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A Comparison of Performance of Deep Excavation using the Top Down and Bottom Up Methods in Kenny Hill Formation

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ABSTRACT: This paper presents the comparison of performance between two deep retention systems using the Top down and Bottom Up methods in Kenny Hill Formation. Both the deep excavations are for the Klang Valley MRT underground stations; namely the Bukit Bintang and Merdeka stations which have similar retained depth of 33.5 m and 31 m respectively and both having 1.2 m thick Diaphragm walls. Both the stations are designed with the same design criteria and factor of safety. The selection of type of retention systems, strutting system, construction sequences and timing and instrumentations are discussed. The predicted and measured diaphragm walls displacements and Strut forces at different stages are then compared and discussed.

KEYWORDS: Deep excavation, Top Down and Bottom Up Methods, Kenny-Hill Formation, Instrumentation, D-wall displacement, Strut forces

1. INTRODUCTION

This paper presents a comparison of performance between two deep retention systems using the Top down and Bottom Up methods in Kenny Hill Formation.

The two deep retention systems with similar final excavation depth of 33.5 m and 31.1 m bgl are the **Bukit Bintang Station** and **Merdeka Station** which are part of the underground package of the KVMRT project which traverse approximately 9.3 km underground. The locations of the Stations in relation to the KL Geological Map are show in Figure 1 below.

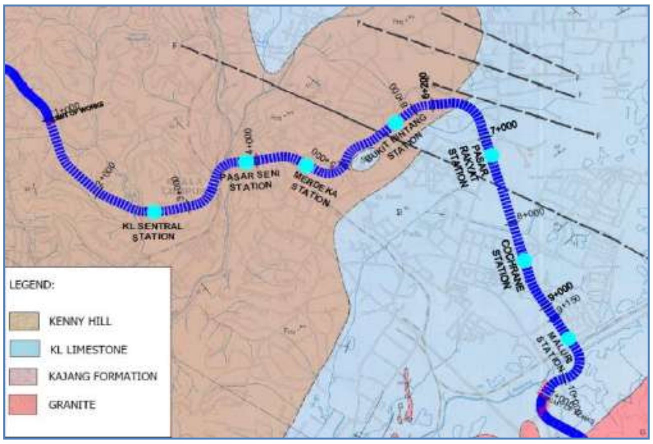

Figure 1 KVMRT alignment with underground stations superimposed on the Geology Map of Kuala Lumpur (1993)

2. GENERAL GEOLOGY AND SUBSOIL CONDITIONS

2.1 General Geology

From the general geological map of Map of Kuala Lumpur, the Merdeka and Bukit Bintang Station are within the Kenny Hill formation.

The subsurface investigation boreholes carried out shows that the Kenny Hill Formation along the alignment to be a sequence of interbedded sandstone, siltstones and shales / mudstones overlain by stiff over-consolidated soils predominately of sandy silty Clay and Silty Sand.

At the Merdeka Station which is located on a hilly terrain at an approximate Reduced Level of 46 m, the subsoil consist of predominately of very stiff to hard silty soil interbedded with occasional blackish soil of high clay content.

Whilst for the Bukit Bintang Station, which is located at the highest point of the MRT underground package at a Reduced Level of approximately 50m, the subsoil consist of predominately Stiff to Hard Soil with high Silt content.

The variability of depth of the hard soil and depth of metamorphosed sedimentary rock for each stations present unique design and construction challenges for the selection of the optimal type of deep retention wall systems.

2.2 Subsoil Investigation and findings

Presented below are the subsurface profiles and findings from the Soil Investigation works carried out for the design of both the underground stations.

2.3 Merdeka Station

Approximately 22 boreholes were carried out for Station Diaphragm wall design. The Kenny Hill overburden soil here is lightly over consolidated and as expected starts with Stiff to Very Stiff SPT 'N' values between 8 to 20 blows within the first 7.5 m depth below ground. The SPT 'N' values gradually increase to between 20 to 50 blows range from 7.5 m to 20 m depth. Beyond 20 m depth, the overburden soil becomes hard having SPT 'N' values greater than 100 blows. The permeability of the soil here are consistent with soils with high Silt content with K values between the ranges of 10^{-7} to 10^{-8} m/s.

Figure 2A to Figure 2C below are the Merdeka Station boreholes layout, simplified subsurface profile and characterised parameters with depth.

2.4 Subsoil Conditions

The soil profile adopted for D-wall section T1 (Gridline 4 to Gridline 13) are based on the worst boreholes BUB-022(US) and BUB-021(US) i.e. the hard stratum of SPT-N > 100 is at the lowest at about 25 mbgl. The Kenny Hill residual soil mainly comprises sandy silt to sandy clay, with a mix of silty sand. The first layer of soil is about 16.5 m thick with an average SPT-N value of 13. The next layer is about 8.5 m thick with average SPT-N value of 58. The hard stratum of SPTN > 100 is then encountered at 25 mbgl and is about 9 m thick. Beyond that, is hard stratum of SPT-N >200. Based on the water standpipe monitoring results, the water level at the field is more than 15 m below ground which is quite low according to past basement construction experience in the Klang Valley. However, for design the water level is taken to be 6 m bgl, this is in view of other nearby ground water monitoring data.

2.5 Bukit Bintang Station

Located at approximately 250 m from the limestone interface zone, the Kenny Hill overburden soil here has slightly lower SPT 'N' values than the Merdeka station sub-soil at similar depth. 28 boreholes were carried out for the Station design, the SPT 'N' values varies between 5 to 15 blows within the first 20 m depth below ground. The SPT 'N' values then gradually increases to generally between 15 to 25 blows up to 30 m depth. Beyond 30 m depth, the overburden soil becomes Hard having SPT 'N' values greater than 100. Bedrock was not encountered in any of the boreholes. The permeability of the soil here are similar to Merdeka with K values between the ranges of 10^{-7} to 10^{-8} m/s although the soil has slight more Silty content.

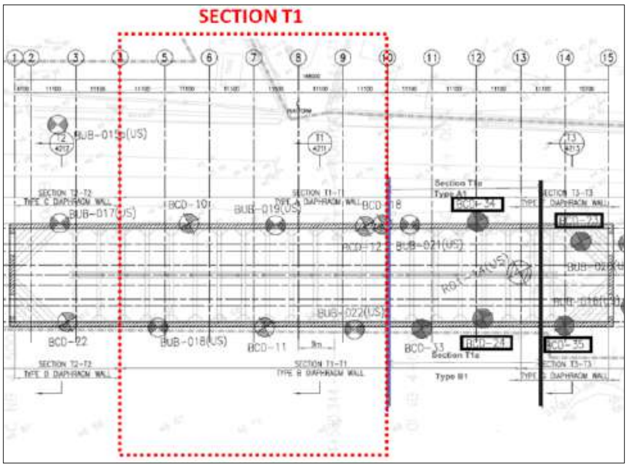

Figure 2A Merdeka Station boreholes layout

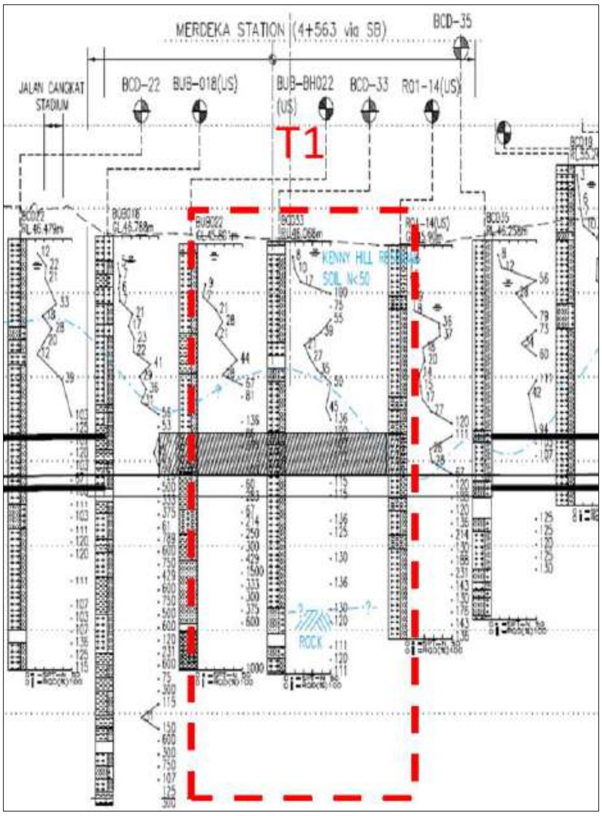

Figure 2B Merdeka Station simplified subsurface profile

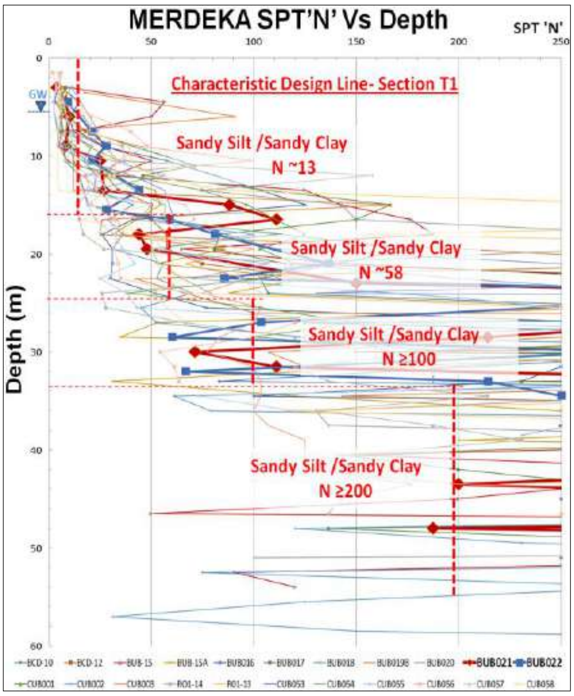

Figure 2C Merdeka Station Characteristic Design Line for D-Wall Section T1

Figures 3A to 3C below shows the respective Bukit Bintang Station boreholes layout, simplified subsurface profile and characterised parameters with depth.

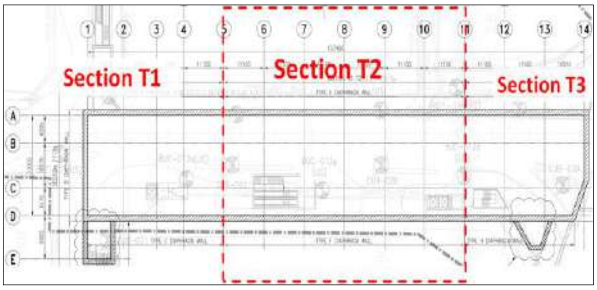

Figure 3A Bukit Bintang Station Borehole layout

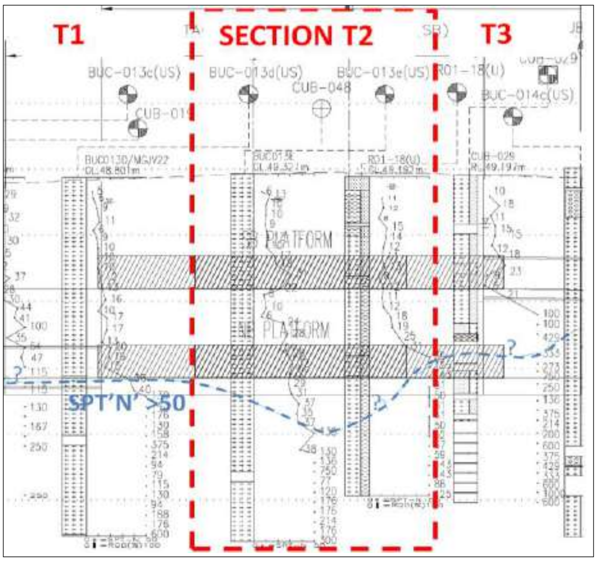

Figure 3B Bukit Bintang Simplified Subsurface profile

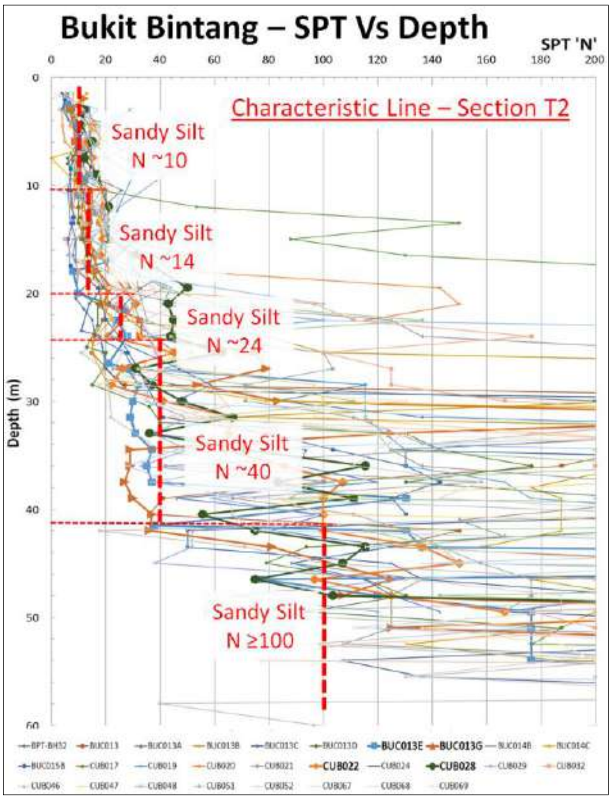

Figure 3C Bukit Bintang Station Characteristic Design Line for D-Wall Section T2

The Figure 3D below shows Plasticity Chart with all the Atterberg Limits results of the Kenny Hill soils stations. Specifically the ranges of values for BB and Merdeka Station are quite similar in a narrow Intermediate Clay and Intermediate Silt (CI and MI) range; with Bukit Bintang being more Silty by being more below the 'A' line.

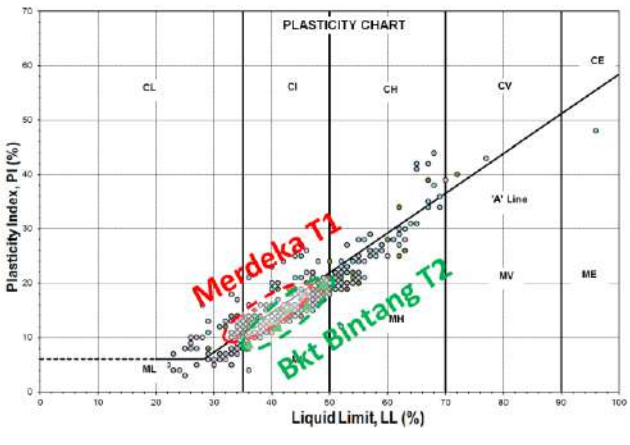

Figure 3D Plasticity Chart of Kenny Hill Soils

3. DESCRIPTION OF THE UNDERGROUND STATIONS

Briefly, below are description of each of the station and the proposed sequences.

3.1 Merdeka

The Merdeka station box starts from Ch 4+480 to Ch 4+628 and is approximately 148 m long and 24 m wide. Because of depth of the station of 31.1 m, the selected retention system is a 1.2 m thick diaphragm wall. The design selection of D-wall thickness is an iterative process of changing the level of Struts, thickness and the steel content.

The key to the design iterations is to keep the deflection movement within less than 0.5% of the excavated depth, lesser if there are sensitive building around. Whilst the strut levels are selected to give a head room of 3 m to 5 m for excavator larger machine to work while not too large to cause large bending moment during the temporary stage. It is preferred that the bending moment during the temporary stages are compatible with the bending moment for the permanent stage when the structural slabs are casted. That way, the wall thickness would not be controlled by temporary works. Lastly, the steel content are kept to a manageable 150 -240 kg/m^3 to keep steel congestion down.

This four-level station with parallel tunnels located at the lowest level is excavated in a **Bottom-Up construction** sequence. The key to the construction sequence decision is related to the mitigation to overall project risk and the timing of the arrival of the Tunnel boring machines (TBM). The TBMs were planned to be launched from the nearby Pudu Launch shaft early and the Station was designed to be a 'Pull through', with the TBM being pull through the station completed base slab. The risk of a non-completed Merdeka Station base slab would affect the TBM tunneling works and subsequent down line station work. Therefore for early completion of the base slab, the bottom up sequence was selected.

The total excavation time to reach the FEL (Final excavation level) after installation of the D-wall is approximately **13 months** for an excavated volume of approximately 110,000 m^3 with 6 levels of strutting.

Figures 4A and 4B show the schematic cross section and construction sequences of the Merdeka station.

3.2 Bukit Bintang

The Bukit Bintang station box starts from Ch 5+670 to Ch 5+820 and is approximately 150 m long and 23 m wide and 33.5 m deep. This four-level station with stacked tunnels is excavated in a Top-Down sequence. The selected retention system is similar to Merdeka Station which is a 1.2 m thick diaphragm wall.

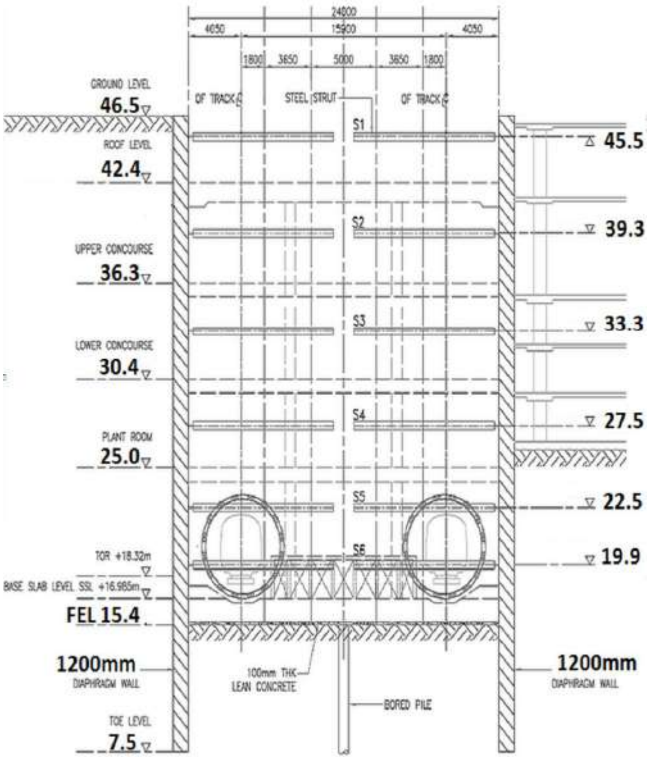

Figure 4A Merdeka Station Cross Section T2

CONSTRUCTION SEQUENCE

MERDEKA STATION BOX EXCAVATION

STAGE 1:

1.1 INSTALL DIAPHRAGM WALL FOR MAIN STATION BOX TO THE DESIGNED DEPTH
1.2 INSTALL KINGPOST / DECKING.

STAGE 2:

2.1 EXCAVATE TO 1M BELOW S1 STRUT LEVEL, INSTALL AND PRELOAD STRUT S1
2.2 REPEAT STEP 2.1 FOR STRUTS S2 TO S6

STAGE 3:

3.1 EXCAVATE TO SUNKEN BASE SLAB SOFFIT LEVEL
3.2 CAST DISH-SHAPED BASE SLAB.

STAGE 4:

4.1 REMOVE STRUT S6
4.2 REMOVE STRUT 55
4.3 NORTH BOUND/SOUTH TBM PULL THROUGH AND RELAUNCH
4.4 CAST REMAINING PORTION OF DISH-SHAPED BASE SLAB TO FINAL SLAB LEVEL
4.5 CAST COLUMNS AND PLATFORM SLAB
4.6 CAST PLANT ROOM SLAB
4.7 REMOVE STRUT S4
4.8 CAST COLUMNS AND LOWER CONCOURSE SLAB
4.9 REMOVE STRUT S3
4.0 CAST COLUMNS AND UPPER CONCOURSE SLAB
4.11 REMOVE STRUT S2
4.12 CAST AND ROOF SLAB

STAGE 5:

5.1 BACKFILL WITH APPROVED FILL MATERIAL TO 1M BELOW STRUT S1.
5.2 REMOVE STRUT SI
5.3 BACKFILL WITH APPROVED MATERIAL, TO 2M BELOW GROUND LEVEL

STAGE 6:

6.1 EXCAVATE TO BASEMENT 1 SLAB SOFFIT LEVEL.
6.2 CAST BASEMENT 1 SLAB.
6.3 REPEAT STEP 6.1 FOR BASEMENT SLAB 3 TO BASEMENT SLAB 6.

STAGE 7:

7.1 DEMOLISH DIAPHRAGM WALL TO AT LEAST 2M BELOW GROUND LEVEL.
7.2 BACKFILL TO GROUND LEVEL

WARISAN MERDEKA EXCAVATION

8.1 EXCAVATE TO BASEMENT 1 BASE SOFFIT LEVEL
8.2 CAST BASEMENT 1 SLAB
8.3 REPEAT STEP 8.1 FOR BASEMENT SLAB 3 TO BASEMENT SLAB 6

(Note: Stages 2.1 to 3.1 take about 13 Months)

Figure 4B Merdeka Station Construction Sequence

The selection of the **Top Down construction** sequence was because of the relatively long duration for the D-wall construction due to multiple road diversion needed. Because of this long duration, the lower TBM was scheduled to reach before the excavation was completed, thus the station was designed as a 'bored through' station. A bottom up sequence would have struts which would be in the way of the TBM bored through.

In addition, the Top Down method is also a more robust and safer choice to support the live traffic on the station roof slab and to retained the excavation nearby to a row of shops.

However, the Top Down method has the disadvantage of being much slower because of the slabs construction and have larger unrestraint height contributing to larger D-wall bending moments.

The total excavation time to reach FEL for this station after installation of the D-wall is approximately **23 months** for an excavated volume of approximately 115,000 m^3 with 4 levels of RC slab and 1 level Strut.

Figures 5A and 5B show the schematic cross section and construction sequences of the BB station.

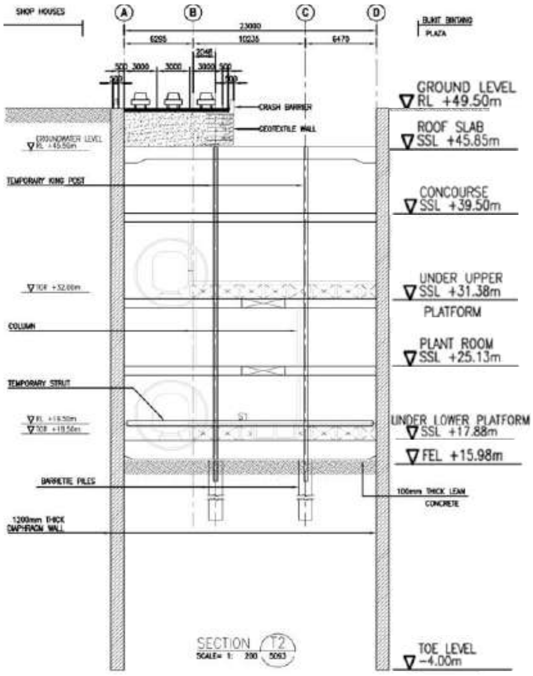

Figure 5A Bukit Bintang Station Cross Section T2

CONSTRUCTION SEQUENCE :

BUKIT BINTANG STATION BOX EXCAVATION

STAGE 1:

1,1 DIVERT TRAFFIC AS PER TRAFFIC MANAGEMENT PLAN
1.2 DIVERT UTILITIES
1.3 INSTALL DIAPHRAGM WALL TO DESIGNED DEPTH
1.4 INSTALL BARRATTE PILES AND TEMPORARY KING POSTS TO DESIGNED DEPTH AND CUT-OFF LEVEL
1.5 BACKFILL ANNULUS AROUND THE TEMPORARY KING POSTS WITH SUITABLE MATERIAL.

STAGE 2:

CONSTRUCTION OF ROOF SLAB

STAGE 3:

3.1 EXCAVATE TO SOFFIT OF CONCOURSE SLAB,
3.2 CAST CONCOURSE SLAB WITH CONSTRUCTION OPENINGS.

STAGE 4:
4.1 EXCAVATION TO SOFFIT OF UNDER UPPER PLATFORM SLAB
4.2 CAST UNDER UPPER PLATFORM SLAB WITH CONSTRUCTION OPENINGS.

STAGE 5:

5.1 ENSURE LOWER TUNNEL (NS) HAS BEEN BACKFILLED AT LEAST 80% FULL (UP TO RL +21.80m) PRIOR TO SUBSEQUENT EXCAVATION,
5.2 EXCAVATION TO SOFFIT OF PLANT ROOM SLAB.
5.3 CAST PLANT ROOM SLAB WITH CONSTRUCTION OPENINGS.

STAGE 6:

6.1 EXCAVATE TO 1m BELOW TEMPORARY STRUT SI.
6.2 INSTALL TEMPORARY WALER, STRUT S1 AND PRELOAD THE STRUT.

STAGE 7:

7.1 EXCAVATE TO FINAL EXCAVATION LEVEL.
7.2 APPLY LEAN CONCRETE AND CAST UNDER LOWER PLATFORM / BASE SLAB.

STAGE 8:

8.1 REMOVE TEMPORARY WALER AND STRUT S1.
8.2 CAST COLUMNS AND PLATFORM STRUCTURES.
8.3 REMOVE TEMPORARY KING POSTS AND CLOSE OFF TEMPORARY CONSTRUCTION OPENINGS.
8.4 BACKFILL TO GROUND LEVEL
8.5 DEMOUSH OIAPHRAGM WALL TO AT LEAST 2m B[LOW GROUND LEVEL AND REINSTATE THE SITE.

(Note: Stages 2 to 7.1 take about 23 Months)

Figure 5B Bukit Bintang Station Construction Sequence

4. UNDERGROUND STATIONS RETENTION SYSTEM DESIGN CRITERIA AND OBJECTIVES

Before we start comparing the performance of the retention systems design, it is noteworthy to list some of the stations common design criteria for temporary condition as follow.

1. Factor of Safety against flotation, F.O.S > 1.10
2. Factor of Safety against Basal heave, F.O.S ≥ 1.2, if moderate conservative values of undrained shear strength are used and where the vertical shear resistance along retained ground shallower than the excavation is ignored.
3. For temporary works and excavation, the possibility of hydraulic uplift is to be assessed. The minimum factor of safety should, F.O.S ≥ 1.2.
4. To prevent failure by piping, the toe of the diaphragm wall is to penetrate to a sufficient depth or to a low permeable layer, such that the vertical seepage exit gradient at the base of the excavation is less than unity.
5. Toe in stability check using method given in the NAVFAC
6. DM7.02 using BS8002 mobilization factors with an overall Factor of Safety of 1.0 shall be adopted. For effective stress parameters, c' and ϕ', the mobilization factors shall be 1.2, and for total stress parameters, cu the mobilization factor shall be 1.5.
7. Table 1 shows the load combinations for strut design adopted under ultimate limit state condition.

Table 1 Load Factors Combination for Strut Design*

Load Combination	Load Factor				
	Excavation load (Soil+ Groundwater)	Dead load	Live load	Temperature load	Impact load
Normal working condition	1.4	1.4	1.6	1.2	-
One strut failure	1.05	1.05	0.5	-	-
Accidental impact	1.05	1.05	0.5	-	1.05

*Note: 1) Hydrostatic water level is adopted for design.
2) Change in temperature = 10 °C
3) Eccentricity, self-weight and unplanned excavations are to be considered.

5. DESIGN OF THE RETENTION SYSTEMS

5.1 Merdeka Station

The design parameter are characterised and selected to be **moderately conservative.**

For example, the t'-s plot below (Figure 5) represent the results for Kenny Hill residual soil with SPT 'N' ≤ 30. From the characterised line, the proposed design parameter is c' = 5 kPa and $\phi = 28^o$

The characterization of the Unload Reload Modulus from pressuremeters versus the SPT 'N' carried out were used for the Elastic Modulus, E for the design (Figure 6). The proposed E is taken as 2.0N MPa limited to 200 MPa.

For deep excavation like Merdeka station, beyond 25 m bgl, the Kenny Hill soil has a consistency greater than SPT 'N" >100 and some of these soils were observed to have some weak rock structure matrix. In order to optimise the design, it is important that high quality undisturbed samples are obtained for testing. Therefore, special drilling method of using high torque low speed coring machines with a T-Junction relief valve were to control the drilling water flow rate and improve the recovery. To even further improve the undisturbed sample recovery and reduce disturbance; double tube swivel type core barrels were used with a plastic liner. Below are the photos of the special SI work setup for getting the difficult undisturbed samples. Figure 7 shows photos of obtaining Undisturbed Samples with double tube with plastic liner.

From the in-situ SI and laboratory test results carried out for the Merdeka Station, below is tabulated in Table 2, the Kenny Hill design parameters used for the T1 D-wall Plaxis analysis.

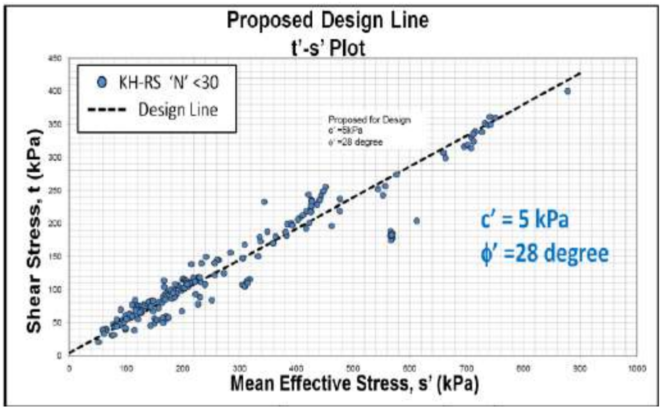

Figure 5 Shear Strength versus Mean Effective Stress plot of Kenny Hill SPT 'N' ≤ 30 Soil

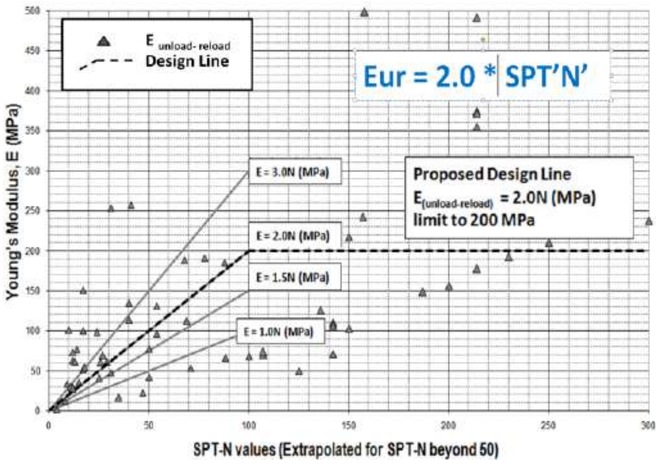

Figure 6 E_{ur} versus SPT 'N' plot of Kenny Hill Soils

Table 2 Kenny Hill Soil Design Parameters

Stratum	Bulk density, γ (kN/m³)	Undrained shear strength, c_u (kN/m²)	Unconfined compressive strength, q_u (MPa)	Effective cohesion, c' (kPa)	Effective angle of friction, ϕ' (degree)	Elastic Modulus, E (MPa)
RESIDUAL SOIL						
Kenny Hill Residual Soil, N≤30	18.5	c_u=5N (limit to 250)	NA	5	28	E_u=2N (limit to 200)
Kenny Hill Residual Soil, 30<N≤100	19		NA	10	28	
Kenny Hill Residual Soil, N>100	20	250	NA	15	29	E'=0.87E_u
Kenny Hill Residual Soil, N>200	20***	250***	NA	22***	31***	250***
SEDIMENTARY ROCKS						
Highly Weathered Rock, G(IV)	20	NA	20 (intact rock) 0.16 (rock mass)**	30*	34*	250**
Moderately Weathered Rock, G(III) & better	23	NA	22 (intact rock) 0.99 (rock mass)**	100*	40*	1350**

The Merdeka T1 D-Wall design has been modelled using PLAXIS 2D version 9.0 which facilitates the modelling of a staged excavation. It is a two-dimensional (plane-strain) finite element program, specifically developed for the analysis of deformation and stability in geotechnical engineering problems.

The soil has been modelled using the Hardening soil model to reflect the nature of the site geotechnical conditions and the excavation activity and the analysis was carried out assuming drained conditions with steady state seepage. Input geotechnical design parameters can be referred to Table 2. The stiffness of the diaphragm wall was estimated from the compressive strength of the concrete and reduced by 30%, considering the possibility of bending moment induced cracks in the wall and relatively low water quality of concreting in water. The struts were modelled using node to node anchor with axial stiffness (EA) of the struts and spacing. The permanent concrete column has been modelled using node-to-node anchor elements to simulate the behaviour of an axially loaded member. The permanent station slabs have been modelled using plate elements to simulate the behaviour of members undergoing both axial and bending.

Figure 7 Photos of obtaining Undisturbed Samples with double tube with plastic liner.

Figures 8 to Figure 10 show the results from the FEM analysis.

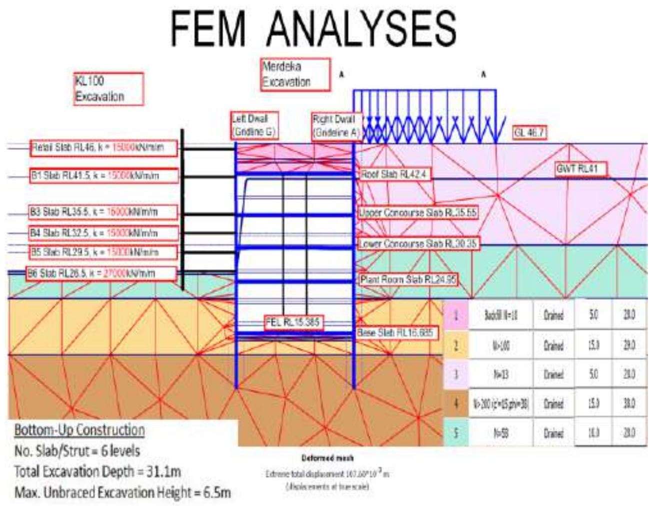

Figure 8 Merdeka Station - Plaxis Meshing Model.

5.2 Bukit Bintang Station

Similarly, the design parameter are characterised and selected to be **moderately conservative.** The SI works carried out for Bukit Bintang is similar to Merdeka but with 28 boreholes. As expected, the characterised Kenny Hill parameters for these boreholes are quite similar to Merdeka since they are just approximately 1.2 km away than therefore the values in the previous Table 2 are maintained for the T2 D-wall design. Figures 11 to 13 show the results from the Plaxis Meshing Model, SLS Bending Moment Envelope and Analysed Displacement Profiles at Various Stages respectively.

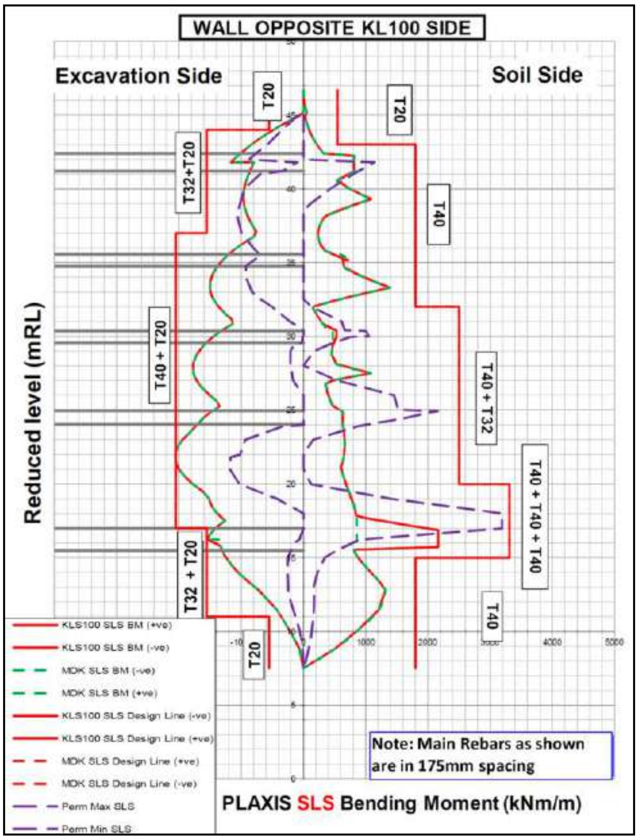

Figure 9 Merdeka Station - SLS Bending Moment Envelope (KL118 Side)

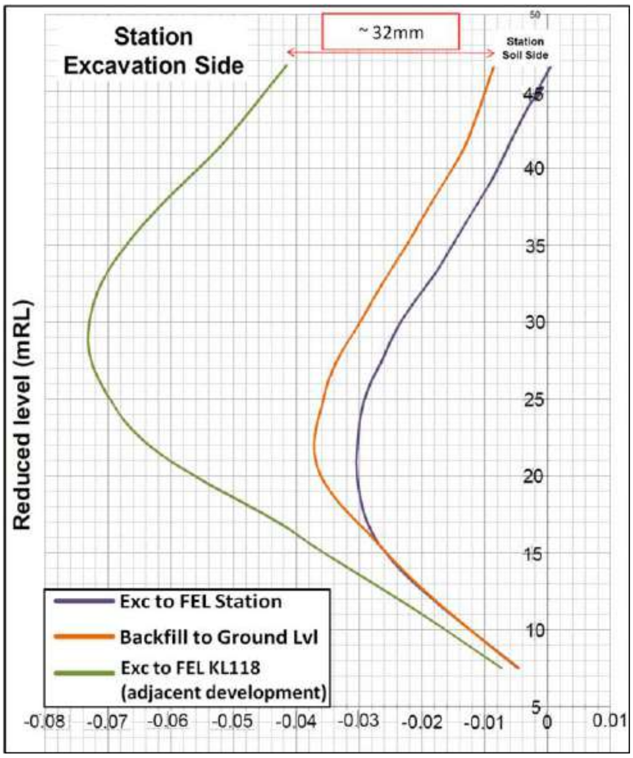

Figure 10 Merdeka Station - Analysed displacement Envelopes

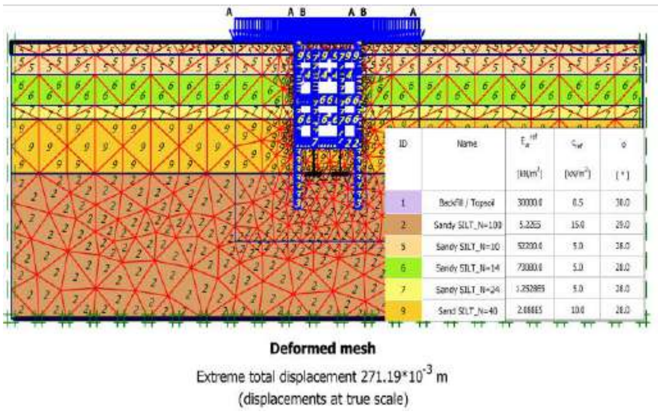

Figure 11 Bukit Bintang Station - Plaxis Meshing Model

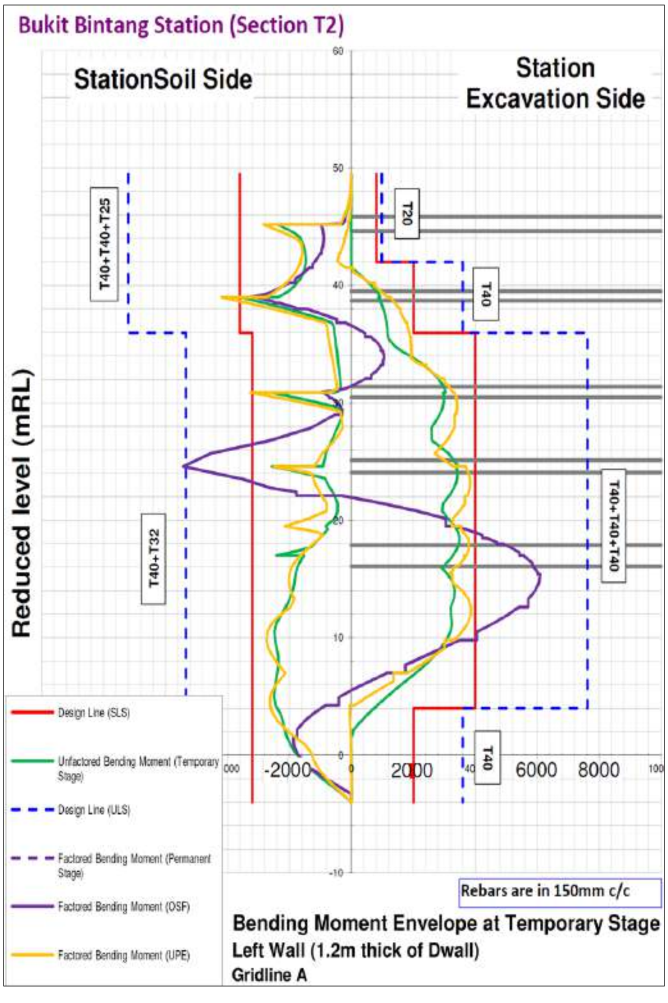

Figure 12 Bukit Bintang Station - SLS Bending Moment Envelope (Shops Side)

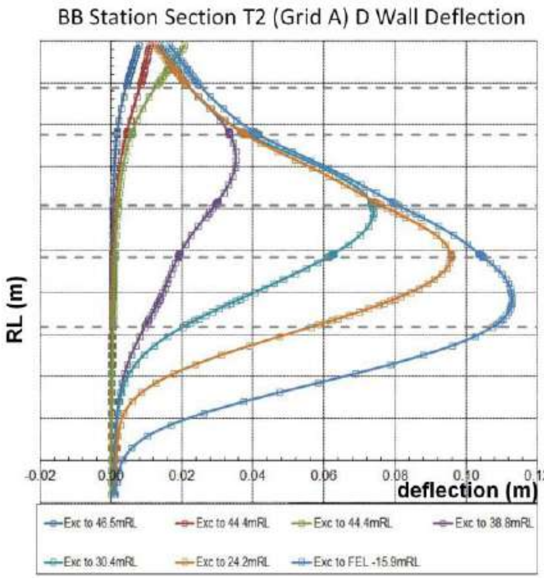

Figure 13 Bukit Bintang Station - Analysed Displacement Profiles at Various Stages

6. INSTRUMENTAION OF STATIONS

In order to monitor the performance of the UG Station, a set of instrumentation which includes 10 and 13 Inclinometers were installed within the Merdeka and Bukit Bintang Diaphragm walls to hard layer depth 10 m beyond the toe of the D-wall.

Figure 14 and 15 show the location of the in-wall Inclinometer INW2 and INW11 which will be used to evaluate the performance of the D-Wall design.

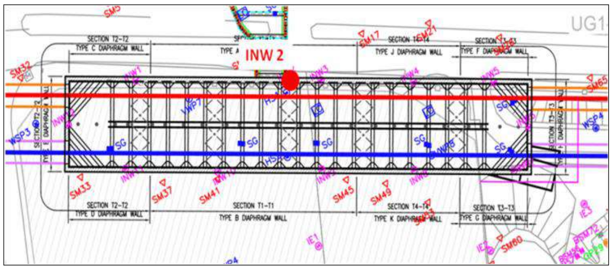

Figure 14 Merdeka in-wall Inclinometer INW2 for T1 D-wall

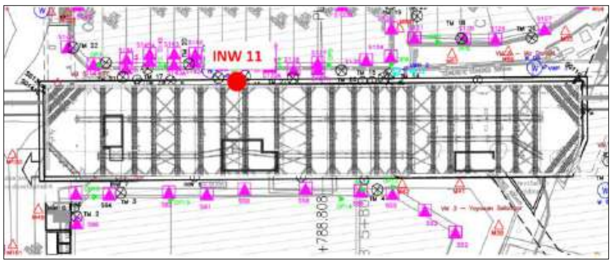

Figure 15 Bukit Bintang in-wall Inclinometer INW11 for T2 D-wall

All 6 levels of Struts for Merdeka and 1 level for BB were monitored with Load Cells and Strain Gauges. Approximately 15% of all the Struts are monitored with Strain Gauges and / or load cells. At least 25 % of the struts with strain gauges are also monitored with load cells.

The monitoring frequencies of the instruments are as shown in Table 3.

Table 3 Instruments Monitoring Frequencies

	INSTRUMENT	MONITORING FREQUENCY			
		PRIOR TO EXCAVATION	DURING EXCAVATION	DURING STRUT REMOVAL	AFTER BACKFILLING
	GROUND SETTLEMENT MONITORING				
1	POINT	WEEKLY	DAILY	DAILY	WEEKLY
2	HEAVE STAKE	WEEKLY	DAILY	DAILY	WEEKLY
3	V.W. PIEZOMETER	WEEKLY	DAILY	DAILY	WEEKLY
4	INCLINOMETER IN WALL	WEEKLY	DAILY	DAILY	WEEKLY
5	INCLINOMETER / EXTENSOMETER IN SOIL	WEEKLY	DAILY	DAILY	WEEKLY
6	ROD EXTENSOMETER	WEEKLY	DAILY	DAILY	WEEKLY
7	CONVERGENCE MEASUREMENT	WEEKLY	DAILY	DAILY	WEEKLY
8	CRACKMETER	WEEKLY	DAILY	DAILY	WEEKLY
9	BUILDING SETTLEMENT MARKERS	WEEKLY	DAILY	DAILY	WEEKLY
10	TILTMETER	WEEKLY	DAILY	DAILY	WEEKLY
11	STRAIN GAUGE & LOADCELLS ON STRUTS	NIL	REAL-TIME	REAL-TIME	WEEKLY
12	VIBRATION SENSOR	NIL	DAILY	DAILY	WEEKLY
13	EL SENSOR / TILTMETER	*WEEKLY	*DAILY	*DAILY	WEEKLY
14	OPTICAL PRISM	WEEKLY	DAILY	DAILY	WEEKLY

The trigger levels for the instrument are set approximately at 50 %, 70 % and 100 % of the predicted values in the Plaxis design model (which uses moderately conservative parameter).

Tables 4 to 7 below show the Trigger levels for the wall Movement and Struts load for Merdeka and BB Stations.

Table 4: Merdeka station wall horizontal displacements trigger Levels

CONSTRUCTION STAGE	ALERT LEVEL	ACTION LEVEL	ALARM LEVEL
	(mm)	(mm)	(mm)
EXCAVATE TO S1	17	21	25
EXCAVATE TO S2	17	21	25
EXCAVATE TO S3	17	21	25
EXCAVATE TO S4	17	21	25
EXCAVATE TO S5	24	30	35
EXCAVATE TO S6	24	30	35
EXCAVATE TO FEL	28	34	40
REMOVE S6	31	38	45

Table 5 Merdeka station T1 D-Wall strut load trigger levels

CONSTRUCTION STAGE	REVIEW LEVEL	Section T1–T1					
		S1	S2	S3	S4	S5	S6
EXCAVATE TO S1	-						
EXCAVATE TO S2	ALERT LEVEL	280					
	ACTION LEVEL	400					
	ALARM LEVEL	560					
EXCAVATE TO S3	ALERT LEVEL	165	625				
	ACTION LEVEL	210	1000				
	ALARM LEVEL	560	1250				
EXCAVATE TO S4	ALERT LEVEL	170	625	890			
	ACTION LEVEL	210	800	1380			
	ALARM LEVEL	560	1250	1780			
EXCAVATE TO S5	ALERT LEVEL	170	625	890	1190		
	ACTION LEVEL	215	790	1240	1620		
	ALARM LEVEL	560	1250	1780	2380		
EXCAVATE TO S6	ALERT LEVEL	165	625	890	1190	840	
	ACTION LEVEL	205	790	1250	1660	1310	
	ALARM LEVEL	560	1250	1780	2380	1680	
EXCAVATE TO FEL	ALERT LEVEL	170	625	890	1190	840	535
	ACTION LEVEL	210	800	1260	1720	1345	860
	ALARM LEVEL	560	1250	1780	2380	1680	1070
REMOVE S6	ALERT LEVEL	170	625	890	1190	840	
	ACTION LEVEL	215	810	1270	1790	1345	
	ALARM LEVEL	560	1250	1780	2380	1680	

Table 6 BB Station Wall Horizontal Displacement Trigger Levels

CONSTRUCTION STAGE	Section T2-T2 (Grid A)		
	ALERT LEVEL	ACTION LEVEL	ALARM LEVEL
	(mm)	(mm)	(mm)
EXCAVATE TO ROOF	22	26	31
EXCAVATE TO CONCOURSE	31	37	44
EXCAVATE TO UPPER PLATFORM	48	59	69
EXCAVATE TO PLANT	58	71	83
EXCAVATE TO S1	67	81	95
EXCAVATE TO FEL	71	87	102

Table 7 BB station T2 D-Wall strut load trigger levels

CONSTRUCTION STAGE	Section T2-T2 (Grid A)		
	ALERT LEVEL	ACTION LEVEL	ALARM LEVEL
	kN/m	kN/m	kN/m
INSTALL S1	400	640	800
EXCAVATE TO FEL	1343	2148	2685

7. PERFORMANCE OF MERDEKA BOTTOM UP EXCAVATION

The Bottom-Up Merdeka Station excavation reached the final excavation level of 31.1 m bgl within 13 months from the start of excavation, and the as built progress is as tabulated in Table 8.

Table 8 Merdeka Station as built construction dates

Stage	Item	Date	
		Start	Finish
1	Excavate to RL 44.0m	20-Feb-13	18-Jun-13
	Install Strut Layer 1	1-Mar-13	25-Jun-13
2	Excavate to RL 38.3m	26-Mar-13	19-Jun-13
	Install Strut Layer 2	24-May-13	4-Aug-13
3	Excavate to RL 35.0m	18-Jul-13	30-Aug-13
	Excavate to RL 32.8m	18-Jul-13	31-Aug-13
	Install Strut Layer 3	29-Jul-13	30-Sep-13
4	Excavate to RL 27.8m	19-Jul-13	30-Oct-13
	Install Strut Layer 4	30-Sep-13	17-Nov-13
5	Excavate to RL 25.0m	10-Sep-13	7-Dec-13
	Excavate to RL 23.0m	1-Nov-13	7-Dec-13
	Install Strut Layer 5	15-Nov-13	22-Dec-13
6	Excavate to RL 22.0m	1-Nov-13	7-Dec-13
	Excavate to RL 19.5m	1-Nov-13	8-Jan-14
	Install Strut Layer 6	23-Dec-13	24-Jan-14
7	Excavate to RL 16.5m	4-Dec-13	14-Mar-14
	Excavate to Base Slab Level	16-Jan-14	14-Mar-14

Inclinometer INW2 measures the displacement profile daily during the excavation works and Figure 16 shows the measured displacement profiles of Merdeka INW2 comparing to the Plaxis predicted displacement envelope and the Alert triggers values set.

All Struts types in each strutting levels for each D-Wall type are monitored daily during excavation and Table 9 below compares the maximum measured strut forces versus the predicted values.

Figure 17 shows the Merdeka Station, bottom up excavation in progress after the second strut level. Figure 18 shows the displacement profiles from Inclinometer INW11 Bukit Bintang T2

D-wall panel, taken from the project online data management system Maxwell geosystems' Mission OS Portal.

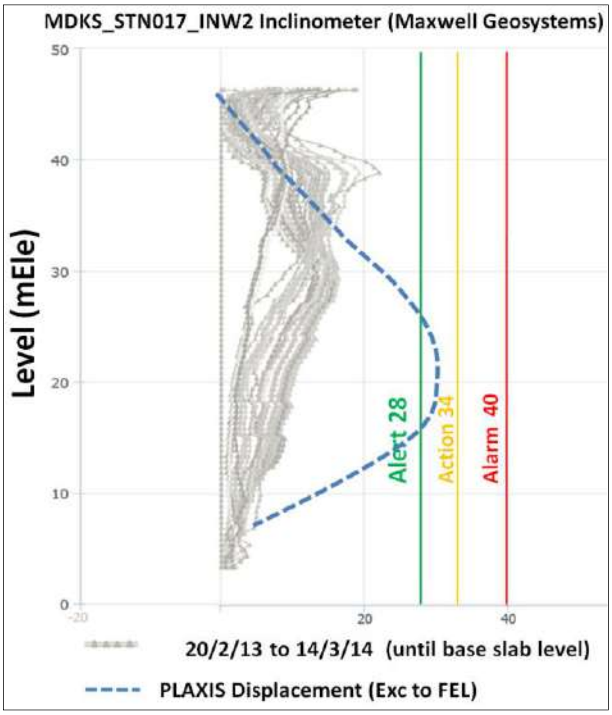

Figure 16 Displacement profiles from Inclinometer INW2 Merdeka T1 D-wall panel

Table 9 Strut loading Measured versus Designed Values

Struts	Max Designed (kN/m)	Max Measured (kN/m)
S1	560	300 (53%) (SG*)
S2	1250	879 (70%) (SG)
S3	1780	1419 (79%) (SG)
S4	2380	1513 (64%) (LC**)
S5	1680	1315 (78%) (SG)
S6	1070	762 (68%) (LC)

* SG = Strain Gauge,** LC= Load Cell
Note: The loads measured are converted in to equivalent per m run for easy comparison with designed values.

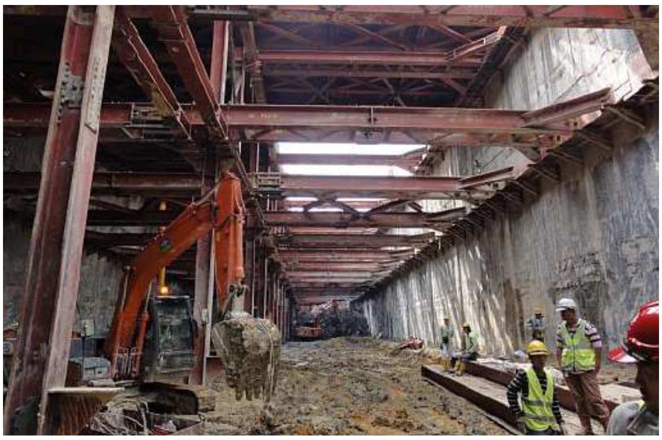

Figure 17 Bottom up excavation at the Merdeka Station

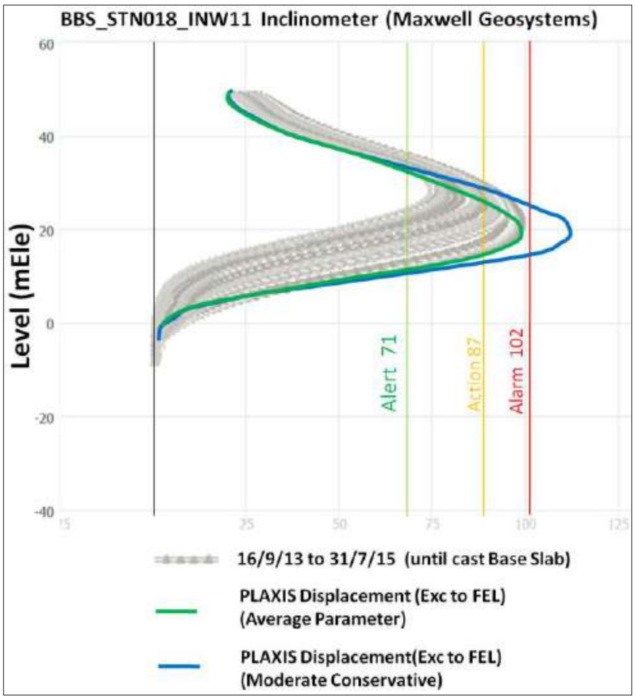

Figure 18 Displacement profiles from Inclinometer INW11 Bukit Bintang T2 D-wall panel, taken from the project online data management system Maxwell geosystems' Mission OS Portal

8. PERFORMANCE OF BUKIT BINTANG TOP DOWN EXCAVATION

For the Top-Down Bukit Bintang excavation, the final excavation level of 33.5 m bgl was reached within 23 months from the start of excavation, and the as built progress is as tabulated in Table 10 below.

Table 10 BB construction as built construction dates

Stage	Item	Date	
		Start	Finish
1	Excavate to Top Slab Stage 1	16-Sep-13	13-Nov-13
	Install Top Slab Stage 1	25-Sep-13	22-Nov-13
	Backfill	25-Nov-13	10-Jan-14
2	Excavate to Top Slab Stage 2	01-Jun-14	18-Aug-14
	Install Top Slab Stage 2	30-Jun-14	20-Sep-14
	Backfill	25-Aug-14	08-Jan-15
3	Excavate to Concourse Slab	22-Aug-14	30-Nov-14
	Cast Concourse Slab	30-Sep-14	17-Jan-15
4	Excavate to Upper Platform	22-Nov-14	28-Feb-15
	Cast Upper Platform Slab	22-Dec-14	28-Feb-15
5	Excavate to Plant Room	18-Jan-15	31-Mar-15
	Cast Plant Room Slab	07-Feb-15	10-Apr-15
6	Excavate to RL 18.5m	08-Mar-15	11-May-15
	Install Strut S1	11-Apr-15	31-May-15
7	Excavate to FEL	06-May-15	17-Jun-15
	Cast Base Slab	25-May-15	31-Jul-15

The above monitoring AAA triggers were re-set using improved parameter, i.e. 'Average' Soil parameter instead of the original designed one which was 'moderately conservative'). With the improved parameter the predicted design displacement reduces from 113 mm to 98 mm and the Alarm trigger level was revised by the Supervising Consultant to be 102 mm. This revision of the design parameters towards the end of the excavation works was to facilitate the more accurate prediction of 'building damage category' of the nearby shops.

Figure 19 shows the predicted effects of using a better soil and concrete young modulus. (i.e. without the 30 % reduction of E modulus due to design crack width requirement) and improved soil parameter (Average parameters) to simulate more realistic movement.

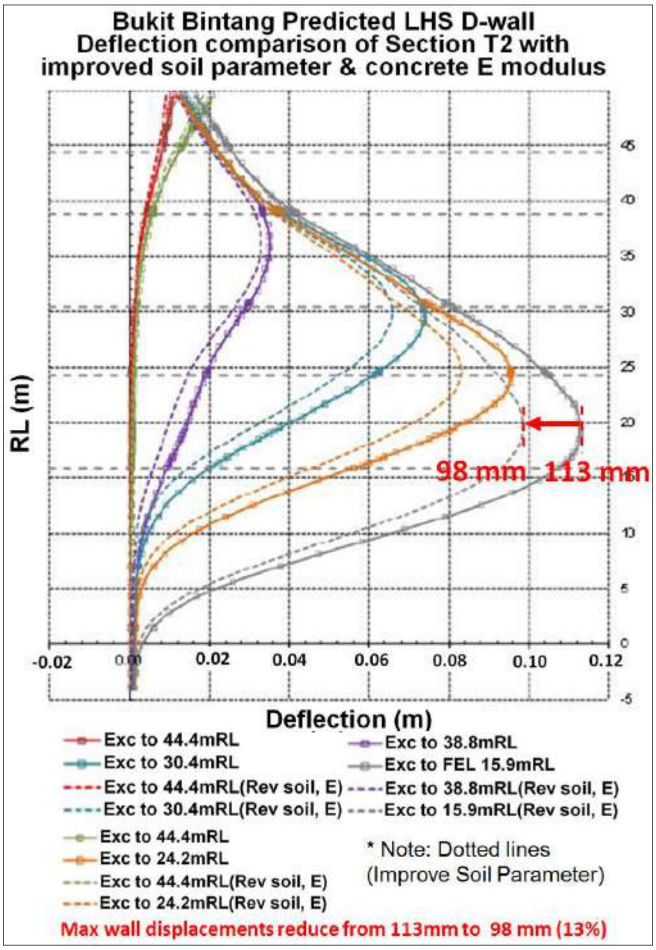

Figure 19 Comparison of displacement using better parameters versus design parameters (moderately conservative)

Dotted lines are the new predictions with better parameters whilst solid lines are the prediction using Design Parameters.

Bukit Bintang station being Top Down construction, has only one level of Struts which are needed to keep the D-Wall size reasonable while facilitating the excavation of the lower platform level. This paper has included the measurement of the Struts forces at T2 and as well as at the diagonal sturts at both side of the station for comparison in Table 11 below.

Table 11 Max Strut loading Measured versus Max Designed Values

Struts	Max Designed (kN/m)	Max Measured (kN/m)
S1 (T2 - Centre)	2685	2201 (82%) (SG)
S1 (T1- Diagonal)	2685	1692 (63%) (LC)
S1 (T3- Diagonal)	2685	1732 (64%) (LC)

Figure 20 shows the Bukit Bintang Station, Top-up excavation in progress at the lower platform level.

Figure 20 Bukit Bintang Station, Top-up excavation in progress at the lower platform level.

9. COMPARISON OF RESULTS & DISCUSSIONS

The design analyses have been undertaken with moderately conservative drained parameters and on a drained basis; the performance and results are therefore expected to be conservative. This is because with at normal rates of progress it is more likely in ground conditions with low permeabilities of k = 10^{-7} m/s, such as those apparent at Merdeka and BB, that the ground will remain partially undrained, prior to support being installed at the new excavation level. Moreover, during construction the stiffness of the diaphragm wall may well be higher than the cracked stiffness used in the analyses (E_{crack}=0.7 $E_{concrete}$) used to simulate a cracked section of wall in the long term.

For Merdeka Station, this partial undrained effect is quite apparent, with each period unsupported excavation before installation of the strut generally between only 1 to 2 months. This effect is not pronounce at shallow depth of less than 10m bgl, but become more dominant at deeper depth when the negative excess pore pressure drainage path become longer and the soil becomes harder and harder. As can be seen in Figure 16, the actual displacement for a top down structure at deep depth in Kenny Hill soils is significantly smaller than predicted.

The measured strut forces for a top down Merdeka excavation as can been seen Table 9 are between 53% to 79% of the designed values. The inabilities of the struts forces to move toward fully to their design values are related to the partially undrained behaviour and the moderate conservative parameter used. This fact was predicted earlier before the design and exploited by MGKT and the design consultant to set the Instrument and Monitoring trigger values at 50 %, 70 % & 100 % of the designed values.

For Bukit Bintang station, the measured displacements are within approximately 90 % of the designed values using moderate conservative value and almost the same as predicted using average values without reduction in concrete stiffness. Unlike, Merdeka, the measured displacement for BB follow closely to the designed values even beyond 10 m bgl. Also, the measured Strut forces are approximately 82 % of the designed values, which are higher ratio than those of Merdeka.

The unsupported heights for Bukit Bintang top down method are much larger, i.e. 6.3 m to 8.1 m compared with Merdeka of 2.6 m to 6.3 m. As such the predicted deflected movement are much larger and the deflection ratio is about 0.35 % of the excavated height. With larger excavation volume between the supports and with installation of the cast in situ slabs; the period of unsupported excavation for BB increases to between 3 to 4 months. This longer duration enable more of the negative excess pore pressures generated during the stress relief to be relieved. Moreover, the

Kenny Soil here at deeper depth although very Hard, does not contain rock matrix structures like Merdeka; probably due to proximity to the geology interface which are known to alter the characteristic of the Kenny Hill formation.

10. CONCLUSION & RECOMMEDATIONS

At 31.5 m and 33.5 m, the Merdeka and BB stations are the two deepest Stations excavated using the D-Wall retention system in Malaysia at the time of writing. Therefore, the cost of these walls are not insignificant part of the Stations' construction cost.

From comparisons above, the Merdeka Station excavated using Bottom up method; the D-wall can be concluded to be slightly over designed with measured displacements and struts forces somewhat smaller than the designed values. While for Bukit Bintang station excavated with Top Down construction; the predicted displacements and forces are closely matching the design values.

Therefore the Merdeka D-wall at 1.2 m thick, with steel reinforcement contents between 187 - 240 kg/m^3 (2.4 % - 3.1 %) and D-wall lengths varying between 39 m to 51 m still have some room to be optimised. For bottom up construction excavated for short duration it may be appropriate to use a slightly more optimistic parameters and this can be supported by back analysis of the Station deformation and further testing of the hard soils to obtain its rheological behaviour.

From the Bukit Bintang station's instrument and monitoring (I&M) measurement results, it can be concluded that the Kenny Hill soil design parameters, as per Table 2 are appropriate and validated.

For the design of future stations similar to BB Station, the D-wall of 1.2 m thick and length of up to 53.5 m can be possibly optimised if the height and duration of unsupported excavation can be reduced or adjusted to enable the use of more optimistic parameters similar to those obtain for the top down Merdeka station.

In future; with more observational data, better analytical modelling methods and better feedback from I&M monitoring systems, it will be possible use more optimum Kenny Hill design parameters adjusted according to the construction sequence to enable more optimal D-wall design. While, the prediction of D-wall displacements and ground movements adjacent to sensitive structures can be more confidently predicted in order to mitigate building damage risk.

11. REFERENCES

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