International Journal of Engineering & Technology, 8 (1.2) (2019) 28-33

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Analysis of Behaviour Support System for Mass Rapid Transit Underground Station Using Numerical Modelling Method

Muhamad Razuhanafi Mat Yazid [1,2]*, Muhammad Fikri [1], Rufaizal Che Mamat [1], Syazwan Md. Rahim [1], Aizat Mohd Taib [1]

[1] Smart and Sustainable Township Research Centre (SUTRA)
[2] Civil Engineering Programme
Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia
**Corresponding author E-mail: razuhanafi@ukm.edu.my*

Abstract

Deep basement construction has always been extensively constructed in urban areas especially in Kuala Lumpur where the area is dense and limited. The design of basement retaining wall and its support system involves careful analysis, design and monitoring system. The focus in this study is to model the actual cases on site by using Finite Element Software Plaxis2D. The site is located in Kenny Hill Formation categorized as a completely decomposed rock and generally has the consistency of a clayey silt soil. This study indicates that the numerical analyses can be constructive tools to predict the behaviour of soil during installation of support systems and excavations. The results obtained from the analysis recorded maximum deflection value of the retaining wall at 32.4 mm which occurred on the left wall at the last stage of construction, whereas the bending moment, shear force and maximum axial force of the retaining wall recorded 5232 kN/m, 1860 kNm and 4155 kN/m respectively. The most critical condition can be seen at the last stage of simulation. At this stage, the safety factor was tested and the value obtained was 2.3 which exceeded the geotechnical global standards.

Keywords: *Deep excavation; finite element method; ground movement; retaining wall; wall deflection*

1. Introduction

To optimize the high cost of land in urban development especially in Kuala Lumpur, the basement is used to reduce the burden of acting on the ground and to increase the available space. The deep dredging method is used to build various types of underground infrastructure such as basements, underground stations and service tunnels. Nowadays, numerical analysis such as finite element method (FEM) has played an important role in estimating ground deformation and retaining wall [1].

In general, deep dredging is to be expected when the need to use the basement for the construction of underground structures such as parking, subway stations, service tunnels and other uses in expensive and crowded urban areas. In Malaysia, deep dredging has been extensively built, but there are some failures associated with retaining walls used as support systems for dredging and underground work. The design of retaining walls and support systems for the construction of underground structures requires careful analysis, design and performance monitoring at the planning stage. This is because the risks associated with deep dredging are due to soil profile failure, retaining wall movement and impact on adjacent structures. Deep excavation for the construction of basement structures leads to movement resulting from the release of pressure from excavation work and increased overhead pressure on the detained soil. The movement of land along the excavation resulted in damage to existing structures located nearby [2].

The change and displacement of the wall caused by deep dredging depends on many factors, such as soil and groundwater, dredging geometry, surcharge load, adjacent structures, construction methods, types and installation of support systems and soil improvements [3]. Specific problems that led to this issue when a study by [4] in 2007 that has listed 43 failures since 2001 in relation to the work of the MRT in which eight failures associated with the retaining walls and these failures have resulted in death, collapsed buildings and economic losses. Some suggestions by [4] are having risk management programs that are supposed to relate to underground work and a strong understanding of the geotechnical foundations to complement the use of computer software. Proper implementation of risk management programs and the use of computer software requires a good understanding of the design and construction of underground workings so that risk management becomes effective and computer software is used properly [5].

This study aims to present a study using finite element method using computer software, Plaxis2D. Two-dimensional software using finite element methods selected as numerical tools and underground construction projects for the construction of subway stations for MRT Stations were selected as case studies. Implementation of this inlet requires the use of retaining wall and appropriate support system, therefore analysis related to retaining wall behaviour needs to be analyzed.

2. Methodology

The location of the case study is at MRT-KLCC East station located in Kuala Lumpur, Malaysia. It is an underground MRT stations with a deep basement area and close to adjacent buildings. The construction of basement involves 39.2 m deep of excavation, approximately 25 m wide and 35 m long, in weathered residual soils of Kenny Hill Formation. The excavation was performed using the top-down method. The diaphragm wall was constructed by 61 m deep and 1.5 m thick.

The ground condition at the site generally consists of residual soils and weathered rocks of the Kenny Hill Formation. This geological formation is also referred by [6] as meta-sedimentary, considering that the sedimentary rocks (e.g. sandstone, siltstone) have been partly metamorphosed into quartzite and phyllite. The weathering process of the rock material which is rather complex have been described by Raj [7].

The soil profile at this project site consists of an upper 10 m of top surficial soil, second layer is Kenny Hill Formation with 51 m depth and underlying rock. For top surficial layer, all the bore-logs show surficial soil layer across the site consisted of sandy silts and silty sands with thickness of about 7.5m to 15m. Beneath of aforementioned top surficial layer is the Kenny Hill formation with SPT *N* larger than 51. The hard Kenny Hill residual soil is typically in the form of gray sandy silt. The above-mentioned Hard Kenny Hill residual soil extends in depth before encountering the underlying moderately weathered and highly fractured limestone. The underlying limestone is located at a great depth of approximately 82 to 122 m below ground level. The groundwater table is located at depth of 5 m below ground surface. Table 1 present the soil parameters for Hard Soil model.

Table 1: Soil parameters for Hardening Soil model

Parameter	Symbol	Unit	Soil Description		
			Top Surficial Layer	**Kenny Hill**	**Hard Kenny Hill**
Bulk Density	γ_b	kN/m3	18	20	20
Apparent Cohesion	c'	kN/m^2	1	10	15
Angle of Friction	φ'	Degree	29	35	36
Poisson's Ratio	v'	-	0.2	0.2	0.2
SPT-N	N	blows/ft	5	75	125
Young's Modulus	E'	kN/m2	10,000	150,000	250,000
Interface Reduction Factor	R_{inter}	-	0.7	0.67	0.67
Permeability	k	m/s	1.0x10^{-8}	1.0x10^{-9}	1.0x10^{-10}
Secant modulus 50% strength	E^{ref}_{50}	MPa	6	90	180
Oedometric modulus	E^{ref}_{oed}	MPa	6	90	180
Unloading-reloading	E^{ref}_{ur}	MPa	18	270	540

An unstructured finite-element fine mesh consisting of 15-node triangular elements was used as shown in Fig.1.

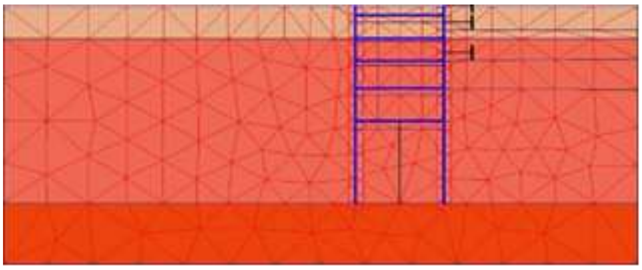

Fig. 1: Geometry of the retaining wall

The Young's modulus of the diaphragm wall was determined using the correlation $E = 4.7 \text{ x}10^6 (\text{fcu})^{0.5}$ kN/m^2, as recommended by Ou (2006), where fcu is the 28 days uniaxial compressive strength of concrete in MPa. For this case, the adopted strength of diaphragm wall was 35 MPa. Table 2 shows the details of the structure parameters.

Table 2: Details of structure parameters.

Structure Elements	Wall Thickness (mm)	Concrete Grade f_{cu} (N/mm^2)	EA (kN/m)	EI (kNm^2/m)
Dafra	1500	35	6.26 x 10^7	1.17 x 10^7
Top slab	2000	35	1.11 x 10^8	3.71 x 10^7
Bottom slab	2500	35	1.74 x 10^8	9.05 x 10^7
Piles	1200	35	2.00 x 10^8	-
Roof floor	2500	35	1.74 x 10^8	9.05 x 10^7

The analysis of the interaction between the excavation and retaining system is undertaken by using Plaxis 2D FEM version 2012. Plaxis is a geotechnical finite element method (FEM) intended for two-dimensional (2D) analysis of deformation and stability in geotechnical engineering. The excavation model was conducted by using plane strain analysis. Full geometry model comprising the entire cross-section of the site with lateral model boundary assigned at sufficiently far from the edge of the excavation to avoid boundary effects. Fig. 2 shows the flow chart for this analysis.

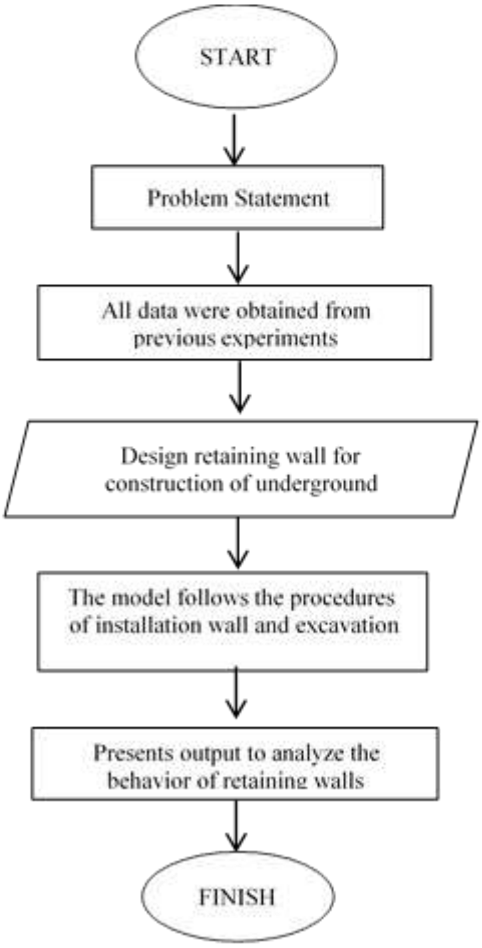

Fig. 2: Flow chart for the analysis

In numerical modelling of the diaphragm wall, calculation of steady-state groundwater flow was performed for each stage of excavation in the analysis. The arrangement of excavation simulated in the FEM analysis are as follows:

1. Initial condition.
2. Installation of left and right diaphragm walls with surcharge.
3. Excavates to 75 mRL.
4. Cast roof slab at 77 mRL followed by excavation to 69 mRL.
5. Cast plant room slab at followed by excavation to 62 mRL; while adjacent side install the ground floor slab followed by excavation to 73 mRL.
6. Cast Concourse level slab at 63 mRL followed by excavation to 52 mRL; while adjacent side (right) cast Concourse slab at 75 mRL by excavation to 64 mRL.
7. Cast upper platform slab at 54 mRL followed by excavation to FEL of 42 mRL.
8. Cast lower platform slab at 44 mRL; while adjacent side cast slab at 66 mRL followed by excavation to FEL of 54 mRL.

3. Result and discussion

3.1. Effect of soil model

Fig. 3 shows the result of different soil model towards lateral wall deflection. Various types of soil models are offered in Plaxis2D. For this study, two types of soil models have been chosen which are Mohr-Coulomb Soil Model (MC) and Hardening Soil Model (HS). In FEM analysis, proper understanding of soil model is vital in order to produce a safe design. Based on the lateral wall deflection as shown in the Fig. 3, MC predicted less lateral wall deflection compared to HS because MC overestimated the shear strength of the soil. HS is preferable to be used because it illustrates the actual behaviour of soil with high accuracy.

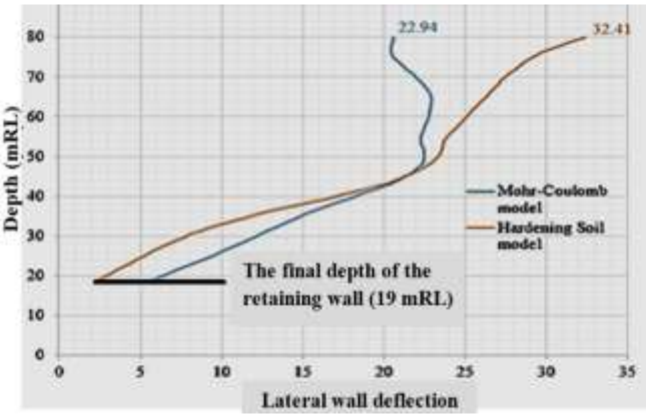

Fig. 3: Effect of soil model (Left wall)

3.2. Axial force

The change in axial force is related to the movement of the wall during excavation (indicated in Fig. 4). These figures show the evolution of the horizontal displacement at five elevations on the wall (at the top of the wall, and at the location of each slab). Left wall shown to move away from the excavation in the negative x-direction. The axial force increases with depth due to excavation and recorded maximum axial force at stage 7.

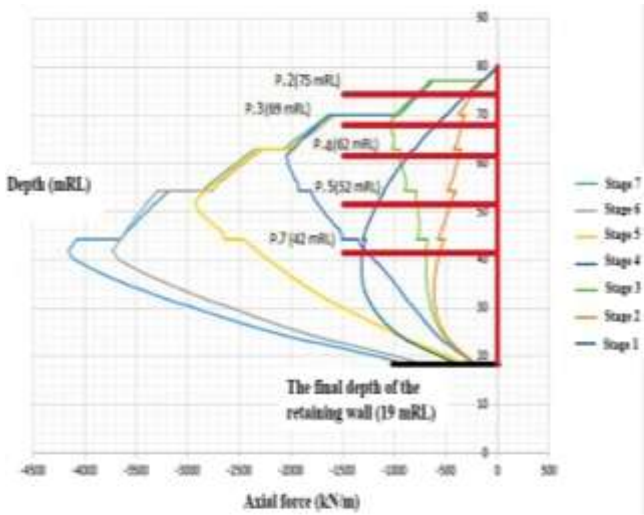

Fig. 4: Axial force (Left wall)

3.3. Horizontal displacement

Fig. 5 indicates large amount of deflection occurs after the excavation reaches to 42 mRL. In the first stage of excavation, the wall behaves like a cantilever wall and initial displacement occurred. According to [8], the passive resistance below the base of the excavation increased up to a certain limit, after which it remained constant with the increase of embedded depth below the final excavation level. It is normalized with respect to the maximum horizontal movement recorded at the end of excavation, and the depth axis is normalized with respect to the height of the wall. Therefore, it is clear that a large deflection occurs as the excavation goes deeper.

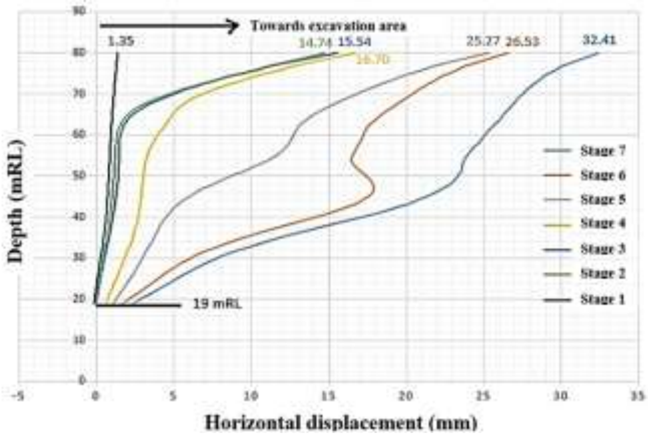

Fig. 5: Horizontal Displacement (Left wall)

3.4. Bending moment

Fig. 6 shows the distribution of bending moment. The magnitude of maximum bending moments indicates that, increasing depth of excavation and wall stiffness affects the results of bending moment. According to [9], the distribution of bending moments is different when the lateral deformation profiles for each soil are different. Thus, the investigation of the effect of bending moment due to stiffness of the structure is highly needed to reduce wall deformation. This study contributes to an effective design of wall.

.

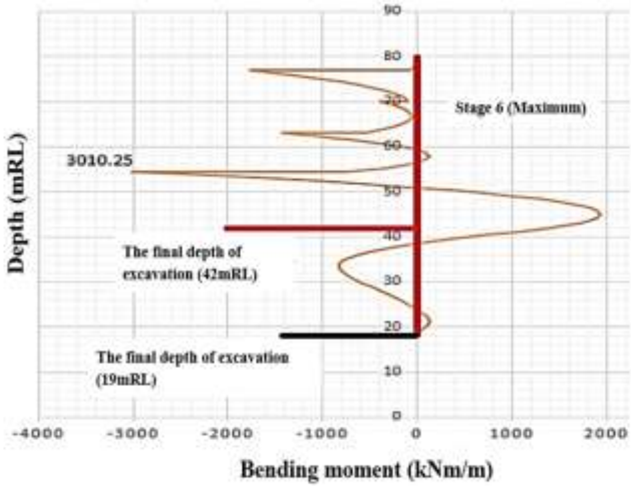

Fig. 6: Bending Moment (Left wall)

3.6. Shear force

Fig. 7 shows the distribution of shear force. The magnitude of the shear force (left wall) 719.2 kN/m, where at level 42 mRL

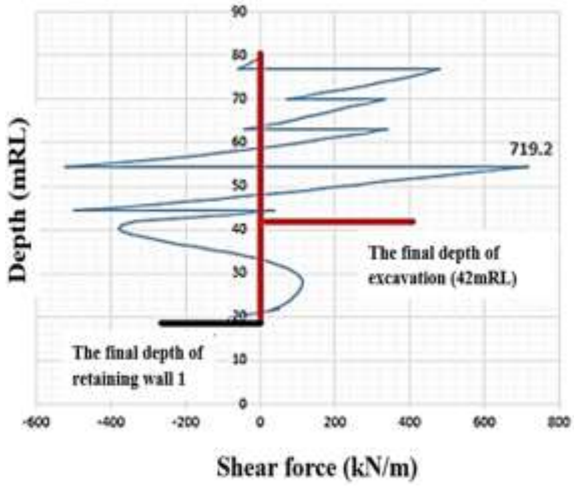

Fig. 7: Bending Moment (Left wall)

The results collectively compiled in Table 3 below for both walls. It should be noted that for evaluating the structural integrity of the diaphragm wall, only bending moment at the edge of connecting slabs is relevant with various elevations. At the final stage, full lift ground water pressure was applied to the basement slab for the long term condition. On the other hand, the geotechnical Factor of Safety (FoS) [10] against geotechnical global failure is calculated with a value above than 1.5 as illustrated in Fig. 8.

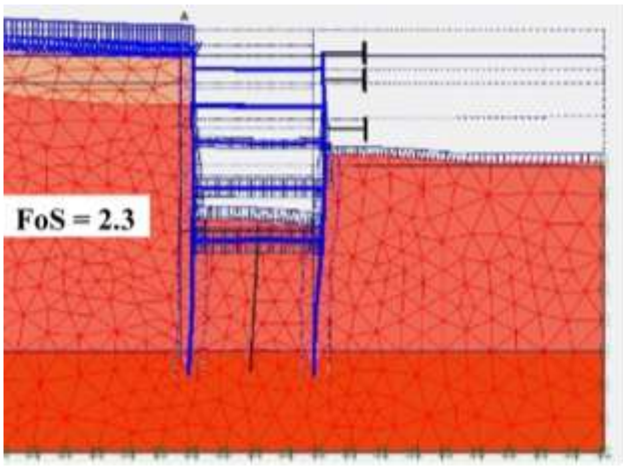

Fig. 8: Geotechnical FoS = 2.3

Table 3: Summary for the wall analysis results

Simulation stage	Left Wall			Right Wall		
	Max. Deflection (mm)	Max. Shear Force (kN/m)	Max. Bending Moment (kNmm)	Max. Deflection (mm)	Max. Shear Force (kN/m)	Max. Bending Moment (kNmm)
1	1.4	17.8	31.5	1.2	13.4	30.9
2	14.7	202.8	1270	14.6	202.3	1270
3	15.5	329.0	1810	15.4	329.0	1820
4	16.7	526.0	2250	14.1	876.1	3270
5	25.3	699.5	1780	8.5	1280	4070
6	26.5	1150	3010	12.7	1300	4450
7	32.4	719.2	1960	21.1	1860	5230

4. Conclusion

The performance of a deep excavation in stiff residual soils of Kenny Hill Formation has been described. The primary goal of this paper is to study the effect and performance of retaining wall for basement work in terms of wall deflections, axial force, shear force, bending moment and ground movements during excavation. Several effects have been studied in this project which are the effect of soil model, effect of construction method and effect of stage construction. Based on the finite analyses, it can be concluded that the ground movement will increase due to depth of the excavation and stiffness of the structure.

Plaxis2D software can be a tool to predict this type of project with actual construction sequences. Application if the HS model in this practical deep excavation problem has shown that the model is suitable not only for analyzing the case for the Kenny Hill Formation but may also be applied for similar type of soils having these kinds of problems. This study indicates that the numerical analyses can be constructive tools to predict the behaviour of soil during installation of support systems and excavation.

Acknowledgement

The authors wish to thank the Department of Civil and Structural
Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM) and Corp. MRT, for their support to carry out this research project. The project was funded by UKM under the Project GGPM-2017-059.

References

[1] Law KH, Othman SZ, Hashim R & Ismail Z (2014), Determination of soil stiffness parameters at a deep excavation construction site in Kenny Hill Formation. *Measurement: Journal of the International Measurement Confederation* 47(1), pp: 645–650.

[2] Zumrawi Magdi ME & El-Amin A, Importance of deep excavation support and its influence on adjacent buildings, *Proceeding of 7th Annual conference of postgraduate studies and scientific research*, 6 (2016), pp:25-29.

[3] Hsiung BCB, Yang KH, Aila W & Hung C (2016), Three-dimensional effects of a deep excavation on wall deflections in loose to medium dense sands. *Computers and Geotechnics* 80, 138-151.

[4] Moh ZC & Hwang RN (2007), Lessons learned from recent MRT construction failures in Asia Pacific (Opening Keynote Address). *Proc. 16th SEAGC*. Subang Jaya, Malaysia.

[5] Tan YC & Chow CM (2008), Design of Retaining Wall and Support Systems for Deep Basement Construction–A Malaysian Experience. *Seminar on "Deep Excavation and Retaining Walls". Jointly organised by IEM-HKIE, Malaysia* (24).

[6] Komoo I, Engineering geologic aspects of clastic metasediment in Kuala Lumpur area, peninsular Malaysia. *Proceeding of GEOSEA V, Kuala Lumpur*, 1(1986), pp:597-612.

[7] Raj JK (1985), Characterisation of the weathering profile developed over a porphyritic biotite granite in peninsular Malaysia. *Bulletin of the International Association of Engineering Geology* 32(1), pp: 121-129.

[8] Chowdhury SS, Deb K & Sengupta A (2013), Estimation of Design Parameters for Braced Excavation: Numerical Study. *International Journal of Geomechanics* 13(3), pp: 234-247.

[9] Bryson LS, Zapata-Medina DG & Romana-Giraldo J, Empirical Method to Estimate Lateral Wall Deformation Profiles and Bending Moment in Excavation Retaining Walls. *Proceedings of the IFCEE* (2018) ASCE Special Publication, pp:65–74

[10] Salmah Salween, Khairul Anuar Mohd Nayan & Mohammad Omar Faruk Murad (2016), Evaluation on the Stability of Slope at Faculty of Engineering and Built Environment (FKAB) using Slope/w. *Jurnal Kejuruteraan* 28, pp: 79-86.