Recent Trends in Civil Engineering and Built Environment Vol. 2 No. 1 (2021) 589-597
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RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN : 2773-5184

A Study on the Effect of Excess Pore Water Pressure on the Deformation of Sheet Pile Wall using PLAXIS 2D

Lian, Y. T.[1], Ling, Felix N. L.[1,*]

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rtcebe.2021.02.01.064
Received 30 January 2021; Accepted 28 April 2021; Available online 30 June 2021

Abstract: Most of the coastal area in Malaysia is made up of quaternary deposits, which still undergo consolidating and buildup excess pore pressure, and thus increasing the pressure imposed on sheet pile wall. Hence, it emerges the importance to study the effect of excess pore water pressure of retained soil on the deformation of sheet pile wall. The simulation works were carried out using PLAXIS 2D 2019. Model of Muar trial embankment was utilized as a base model while the parametric studies were conducted with a proposed row of 6 m long sheet pile wall at the toe of simplified Muar trial embankment model. The findings showed that elevated excess pore water pressure recorded a higher deformation of the sheet pile wall. Thus, an appropriate type of sheet pile wall must be proposed to safeguard the stability of sheet pile wall constructed in unconsolidated soil deposit.

Keywords: Sheet Pile Wall, Quaternary Deposit, Excess Pore Pressure

1. Introduction

Sheet pile wall may be divided into two basic categories; which are cantilever and anchored. Cantilever sheet pile wall is generally used to retain earth of moderate height while anchored sheet pile wall is more economical to be used when backfill height exceeds 6 m. Generally, sheet pile wall is widely used as the temporary retaining structure or acts as a permanent retaining structure in some cases due to its simplicity in construction and cost [1]. However, the sheet pile wall may fail by mechanisms such as overturning about its toe and sliding along its base. Underestimated deformation of sheet pile wall is considered as one of the main causes of sheet pile wall failure. This deformation of the sheet pile wall may be caused by the behaviour of the soil retained by it. The stability of the sheet pile wall depends on the generation of earth pressures on either side of the wall, which in turn relies on a close relationship between the soil and sheet pile wall [2]. Therefore, it is important to study the geotechnical properties of soil retained by sheet pile wall as sheet pile wall failure is always due to geotechnical aspects [3].

The soft soil in Malaysia is categorized as a quaternary deposit that consists of alluvial deposits and organic or peat soils. This kind of soil deposit is found in many coastal regions in Malaysia [4]. Quaternary deposit is consists of unconsolidated soil, therefore the consolidation process is found to be

Corresponding author: felix@uthm.edu.my

ongoing for this kind of soil deposit [5]. Thus, it is expected that the excess pore water pressure of this kind of soil will increase over time. Apart from it, the excess pore pressure developed in this unconsolidated deposit is also significantly higher. This phenomenon can be caused by these three factors; the residual excess pore pressure which has not dissipated, the behaviour of soil which is more sensitive and higher overburden [6]. This higher excess pore pressure buildup in the soil will increase the pressure acting on the sheet pile wall [7]. Thus, this uncovered excess pore pressure can cause sheet pile wall failure. The ongoing consolidation process is a serious matter but most engineers are not aware of the consequences [8]. This unconsolidated deposit occupies the coastal terrains and floors of some inland valleys in Malaysia [9]. Therefore, it emerges the importance to study the effect of excess pore pressure of retained soil on the deformation of sheet pile wall.

PLAXIS 2D is a commercial finite element method (FEM) software utilized for analyzing two-dimensional problems of deformation and stability in geotechnical engineering; for example, analysis of stability of sheet pile wall. Besides that, the development and dissipation of excess pore pressure in a saturated clay type soil can be analysed using the consolidation analysis in PLAXIS 2D [10]. Hence, PLAXIS 2D can be utilised in this research, which is aimed to evaluate the deformation characteristics of sheet pile wall utilized to retain the quaternary deposits in this region which is unconsolidated. The objectives of this study are broady divided into three which are aimed to determine numerically the developed excess pore water pressure of unconsolidated quaternary deposit in Malaysia, to determine the deformation of sheet pile wall when subjected to changes in excess pore water pressure of soil and to evaluate the effect of excess pore pressure of soil on the deformation of sheet pile wall.

2. Materials and Methods

The methodology of this study is divided into two main parts describing how this study was carried out. The first part is to remodel a published case study while the second part focuses on the parametric study with an attempt to determine the deformation of sheet pile wall when subjected to changes in excess pore water pressure of soil.

2.1 Remodel of Case Study

Model of published Muar trial embankment model along the North-South expressway, Malaysia by Indraratna et al. [11] was utilized as the base model in this study. The Muar trial embankment was modelled using PLAXIS 2D 2019 to determine the effect of the consolidation process and loading from staged construction. Its deformation results were compared to the published findings [11] to verify the model.

The cross-section and soil parameters used to remodel the case study was based on Indraratna et al. [11]. The depth of foundation soil simulated in this study was 9 m with 3 different soil layers which were weathered crust, soft silty clay, and sandy clay. In the PLAXIS 2D model, the embankment was assumed as symmetrical and only half of the embankment was modelled, with the dimension of embankment base as 28 m, crest as 20 m and 6 m in height. Below the ground level, the weathered crust was set to 1 m deep, soft silty clay as 6 m and sandy clay as 2 m. The groundwater table was located at 1 m below the ground surface. The cross-section of the Muar trial embankment model simulated in PLAXIS 2D is shown in Figure 1.

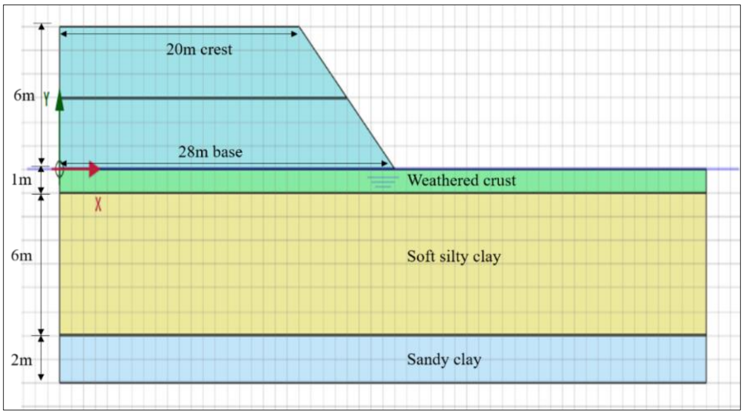

Figure 1: Muar trial embankment cross section in PLAXIS 2D

All the soil were modelled as drained condition except for the soft silty clay which was as the undrained condition. Soft silty clay was in undrained condition because water is expected not able to discharge immediately when saturated clayey soil was loaded. The soil parameters used in this study are listed in Table 1. For the calculation part, consolidation analysis was conducted for two phases of 15 days each. Staged construction was chosen as the loading type.

Table 1: Embankment and soil parameters used in PLAXIS 2D [11]

Materials	Embankment	Crust	Soft silty clay	Sandy clay
Material model	Linear Elastic	Soft Soil	Soft Soil	Soft Soil
Drainage type	Drained	Drained	Undrained (A)	Drained
Soil unit weight above phreatic level, γ_{unsat} (kN/m^3)	17.0	12.0	13.5	14.0
Soil unit weight below phreatic level, γ_{sat} (kN/m^3)	20.5	16.5	15.5	15.5
Initial void ratio, e_{init}	0.5	0.5	1.0	1.0
Young's modulus, E (kPa)	5100	-	-	-
Poisson ratio, v	0.3	-	-	-
Cohesion, c (kPa)	-	8.0	14.0	17.0
Friction angle, $\emptyset'$ (°)	-	12.5	31.0	31.0
Dilatancy angle, φ (°)	-	0	0	0
Modified swell index, κ*	-	0.05	0.05	0.08
Modified compression index, λ*	-	0.13	0.13	0.11

2.2 Parametric Study

The parametric study was carried out with the proposed row of a 6 m long sheet pile wall at the toe of the simplified Muar trial embankment model. The layered soil of the Muar trial embankment was replaced with a homogenous layer of marine clay as published by Brand [12]. Simplification is aimed to reduce the variables that may affect the deformation of sheet pile wall. Hence, the soil stratigraphy was redefined as Muar marine clay based on Brand [12], which was 9 m deep to model for quaternary deposit. Figure 2 shows the cross-section of the simplified Muar trial embankment model adopted in this study.

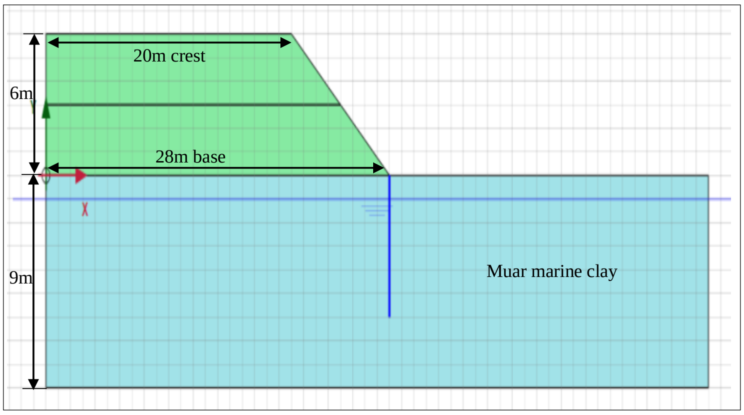

Figure 2: Cross section of simplified Muar trial embankment model

The modified compression, swell and creep index were obtained from past publication. [13]. The embankment properties were referred to Indraratna et al. [11]. Table 2 lists the embankment and soil parameters used in the parametric study. The Soft Soil Creep model was used as it is most suitable for unconsolidated deposit. Unconsolidated deposit normally exhibits creeping behaviour.

Table 2: Embankment and soil parameters used in parametric study

Materials	Embankment	Soft silty clay
Material model	Linear Elastic	Soft Soil Creep
Drainage type	Drained	Undrained (A)
Soil unit weight above phreatic level, γ_{unsat} (kN/m^3)	17.0	14.7
Soil unit weight below phreatic level, γ_{sat} (kN/m^3)	20.5	20.0
Initial void ratio, e_{init}	0.5	1.00
Young's modulus, E (kPa)	5100	-
Poisson ratio, v	0.3	-
Cohesion, c (kPa)	-	14
Friction angle, $\emptyset'$ (°)	-	31
Dilatancy angle, φ (°)	-	0
Modified swell index, κ*	-	0.093
Modified compression index, λ*	-	0.041
Modified creep index, μ*	-	0.0046
Coefficient of permeability, k (m/day)	-	3.456×10^{-4}

Z-section sheet pile, AZ 12 was chosen in this study. Figure 3 shows the shape of the AZ 12. The geometry properties of AZ 12 are shown in Table 3. The steel class used for computing the strength properties is S 240 GP.

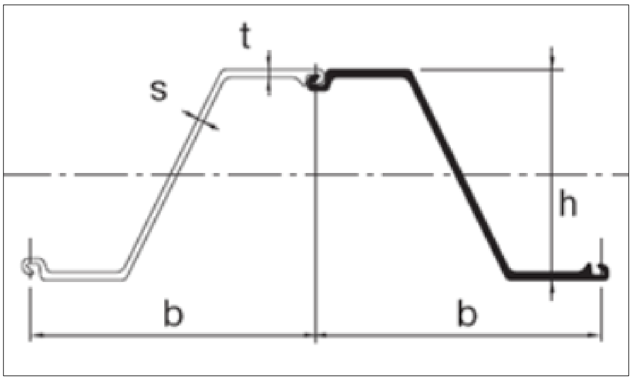

Figure 3: Shape of AZ 12 [14]

Table 3: Geometry properties of AZ 12 [14]

Properties	Width, b (mm)	Height, h (mm)	Thickness (mm)		Area (cm^2/m)	Mass		Moment of inertia (cm^4/m)	Elastic section modulus (cm^3/m)
			t	s		Per pile (kg/m)	Per wall (kg/m^2)		
AZ 12	670	302	8.5	8.5	126	66.1	99	18140	1200

For the calculation part, consolidation analysis was conducted for two phases of 15 days each. Each consolidation phase was carried out after a phase of plastic calculation for 1 day. Safety analysis was then conducted to compute the factor of safety (FOS).

2.3 Modelling Schemes in Parametric Study

There are seven modelling schemes in the parametric study to study the influence of excess pore pressure on the deformation of the installed sheet pile wall. Sheet pile wall is normally designed for short-term condition but in a certain condition, it may be used for long-term. Therefore, both short-term and long-term condition were studied. Different consolidation time indicates the difference between short-term and long-term condition. The short-term condition was referred to two consolidation phases of 15 days each while the long-term condition was referred to two consolidation phases of 180 days each.

Shear strength parameters of soil namely, cohesion and friction angle, were used in modelling schemes as the parameters directly affect the strength of the soil body and also the sheet pile wall installed in it. Besides that, the modelled groundwater level and permeability of soil were varied to observe their effect on sheet pile wall deformation. The modelling schemes of the parametric study are shown in Table 4. The first parameter in each modelling schemes was kept constant.

Table 4: Modelling schemes in parametric study

Condition	Modelling scheme	Variables	Parameters
Short-term	1	Cohesion	14 kPa [12]
			12 kPa [15]
			10 kPa [15]
	2	Fluctuation of groundwater level	1m below ground surface
			2m below ground surface
			3m below ground surface
	3	Coefficient of permeability	3.456 x 10^{-4} m/day [12]
			1.67 x 10^{-4} m/day [16]
			1.12 x 10^{-4} m/day [16]
Long-term	4	Cohesion	14 kPa [12]
			12 kPa [15]
			10 kPa [15]
	5	Friction angle	31° [12]
			27° [15]
			24° [15]
	6	Fluctuation of groundwater level	1m below ground surface
			2m below ground surface
			3m below ground surface
	7	Coefficient of permeability	3.456 x 10^{-4} m/day [12]
			1.67 x 10^{-4} m/day [16]
			1.12 x 10^{-4} m/day [16]

3. Results and Discussion

In the remodelling case study of Muar trial embankment, the result in term of deformation of soil body is presented. In parametric study, the results of modelling schemes were observed in terms of soil deformation, mode of failure, displacement and bending moment of sheet pile wall and excess pore water pressure developed in soil. The soil deformation reflects on the deformation of quaternary deposit due to additional loading from staged construction and ongoing consolidation as it is unconsolidated soil, which is still under consolidation. Meanwhile, the mode of failure is obtained as the strength of soil is numerically reduced until failure occur when subjected to loading. The results of the stability analysis is shown in terms of FOS. Besides that, displacement and bending moment of sheet pile wall were observed as they are critical parameters to design sheet pile wall. The excess pore pressure developed in the soil can also change the effective strength of soil and therefore its stability. Then, the relationship between excess pore pressure and deformation of sheet pile wall for both short-term and long-term condition is shown in graphical form.

3.1 Remodel of Case Study

The total deformed value of the Muar trial embankment in the published article [11] was 0.6972 m. While the total deformation obtained in remodelling was 0.5917 m. Hence, the model of this study was verified as the difference between the published total soil deformation and total soil deformation obtained in remodelling is relatively small.

3.2 Parametric Study

In parametric study, similar findings were found for both short-term and long-term condition. The sheet pile wall in the soil having lower cohesion, friction angle and permeability but higher groundwater level, recorded a higher deformation. Besides that, variation of cohesion, friction angle and groundwater level did not directly correlate to the developed excess pore pressure as there was no consistent pattern of change at a different phase as excess pore pressure fluctuated differently at each phase. However, the excess pore pressure was said to inversely change with permeability. When soil has a lower permeability, the excess pore pressure will dissipate slower out of the soil. Hence, the excess pore water pressure will be higher as it has not fully dissipated [17]. A graph of sheet pile wall deformation versus excess pore pressure was plotted for modelling schemes for both short-term and long-term condition, as shown in Figure 4.

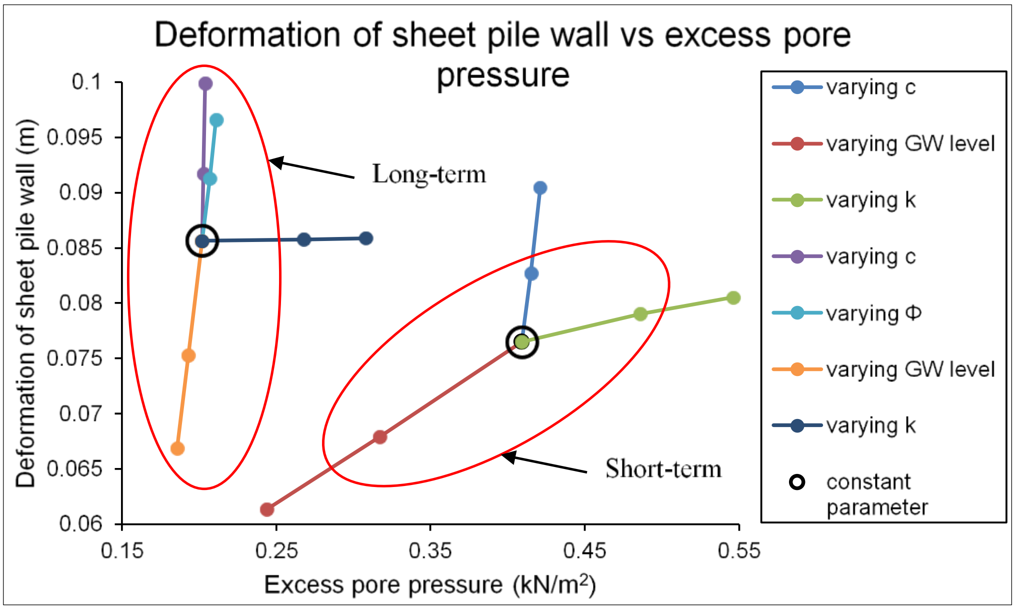

Figure 4: Graph of sheet pile wall deformation versus excess pore pressure

In short-term condition, the excess pore pressure is higher than in long-term condition. This is because, in long-term condition, most of the excess pore pressure had dissipated. While sheet pile wall for long-term condition recorded a higher deformation than short term condition. This could be due to the accumulative stresses over time. It may not rebound as it may deform permanently.

At the same time, it is found that in long-term condition, the deformation is not directly correlated with excess pore pressure and cohesion. When cohesion decrease, the soil strength decrease and therefore deformation increase but the excess pore pressure is not significantly influenced. The strength is said to be directly correlated with the sheet pile wall deformation but there is no direct correlation between excess pore pressure and deformation in this long-term situation.

Based on the model of varying permeability in long-term condition, permeability is strongly correlated to the excess pore pressure but it is not directly correlated to the strength. Excess pore pressure based on this model does not significantly affect the deformation. This is because the soil strength is directly correlated with the sheet pile wall deformation.

Fluctuation of groundwater table will affect lateral earth pressure. The pore pressure will have variation and therefore affecting excess pore pressure and sheet pile wall deformation. Variation of friction angle also affects excess pore pressure. Friction angle indicates the strength of soil, therefore affecting the deformation of sheet pile wall.

Therefore, the deformation of sheet pile wall linearly changes with the excess pore pressure for short-term condition, however, for a long-term condition, there are some exceptional cases where sheet pile wall deformation depends on soil strength.

4. Conclusion and Recommendations

Through this research, it can be concluded that elevated excess pore water pressure recorded a higher deformation of sheet pile wall. Monitoring of excess pore water pressure fluctuation can be used as an indication of the stability of sheet pile wall as excess pore pressure can be measured in-situ by piezometer. Thus, an appropriate type of sheet pile wall must be proposed to safeguard the stability of sheet pile wall constructed in unconsolidated soil deposit. The findings are served as a guide for the geotechnical engineer to make an appropriate decision on the construction of sheet pile wall to prevent excessive deformation and hence to ensure the stability of sheet pile wall. Some recommendations can be suggested for future research; for instance, to include infiltration of rainwater. Layered soil can be taken into consideration in modelling. Unsaturated soil behaviour can also be modelled.

Acknowledgement

The authors would like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support.

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