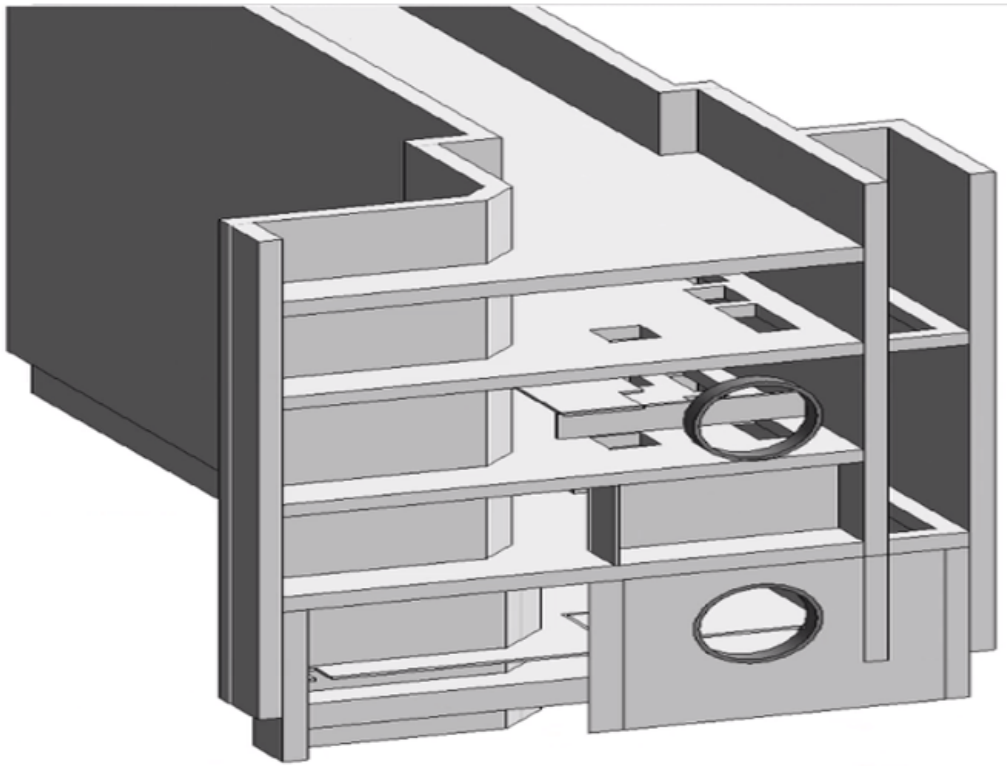
B. 3D cross sectional view of Island station

Typical case-1 cross section and 3D cross sectional view of corridor 4 Thirumayilai Island station

Model of the Case Study….Continued



A. Cross Section of stacked station with case-2 condition

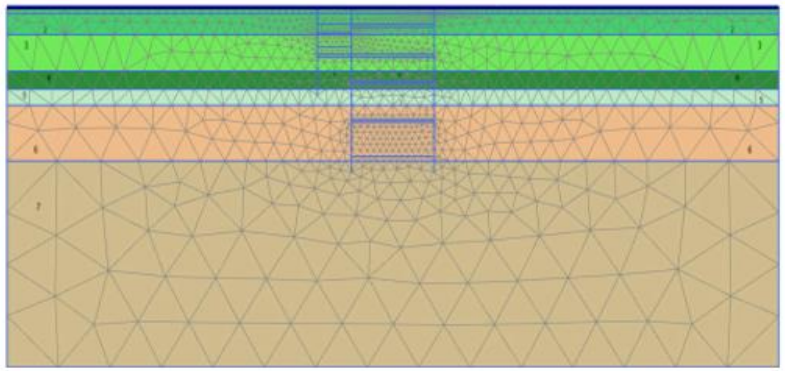


B. 3D cross sectional view of stacked station

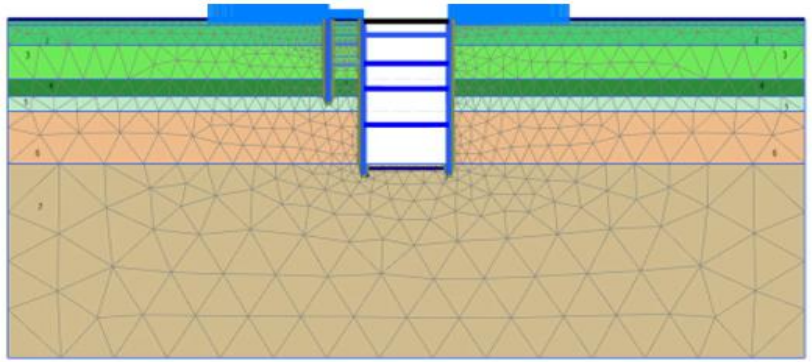
Cross section with case-2 condition and 3D cross sectional view of stacked part of Thirumayilai station

Construction Stage Analysis

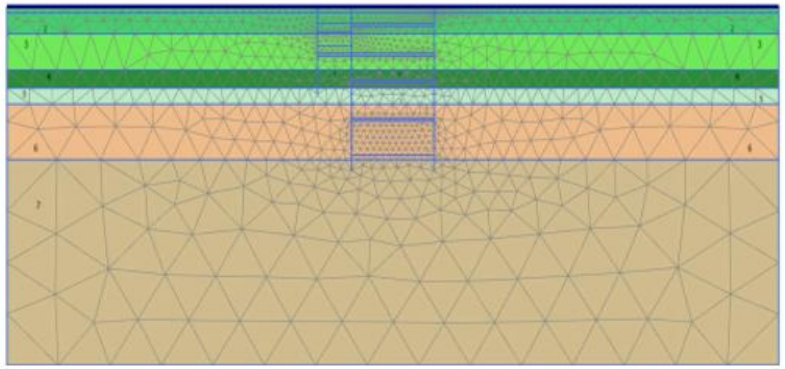
Different stages of construction sequence of typical top-down construction sequence of both case-1 and case-2 conditions station with entrance modelled in PLAXIS 2D.



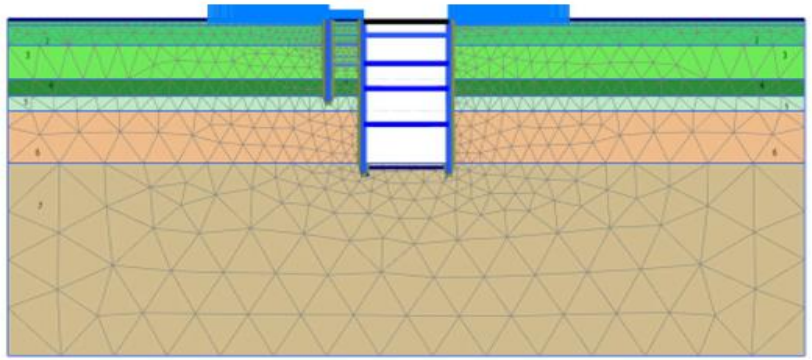
A. Initial stage



B. D-Wall Installation and station excavation stage



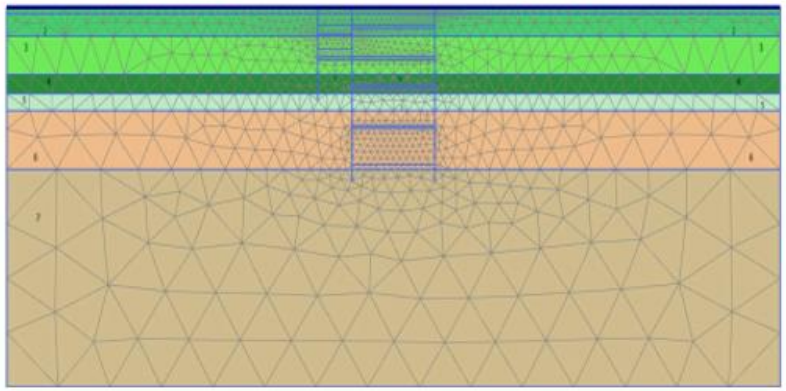
C. Entrance Excavation Stage



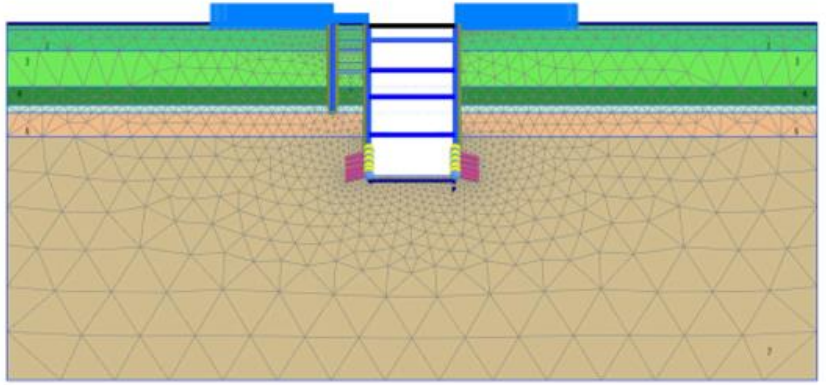
D. Backfill to GL Stage

Different construction sequence of Island part of the station with case-1 condition

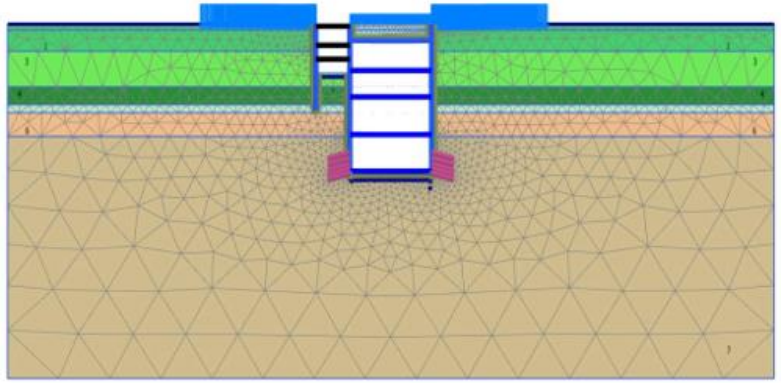
Construction Stage Analysis….Continued



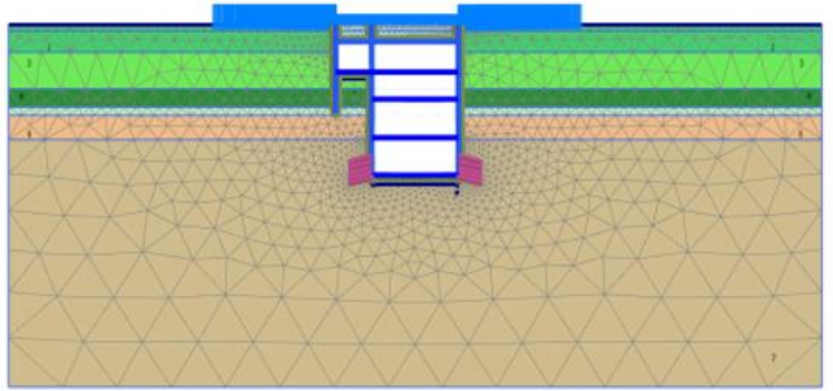
A. Initial stage



B. D-Wall Installation and station excavation stage



C. Entrance Excavation Stage



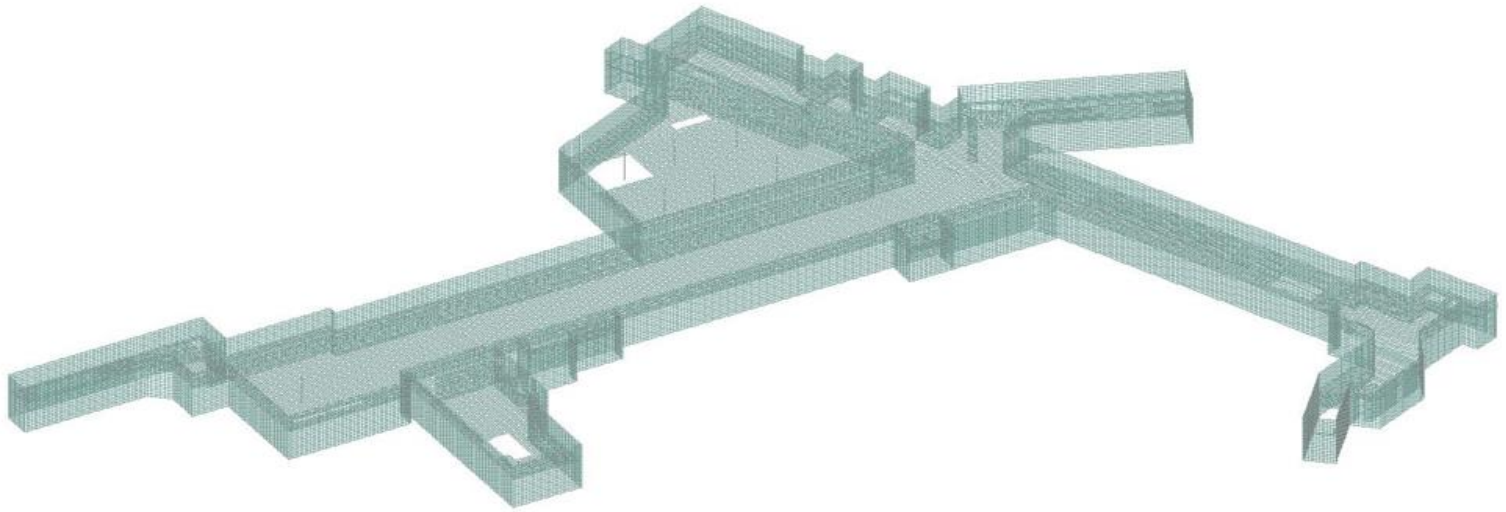
D. Backfill to GL Stage

Different stages in construction sequence of narrow width stacked part of the station with case-2 condition

Service Stage Analysis

A. STAAD Frame model– Case 1 B. STAAD Frame model– Case 2

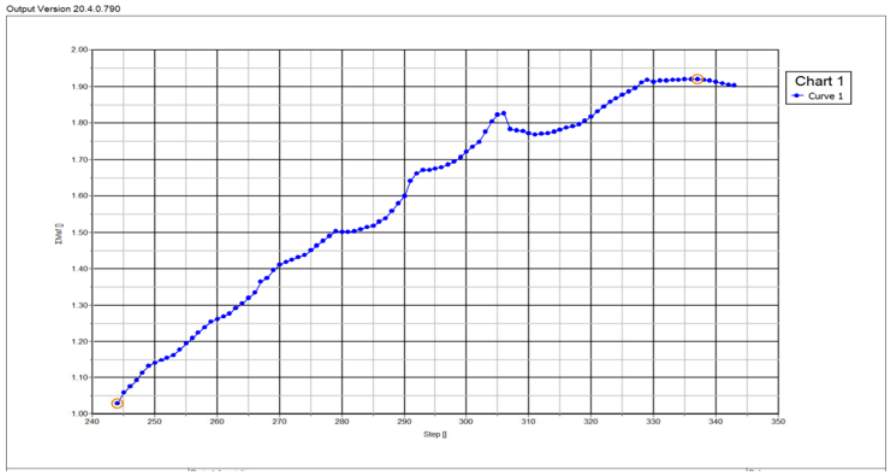
STAAD two-dimensional frame models showing Case 1 and Case 2



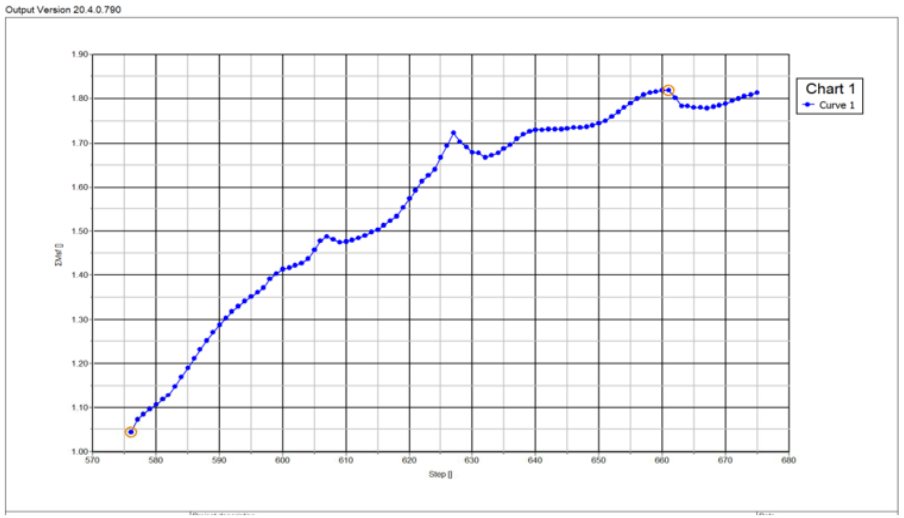
STAAD three-dimensional plate models with permanent openings at top of the station box

Stability Analysis

- The complete cut & cover station structure has been checked against toe stability, which has also been checked from PLAXIS 2D model for both Island part and stacked part of the station.



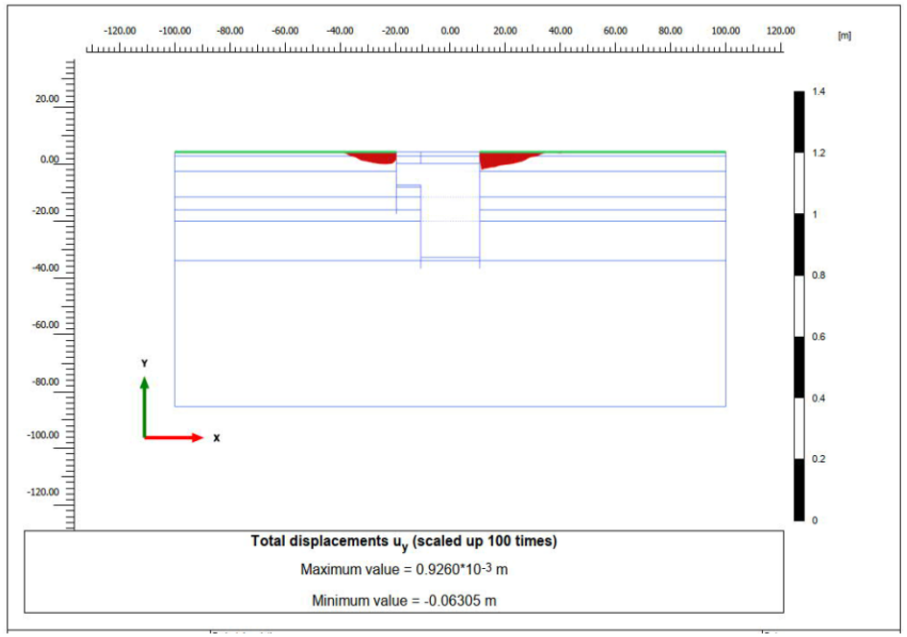
Toe stability factor curve of PLAXIS 2D output envelop for Island part of the station



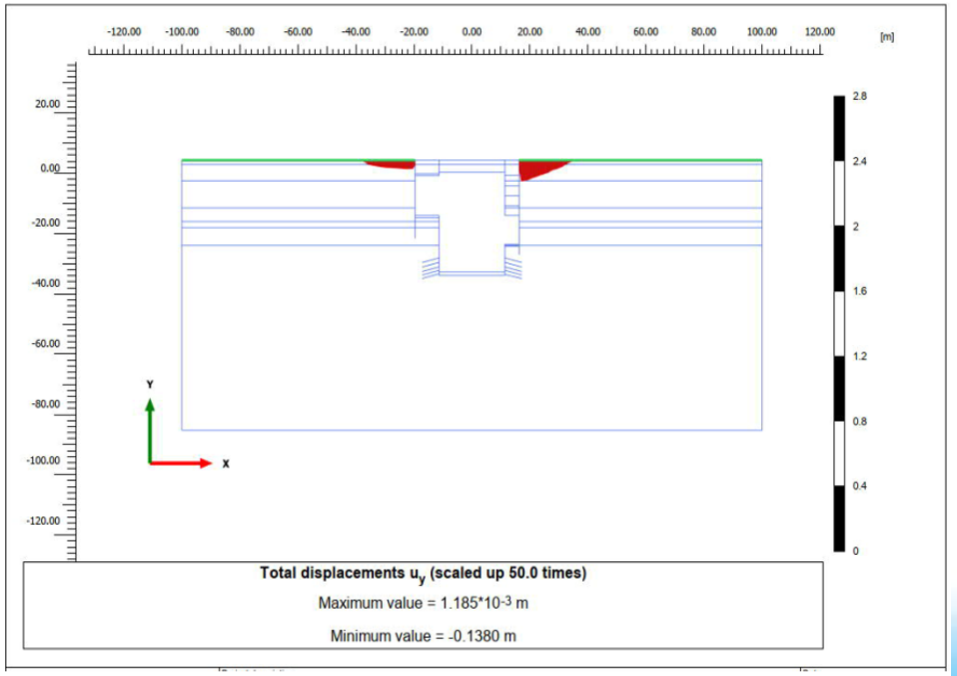
Toe stability factor curve of PLAXIS 2D output envelop for stacked part of the station

Stability Analysis….Continued

- Ground stability analysis for entire stage of excavation and construction has been performed in PLAXIS 2D for both Island part and stacked part of the station.



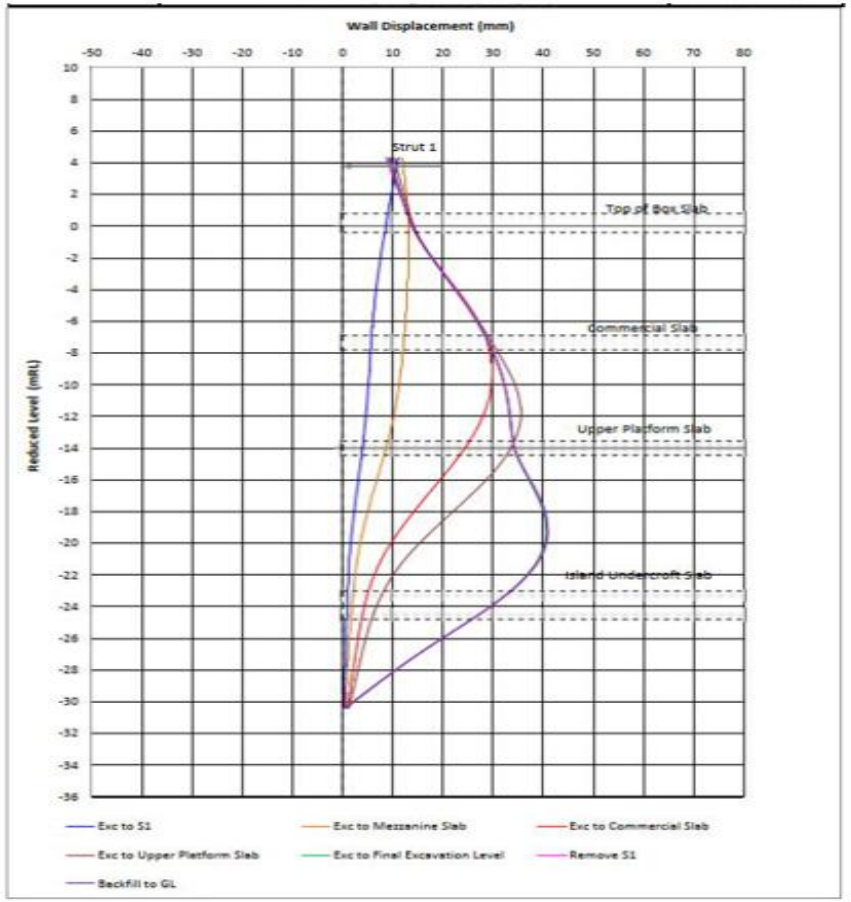
Ground settlement curve of PLAXIS 2D output envelop for Island part of the station



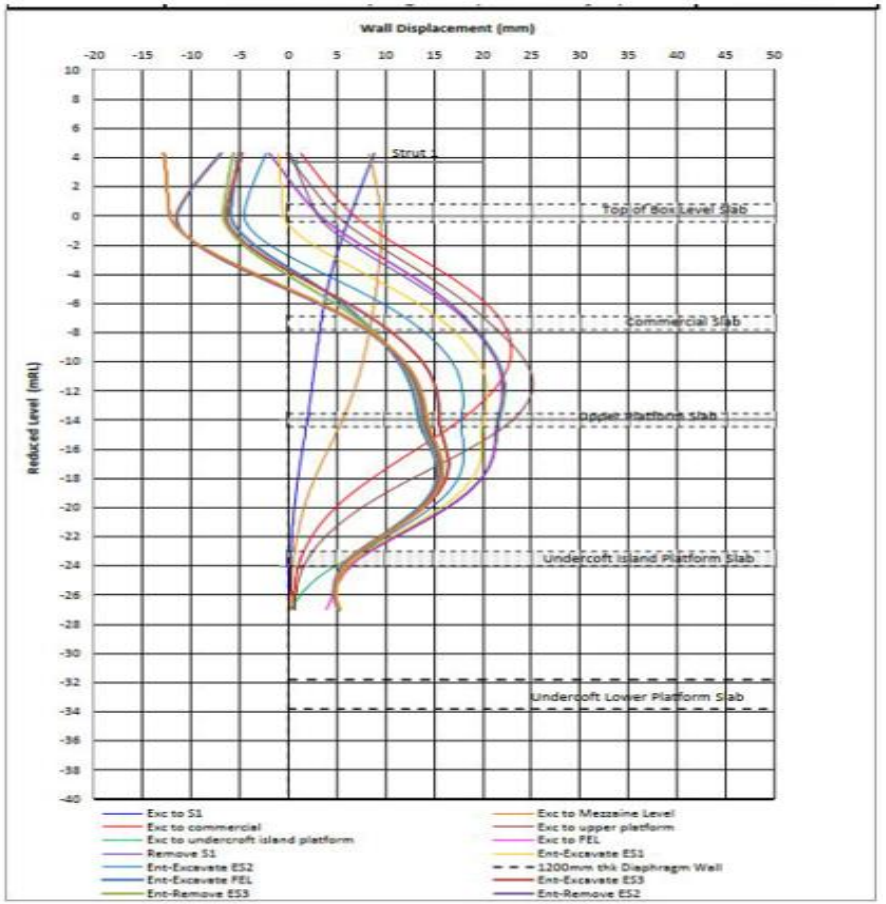
Ground settlement curve of PLAXIS 2D output envelop for stacked part of the station

Discussion on Analysis and Results

- Horizontal deflection of diaphragm walls in different stages of excavation at different depths of the diaphragm wall have been plotted for both Island part and stacked part of the station.



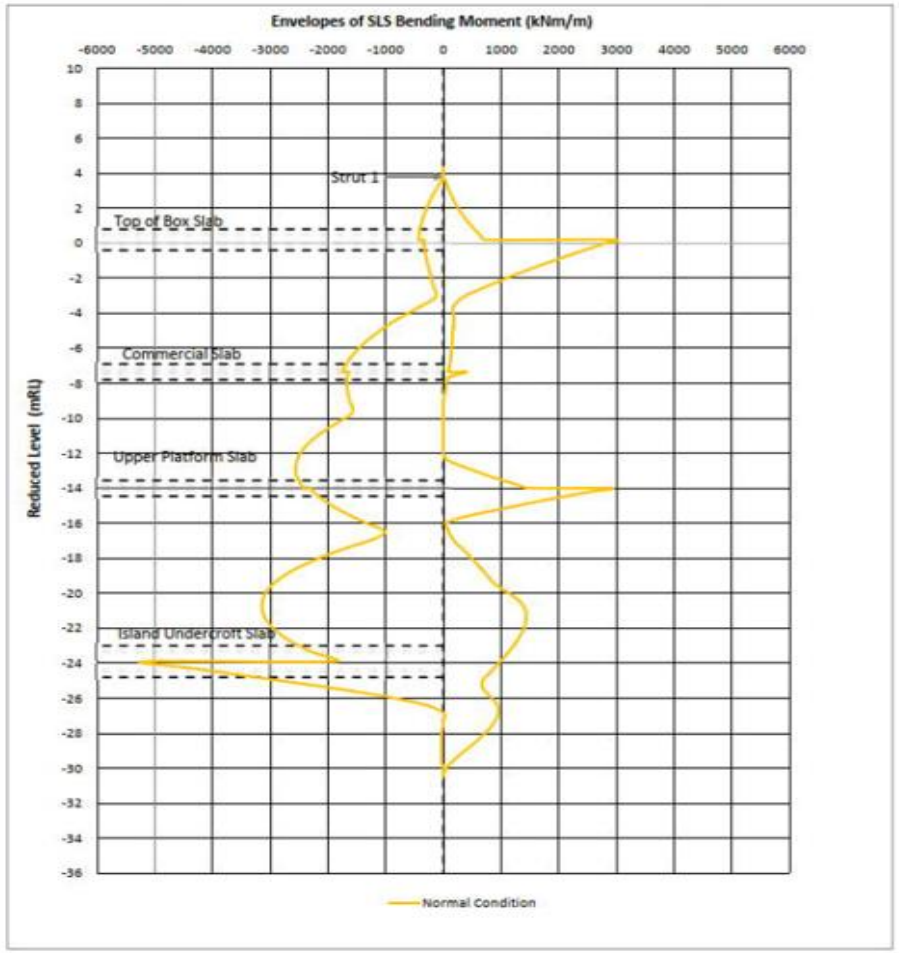
Island part of the station



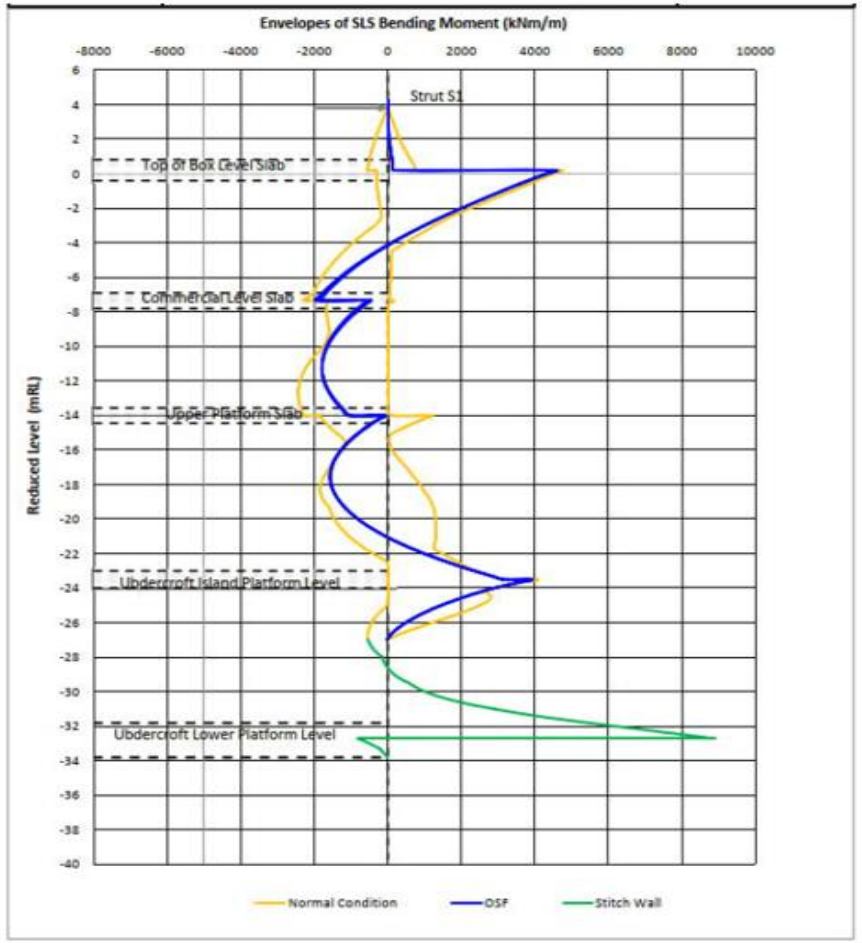
Stacked part of the station

Discussion on Analysis and Results….Continued

- Bending moment diagrams of diaphragm walls have been plotted for different stages of excavation, backfill and service condition for both Island part and stacked part of the station.



Island part of the station



Stacked part of the station

- Structural reinforcement concrete design of diaphragm walls has been done with respect to the envelop for different stages.

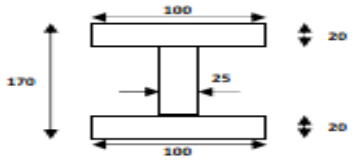
Design Check for D-Wall Toe Pin

AECOM	Project	CMRL Phase II Corridor 3		Job Ref.	60597840
	Part of Structure	STY Shear Pin Capacity		Revision	R0
				Date	14-03-2022
Office of Origin: **Kolkata**	Calculations by	Checked by	Approved by		
	AS	CS	JKK		

Section Type: Built-up section
Grade of Steel: E350 (Fe490)

d = 130 mm
tw = 25 mm

Final Shear Capacity
562.917 kN



Yield Stress = 330 N/mm2 *(For thickness more than 20mm)*
E= 200000 N/mm2
μ = 0.3

1. Plastic Shear Resistance

Vd =Vn/γm0 γm0 = 1.1

Vn = Vp = $\frac{Av * fvw}{\sqrt{3}}$ = 619208.2 N = 619.2082 kN

Vd = 562.917 kN

2. Resistance to Shear Buckling

a) Check for requirement of Shear Buckling Check

d/tw > 67ε*√(Kv/5.35) Kv = 5.35 c = 0 mm

Here, d/tw = 5.2 ε = √(250/fy)= 0.87

5.2 < 58.32

Therefore, check not required.

b) Shear buckling capacity *(Not required)*

Vd =Vn/γm0 γm0 = 1.1

Vn = Vcr = Av*τb

$\tau_{cr,e} = \frac{Kv*(\pi^2)*E}{12(1-\mu^2)} \left(\frac{tw}{d}\right)^2$ = 35764.67 N/mm2

λw = √{fyw/(√3*τcr,e)} = 0.07

τb = 190.53 N/mm2

Therefore, Vn = 619208.16 N = 619.2082 kN

Vd = 562.917 kN

Number of shear pins used 3 per 6 metres

Therefore, capacity of shear pin per m = 281.46 kN
Factored shear force from analysis = 273 kN

Therefore, okay.

Conclusions

- Due to site constrains and land issue, corridor 3 part of Thirumayilai station is adopted with narrow width stacked station. Thus corridor 4 part of the station is proposed as island station between stacking of upline and downline with an interchange connection area.
- As part of economical approach in design and construction, Thirumayilai underground metro station is proposed with top-down method to get advantage of diaphragm wall as well faster construction, less manpower and equipment.
- Due to encounter of hard rock layer, shallow depth diaphragm walls and toe pins embedded into rock strata system have been adopted. Further a stitch wall has been provided as connection between diaphragm to base slab.
- Major challenges were faced due to unsymmetrical and irregular shape of the station box, different levels at interchange connection area, uncertainty of rock profile which occurs complex behaviour station geometry under various loading conditions.
- Structural stability and safety have ensured by checking limiting value in every stage of analysis and design.

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Acknowledgement

- The authors acknowledge the support from the entire team involved in the project of Chennai Metro Rail Corporation Corridor 3 and Corridor 4.

THANK YOU

"*Construction is matter of optimism; it's a matter of facing the future with confidence.*"
– Cesar Pelli

Gratitude and solicitation to Mr. Pughazendhi Ganesan

RIP Pugha sir