Recent Trends in Civil Engineering and Built Environment Vol. 3 No. 1 (2022) 1656-1664

RTCEBE

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

Comparative Study of the Steel Sheet Pile Wall with Concrete and Polymer Sheet Pile Wall

Roslan A[1], Ling, Felix N. L.[2]*

[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.2022.03.01.185
Received 4 July 2021; Accepted 13 December 2021; Available online 15 July 2022

Abstract: A suitable type of sheet pile walls, namely steel, concrete and polymer need to be chosen based on the site condition, application and its allowable and ultimate moment depending on the lateral earth pressure. Deformation of sheet pile walls depends on its material characteristics and differs for ductile materials and rigid materials. Hence, it is crucial to study the effect of material type on the deformation and stress distribution of cantilever sheet pile walls. A case study at Yan, Kedah was utilized as a base model and parametric study was conducted numerically by adding a 6 m long sheet pile wall at the toe of embankment with different material types. The purposes of installing sheet pile wall at the toe of embankment as temporary structure was to protect and increase the stability of the embankment. The simulation analysis was carried out by using PLAXIS 2D. The results of analysis had shown that different material types of sheet pile wall had shown differences in terms of deformation, bending moment, shear force and axial force when subjected to the same loading condition. Hence, it is advisable to carefully choose the materials of sheet pile walls depending on the requirement of the project.

Keywords: Sheet Pile Walls, Deformation, Bending Moment, Simulation Modelling

1. Introduction

Sheet pile wall is now commonly used as a retaining structure for temporary and permanent walls for the construction industry. The sheet piling can be designed for use in cantilever and anchor systems based on their function. The height of the cantilever sheet pile wall normally constructed between 3 m to 6 m and when the height exceeds 6 m, an anchored system is added to increase the stability. They can be made of different types of materials such as wood, aluminum, concrete, polymer and steel. The determination of material for sheet pile walls depends on a variety of factors such as application and soil layers [1]. Failure of a cantilever sheet pile wall can be caused by foundation weakness, seepage piping, distortion and degradation, earthquakes, and incorrect material selection for cantilever sheet pile walls. One of the most hazardous damages that may occur on a sheet pile wall is incorrect material selection for cantilever sheet pile walls. This catastrophe would have a severe impact on the structure, resulting in physical damage and loss of life [2].

**Corresponding author: felix@uthm.edu.my*

The aim of this study is to evaluate the effect of material type on the deformation and stress distribution of cantilever sheet pile wall. The understanding of the theory of sheet pile wall is important in the designing process. This study also reviews and summarizes the usage of polymer, steel and concrete sheet pile walls in Malaysia. To avoid the collapse of the sheet pile, it is required to make observations before and after construction. This will involve researching the conditions of the soil at these sites, pore water pressures, stresses, and soil behavior, so that the right and suitable material types of pile sheet walls can be proposed and adopted.

2. Numerical Modelling of Sheet Pile Walls

Several types of sheet piles are used in the construction industry are wooden sheet piles, precast concrete sheet piles and steel sheet piles. Certain considerations such as applications and the form of floor layers are used in deciding the suitable material for the building of retaining walls of sheet pile [1]. Other than that, the allowable and the ultimate moment of the sheet pile wall is an important factor to ensure the sheet pile can withstand the high lateral earth pressure or not. Generally, the sheet pile wall with high value of allowable bending moment can withstand the high lateral earth pressure compared to material that has lower allowable bending moment.

Concrete sheet pile wall is used as road embankment, used in fresh or saltwater as bulkheads and marine defense structure [3] [4]. Steel sheet pile walls can be used to transfer loads in some situations [5]. In some applications, steel sheet pile walls are used as tunnels and semi tunnels, embankments of approaches to engineering structures in enclosure out of steel walls and construction of railway and over-bridges [5]. Then, polymer sheet pile walls have been used successfully to build walls for waterfront and ocean structures industry [6].

PLAXIS 2D Version is a package of finite elements for two-dimensional analysis of geotechnical deformation and stability [7]. PLAXIS 2D was utilized to determine the behaviour of sheet pile walls during the design stage and also when there is a failure. Sheet pile walls were modelled as a beam element in 2D modelling [8]. Hence, PLAXIS 2D was utilized in this study to determine the deformation and stress distribution of cantilever sheet pile walls with different material properties namely steel, concrete and polymer.

3. Materials and Methods

The methodology in this study is broadly divided into two parts. The first part is to replicate a published case study model and the second part is conducting a series of parametric studies to determine the deformation and stress distribution of sheet pile walls with different types of materials.

3.1 Replicate of Published Model

The case study of the published model is Yan trial road embankment which is located at Kedah, Malaysia [9]. The results of simulation analysis were compared with the published data with the aim to verify the calculation stage and assumptions adopted for the modelling. The soil layers used in this study were clay silt, silty clay, soft clay and clay silt with different depths. The trial embankment was modelled as 11 m long at crest and 1.1 m in height. The illustration of Yan Road embankment is shown in Figure 1.

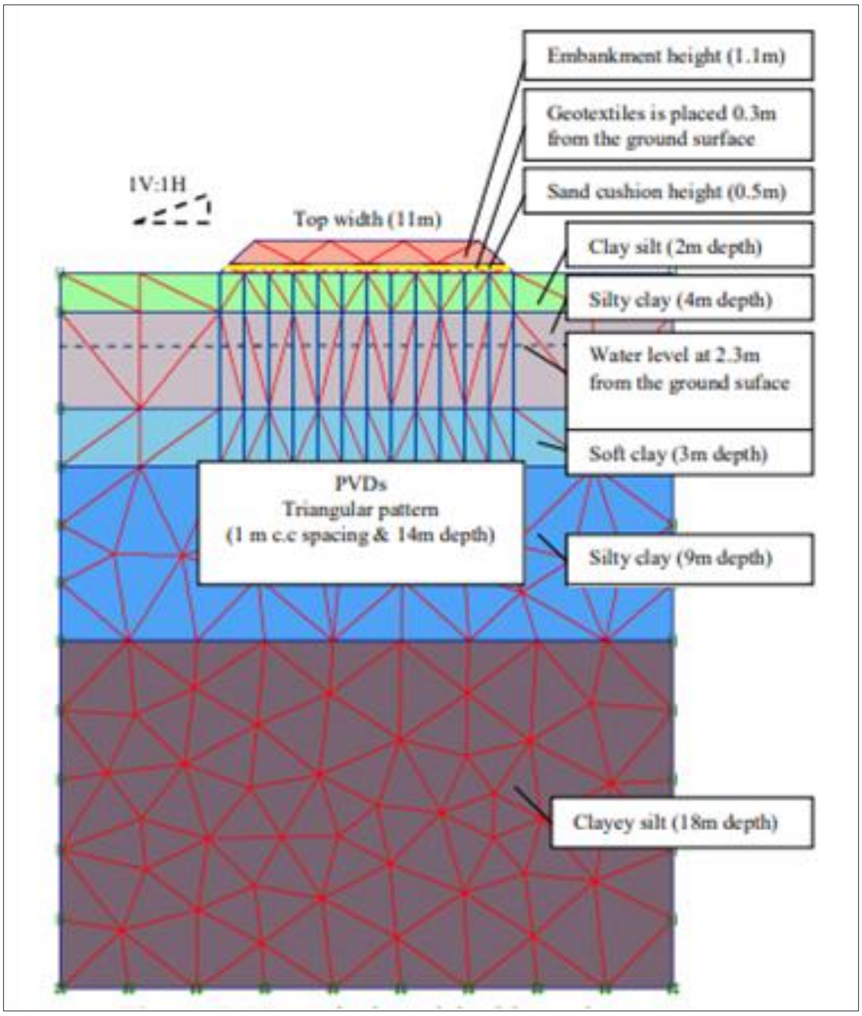

Figure 1: Yan Road embankment [9]

. The soil properties used in PLAXIS 2D are shown in Table 1. For the calculation step, staged construction was chosen in order to replicate the construction sequence in building up the embankment. Initial phase was set to the K0 procedure in order to model the geostatic stresses in soils. Phase 1 was set to plastic analysis with a 2 day interval with the aim to replicate the construction stage in building up the first layer of embankment within two days. Phase 2 was set to consolidation analysis with a 30 days interval in order to simulate the consolidation process for the first layer of embankment. Phase 3 was set to plastic analysis with 1 day interval to simulate the construction time for the second layer of embankment. Lastly, phase 4 was set to consolidation analysis with a 2 days interval to simulate the consolidation process of the second layer of embankment.

Table 1: Soil properties used in PLAXIS 2D [9]

Soil layer	USCS	SPT(N)	$\boldsymbol{e_o}$	$\boldsymbol{G_s}$	$\boldsymbol{C_c}$	$\boldsymbol{P_c}$ (kPa)
Clay silt	ML	1	2.17	2.54	0.983	21
Silty clay	CH	2	2.33	2.54	1.02	18
Soft clay	CH	1	2.67	2.52	0.952	21
Silty clay	CH	14	3.00	2.52	1.07	17
Clay silt	ML	39	3.09	2.51	0.944	22

3.2 Parametric Study

A series of parametric studies were carried out to determine and evaluate the deformation and stress distribution of sheet pile walls when using different types of materials. Three different material types of sheet pile were constructed near the toe of the embankment as a temporary structure to protect the embankment during the excavation. In this study, U-section of sheet piles were chosen and designed as cantilever sheet pile walls and their responses during excavation were modelled using PLAXIS 2D 2019. Figure 2 illustrates the shape of sheet pile walls and Table 2 shows the geometry properties of sheet pile walls. Ultimate moment capacity for the steel and concrete sheet pile wall simulated in this study were 478 kNm/m and 450 kNm/m, respectively. The differences in ultimate moment capacity for these two types of sheet pile walls were small. However, the ultimate moment capacity utilized of polymer sheet pile modelled in this study was 48.8 kNm/m which is relatively small when compared to the other two types of sheet pile. Generally, polymer sheet pile with the same section properties will have lower ultimate moment capacity when compared to the steel and concrete sheet pile.

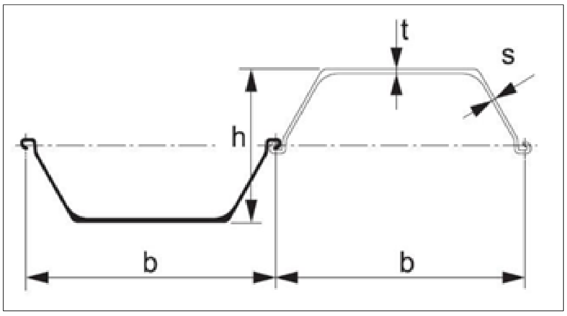

Figure 2: Shape of sheet pile wall [10]

Table 2: Geometry properties of sheet pile wall [10] [11] [12]

	Type		Steel	Concrete	Polymer
	Brand		ArcelorMittal	Hume Concrete Precast Solution	ESC Steel
	Model		AU 14	W600x1.0	GW610-9.0
Dimension	Width	mm	750	1000	606
	Height	mm	408	600	230
	t_f	mm	10.0	120	9
	t_w	mm	8.3	120	9
Mass	Per pile	Kg/m	77.9	476	13.6
	Per wall	Kg/m^2	104	476	22.6
Moment of inertia		cm^4/m	28680	764006	12758
Cross sectional area		cm^2/m	132	2048	157
Ultimate moment capacity		kNm/m	478	450	48.8

Extra calculation steps were proposed in the parametric studies in order to simulate the construction sequence of installing sheet pile walls and excavation in front of the wall. Hence, Phase 5 was added as the installation of sheet pile wall. In this phase, 6 m long sheet pile wall was installed near the toe of the embankment as the supporting system for the embankment. Next, phase 6 was added for the excavation process. In this phase, 2 m depth of topsoil layer was removed as to simulate the excavation process. The ratio of embedded pile length over total length of pile was set as one-third in order to simulate the working condition of cantilever sheet pile walls. The details of the simulation scheme of parametric study are listed in Table 3.

Table 3: Simulation scheme of parametric studies

Modelling scheme	To determine the effect of material types of sheet pile walls on deformation and stress distribution
Design assumptions	All the soil parameters and geometry are constant as published case study of Yan trial embankment.
Variable	Material properties of sheet pile wall
Material Parameters of Sheet Pile Wall	Steel: $EA_1 = 2.772\ x\ 10^6$ kN/m $EA_2 = 138.6\ x\ 10^3$ kN/m $EI = 60.23\ x\ 10^3\ kNm^2/m$ w = 1.020 kN/m/m
	Concrete: $EA_1 = 7.168\ x\ 10^4$ kN/m $EA_2 = 3584$ kN/m $EI = 26.74\ x\ 10^4\ kNm^2/m$ w = 4.67 kN/m/m
	Polymer: $EA_1 = 6.50\ x\ 10^4$ kN/m $EA_2 = 3250$ kN/m $EI = 528\ kNm^2/m$ w = 0.22 kN/m/m

4. Results and Discussion

The results of the sheet pile wall simulation using PLAXIS 2D numerical analysis were discussed. The results were obtained from the replicated case study and parametric study in order to achieve the objectives of this study. The relationship of materials and the deformation of sheet pile walls were discussed further in this subtopic.

4.1 Data Analysis of Replicated Case Study

The ultimate settlement of the Yan trial embankment is 0.01800 m while the deformed mesh with a total deformed value for this study is 0.02641 m as shown in Figure 4.1. Hence, the validity of the simulated model was assured by obtaining small differences in between the published results and the simulated results.

4.2 Data Analysis of Parametric Study

In this study, steel and concrete sheet pile walls had succeeded in 6 phases of calculation. However, the polymer sheet pile wall did not pass to undergo all simulation phases. The polymer sheet pile wall failed at phase no. 5 which is in the installation stage of the polymer sheet pile wall. This is due to the lower value in its allowable bending moment and cannot withstand the high lateral pressures compared to other materials. All the results were analyzed in phase 6 which is after the excavation process. Table 4 shows the summary of properties and output of sheet pile wall. The total displacement, bending moment, shear force and axial force of the sheet pile wall were shown in Figure 3, Figure 4, Figure 5, and Figure 6 respectively.

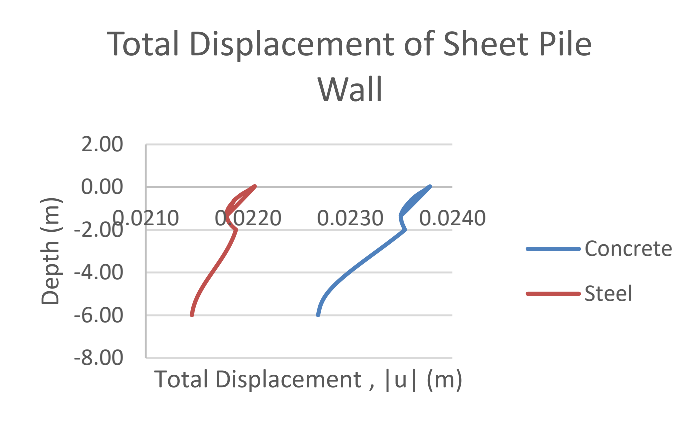

Figure 3: Total displacement of sheet pile wall

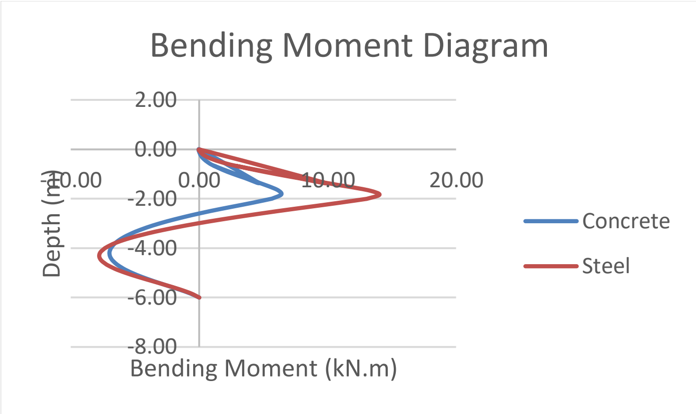

Figure 4: Bending moment of sheet pile wall

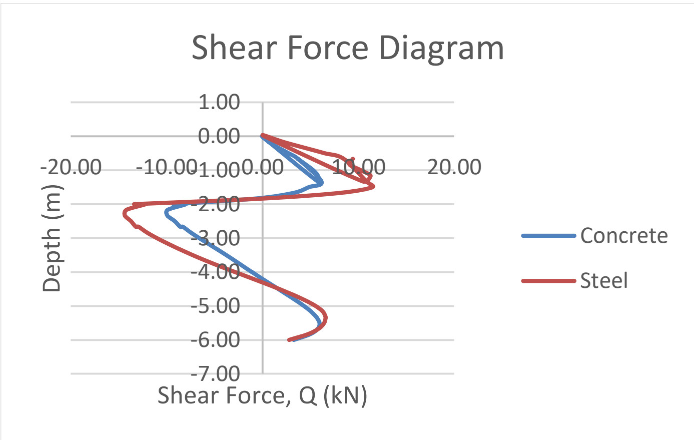

Figure 5: Shear force of sheet pile wall

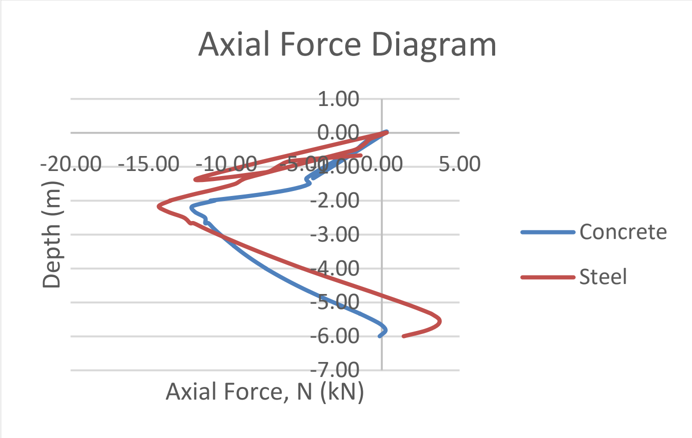

Figure 6: Axial force of sheet pile wall

Table 4: Summary of input properties and output results of sheet pile wall

Material	Steel	Concrete	Polymer
Young's Modulus (N/m^2)	$2\ x\ 10^8$	$3.5\ x\ 10^7$	$4.14\ x\ 10^6$
EA_1(kN/m)	$2.788\ x\ 10^6$	$7.168\ x\ 10^4$	$6.50\ x\ 10^4$
EA_2 (kN/m)	$138.9\ x\ 10^3$	3584	3250
EI (kNm^2/m)	$60.23\ x\ 10^3$	$26.74\ x\ 10^4$	528
Ultimate moment capacity (kNm/m)	478	450	48.8
Total displacement (m)	0.02208	0.02371	-
Bending moment (kNm)	14.03	6.390	-
Shear force (kN)	11.49	6.152	-
Axial force (kN)	3.69	0.2301	-

4.4 Discussion

From the results obtained, a clear view of the difference between the material used in sheet pile wall and its effect on the deformation of sheet pile wall have been identified. Foundation structure is designed at Serviceability Limit State (SLS) and it considers how the structure is expected to behave. It ensures the structure is not exceeding the limit of deformation, cracking or vibration. In this study, the maximum bending moment of the structures is within the moment capacity of steel and concrete. However, only the deformation of the steel sheet pile wall is within the acceptable limit. The horizontal displacement limit for cantilever sheet pile wall is 1% of the excavation height which is 0.0200 m. The displacement of the concrete sheet pile wall, 0.02371 which is slightly exceeded the acceptance limit.

Material that has higher allowable bending moment such as steel and concrete can restrain high lateral pressure. Characteristics of the material used as sheet pile wall is an important factor in generating their deformation and displacement. Higher value of Young's Modulus resulting in higher stiffness value. Then, the strength of materials also increases if the stiffness is increased. In this study, it was proven that material with higher strength will generate less deformation value compared to the material with lower strength. Thus, steel sheet pile is having higher bending moment when compared with concrete sheet pile due to its characteristic of material which has higher value of ductility than concrete. High ductility resulting in the ability to sustain plastic deformation under tensile stress before failure. Steel is good in tensile strength while concrete is bad in tensile strength. Besides that, steel is more durable than concrete material. Higher durability resulting in higher ability to withstand force, pressure and damage. Steel also is higher in flexibility while concrete is rigid. Then, the simulation shows that the steel sheet pile wall has higher value axial force compared to concrete sheet pile wall. This is due to the stress-strain relationship that steel showed higher stress at same strain level when compared to concrete sheet pile. The relationship is influenced by the Young's Modulus of the steel that is higher than concrete.

5. Conclusion

By referring to the objectives, it can be concluded that this study has successfully achieved its aims. From the first objective, the usage of polymer, steel and concrete sheet pile wall has been reviewed and identified. For the second and third objectives, the deformation and stress distribution of the cantilever sheet pile wall when using different types of materials have been identified and evaluated. In this study, it was shown that different material types of sheet pile wall generated different behaviour in terms of deformation, bending moment, shear force and axial force. Polymer sheet pile wall had failed in the installation stage as its allowable bending moment is lower in value, thus it failed to withstand the high lateral earth pressure of the case study. Concrete material shows higher total displacement than steel. Then, steel sheet pile wall had higher value in bending moment, shear force and axial force compared to concrete. Hence, it can be concluded that the characteristics of the material used for sheet pile walls plays an important factor in determining their deformation in the simulation process. Some recommendations were identified, namely, the design of cantilever sheet pile wall structure must be verified by using FEM software such as PLAXIS 2D in order to predict its short term and long term behaviour, propose the sheet pile wall with appropriate allowable bending moment by referring to the lateral earth pressures on site and increase the ultimate bending moment of polymer sheet pile wall to withstand the lateral earth pressure of soil that pressing on the wall.

Acknowledgement

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

References

[1] K. Sadeghi, "Application of Sheet Piles in Onshore and Marine Structures," Asian J. Nat. Appl. Sci., vol. 7, no. 1, pp. 10–18, 2018.

[2] Z. Cao, Y. Wang, and S.-K. Au, "Serviceability Considerations in the Design of Sheet Pile Walls for Risk Management.," GeoRisk 2011, pp. 403–410, 2011.

[3] N. Fadilah, C. Y. Ong, and K. K. Choong, "Precast concrete sheetpile for the stabilization of road embankment on soft ground adjacent to river," Appl. Mech. Mater., vol. 567, pp. 451–456, 2014, doi: 10.4028/www.scientific.net/AMM.567.451.

[4] L. Eskandari and B. Kalantari, "Basic types of sheet pile walls and their application in the construction industry-a review," Electron. J. Geotech. Eng., vol. 16 L, no. August, pp. 1533–1541, 2011.

[5] D. Sobala and J. Rybak, "Steel Sheet Piles - Applications and Elementary Design Issues," IOP Conf. Ser. Mater. Sci. Eng., vol. 245, no. 2, 2017, doi: 10.1088/1757-899X/245/2/022072.

[6] J. Wang, W. Liu, R. Liang, and H. Gangarao, "reinforced polymer sheet piles Analytical and experimental study on flexural behavior of pultruded fibre reinforced polymer sheet piles," no. December, 2015, doi: 10.1177/0021998315621369.

[7] N. Atalla, H. Æ. Abdallah, I. H. Malkawi, and M. M. A. Yamin, "Stability analysis of slopes using the finite element method and limiting equilibrium approach Stability analysis of slopes

using the finite element method and limiting equilibrium approach," no. November, 2008, doi: 10.1007/s10064-008-0156-z.

[8] F. N. L. Ling, "Simulation analysis of slope stability: A case study on slope failure at new laboratory of faculty of mechanical engineering utm" Master dissertation, Dept. Civ. Eng., Teknologi Mara Univ., Malaysia, 2003.

[9] R. C. Mamat, A. Kasa, and S. F. M. Razali, "Performance prediction of road embankment on soft soil stabilized with prefabricated vertical drains using numerical method," Int. J. Adv. Trends Comput. Sci. Eng., vol. 8, no. 4, pp. 1601–1608, 2019, doi: 10.30534/ijatcse/2019/85842019.

[10] *Steel Sheet Piling General Catalogue*. Arcelor Mittal, 2021.

[11] *Concrete Sheet Piling General Catalogue*. Hume Concrete Precast Solution, 2012.

[12] *Polymer Sheet Piling General Catalogue*. ESC Steel, 2021.