J-SUE

http://publisher.uthm.edu.my/ojs/index.php/j-sue

e-ISSN : 2821-2851

Journal of Sustainable Underground Exploration

Effect of Surcharges to The Stability of Mechanically Stabilized Earth Wall Using Finite Element Method: Back Analysis Study Case in Senai City Airport

Muhammad Amirul Nurhakim Bin Alias[1], Mohd Firdaus Bin Md Dan @ Azlan[1]

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

DOI: https://doi.org/10.30880/jsue.2022.02.01.003
Received 29 September 2022; Accepted 25 October 2022; Available online 30 November 2022

Abstract: Mechanically Stabilized Earth (MSE) wall is a composite retaining structure construction made up of alternating layers of compacted backfill and soil reinforcing components. Surcharges on top of MSE wall is one of the factors that can lead to the failure of the MSE wall. In Senai City Airport, a MSE wall with high 9 m and length up to 400 m has been constructed. However, the effect of various surcharges of the MSE wall slope did not well investigate and was poorly understood. This study aims to investigate the effect of surcharge to the stress behaviour and the factor of safety of Mechanically Stabilized Earth Wall (MSE) wall using Finite Element Method (FEM). The study conducted using different loads in order to determine the stress behaviour and the safety factor of MSE wall using PLAXIS software. The geometry and parameters of sandy silt slope of Senai City Airport, Senai, Johor was taken from design consultant and previous soil investigation report, respectively. The soil parameters were used in this study are the unit weight of the soil, cohesion, Poisson Ratio, Young Modulus and the friction angle. This study gave the best result in order to determine the effect of surcharges to the behaviour of stress and safety factor of MSE wall. The highest total displacement was at 100 kN with total displacement 19.23m with 0.884 factor of safety. This study revealed the effect of various surcharges on the behaviour of stress and factor of safety of the MSE wall. The increase of surcharge increased the stress behind the wall and increased the factor of safety (FOS) when the loads was increased.

Keywords: Mechanically Stabilize Earth wall (MSE), Finite Element Method (FEM), Factor of Safety (FOS)

1. Introduction

MSE walls also known as reinforced earth walls are a cost-effective alternative for transportation infrastructure such as roads and railway embankments [1]. MSE walls, which support bridge approach or departure slabs and bridge decks and hold embankment fill materials, are presently the most extensively utilized earth retaining structures in the worlds transportation system [2]. Mechanically Stabilized Earth (MSE) walls are a form of reinforced earth construction that is commonly used for transportation advancement projects such as highway ramps and bridge approach embankments [3]. There are also various load types stability of MSE wall. Internal stability of MSE wall and external stability of MSE walls both are types of stability of MSE walls. In internal stability of MSE walls, it has Coherent Gravity Method, the Tieback Wedge Method, the FHWA Method and Stiffness of Structure Method [4]. The finite element method (FEM) is a popular technique for numerically solving differential equations in geotechnical engineering. In some MSE wall analysis, the numerical studies were carried out using the two-dimensional finite element software which known as PLAXIS software [5]. For instance, geosynthetic reinforced soil slopes, finite element method was used to perform probabilistic slope stability studies [6]. FOS can be determined from finite element method based on several parameters such as friction angle, cohesion, unit weight, Young's Modulus and

*Corresponding author: firdausd@uthm.edu.my

Poisson ratio. Surcharges on top of MSE wall is one of the factors that can lead to the failure of the MSE wall. Calculation of the factor of safety was used to assess the stability of the walls (Fs) model [7].

The aim of this study is to determine the effect of various surcharge to the stability of MSE wall using Finite Element Method (FEM) via PLAXIS software. PLAXIS 2D software was used to determine the stress distribution behind the MSE wall and its factor of safety. Soil parameters were taken from previous soil investigation report from Senai City Airport, Senai, Johor. Slope geometry is based on the proposed by a client for the project. Uniform loads used are 0 kN/m2, 25kN/m2, 50 kN/m2 and 75 kN/m2 and 100 kN/m2. When the stress of the MSE Wall increased, it reduced the factor of safety of the wall. This study provides a whole understanding of the results that obtained will be analyzed to determine the effect of surcharges to the stress behaviour and the safety factor of the MSE wall in order to design MSE walls stability slope. To ensure the safety of MSE walls, FEM is the alternative approached that predict the potentially dangerous designs due to wider failure surfaces that are less likely to mobilize significant amounts of shear strength.

1.1 Application of Finite Element Method in Engineering Field

Geotechnical field application, FEM mostly used in stress analysis, slope stability analysis, soil structure interactions, seepage of fluids in soils and rocks, analysis of dams, tunnels, bore holes, propagation of stress waves and dynamic soil structure interaction. It is the simplest available stress-strain relationship. According to the Hooke law, it only provides two input parameters, that is, Young's modulus E and Poisson's ratio ν [8]. The finite element method (FEM) was created to handle difficulties in various disciplines in engineering fields, such as fluid dynamics and structural analysis, geotechnics and rock mass [9]. This model experienced a slide surface failure. As indicated in Figure 1, there has also been some bulging of the slope and some punching of the crest under the laden zone [10]. Slip failure and bulging of the slope with punching under the loaded zone and regulate the failure pattern [10] when use the parameters of ß=45˚ and cohesion, c= 1.0, 2.5 and 4.7 kN/m2 as indicated in figure 2. A slip surface failure occurs, resulting in the bulging of the upper half of the slope when use the parameters of for = 60° and c = 5.44 kN/m2 similar to figure 1 as indicated in Figure 3 [10].

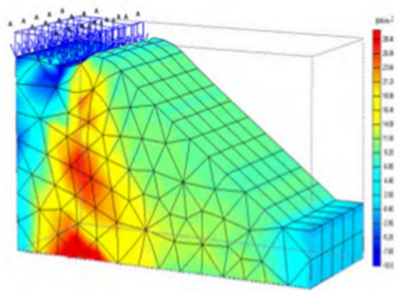

Fig. 1 - Example of Deformed Mesh for β = 30° and c = 5.44 kN/m

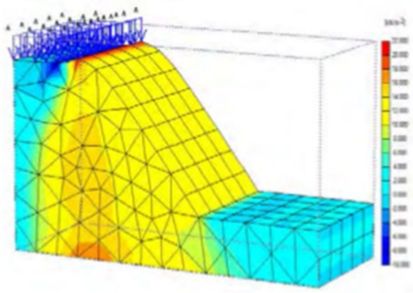

Fig. 2 - Example of Deformed Mesh for β = 45° and c = 5.44 kN/m

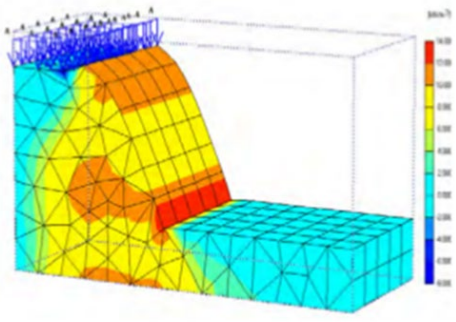

Fig. 3 - Example of Deformed Mesh for β = 60° and c = 5.44 kN/m

In this study, the model had been analyze using PLAXIS software to determine the surcharge due to the different parameter that had been used in this study and to determine the factor of safety (FOS) [10]. Table 2.1 shows the different surcharge loads and their factor of safety with similar cohesion value.

Table 1 - Different surcharge loads and their factor of safety with similar cohesion value [6]

Load (N)	Surcharge load (kN/m2)	Cohesion (kN/m2)	FOS
	Slope angle (ß)=30˚		
5102.65	106.31	5.44	1.615
6873.03	143.19	5.44	1.547
7000.0	145.84	5.44	1.509
	Slope angle (ß)=45˚		
3718.88	77.48	5.44	1.310
4047.85	84.33	5.44	1.172
4500.00	93.75	5.44	1.172
	Slope angle (ß)=60˚		
1343.97	27.99	5.44	0.794
2466.75	51.39	5.44	0.759
3000.00	62.50	5.44	0.750

In constant, the surcharge of MSE wall and the factor of safety of MSE wall can be analyzed using PLAXIS software using the soil parameters that can be obtained from the fieldwork.

1.2 Materials and Methods

The study was to analyze the MSE walls model using data from soil investigation report from Senai City Airport. The data was extracted from soil investigation report in order to model the design of MSE walls using PLAXIS software. The parameter that had been extracted from soil investigation report of Senai City Airport were the friction angle, cohesion, unit weight, Poisson’s Ratio and Young Modulus. The model of MSE walls had been analyzed using PLAXIS software to determine the deformation and the factor of safety (FOS) of MSE walls. The flow of research methodology is showed in figure 4.

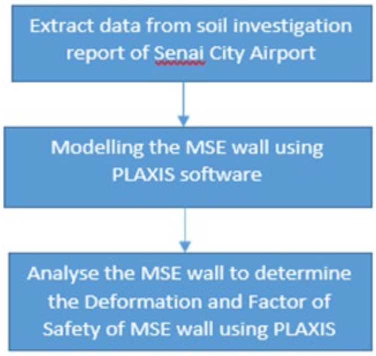

Fig. 4 - Flow of research methodology

1.2.1 Extract Data from Soil Report of Senai City Airport

The data that extracted from soil investigation report was cohesion, unit weight, friction angle, Poisson ratio's and Young Modulus in order to design the MSE walls. Poisson's ratio and Young Modulus need to be determined because of the lack of parameters from Soil Investigation Report of Senai City Airport. In order to find the parameter of Poisson Ratio, figure 5 was used to find the parameter.

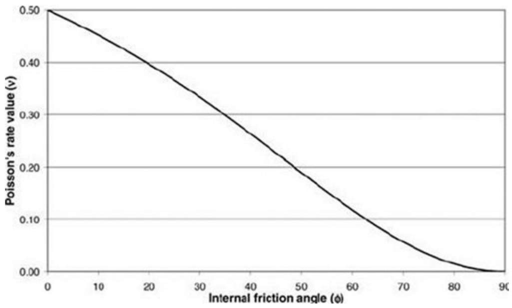

Fig. 5 - Example of Deformed Mesh for β = 60° and c = 5.44 kN/m

The Young modulus formula is shown in equation 1.

$$v = \frac{E}{2u} - 1 \qquad (1)$$

v is a Poisson's ratio at a void ratio. It can be determine using the formula below. Equation 2 shows on how to determine the v values. The v values can be determined after using this formula using in the table below. Table 2 shows standard values of Poisson's Ratio by values c and φ.

$$v = \frac{(0.5 \times \sigma 1 \times (1 - \sin \varphi II - cII \times COS\varphi II)}{\sigma 1 - CII \times COS\varphi II)} \qquad (2)$$

σ1 is the critical value, cII is for cohesion value and φII is the internal friction angle value.

Table 2 - The standard values of Poisson's Ratio

Type of soil	The Poisson Ratio v at a void ratio				
	Liquid limit	0.55	0.65	0.75	0.85
Sandy loam	0< IL<0.25	0.2200	0.2344	0.2556	-
	0.25<IL,0.75	0.2402	0.2556	0.2784	0.3030
Loam	0<Il<0.25	0.2211	0.2211	0.2424	0.2516
	0.25<IL<0.50	0.2332	0.2441	0.2555	0.2745
	0.50<IL<0.75	-	0.2631	0.2763	0.2955
Clay	0<IL<0.25	-	0.2281	0.2386	0.2472
	0.25<IL<0.5	-	0.2415	0.2498	0.2591
	0.50<IL<0.75	-	0.2622	0.2700	0.2840

When the data obtained from figure 5, table 2 had been used. The value from the table 2 was used in equation 2 to get the v value. Lastly, equation 1 had been used to find the Young Modulus value.

1.2.2 Modelling the MSE Wall Using PLAXIS Software

This study used the Moh'r coulomb criteria in order to defined the parameter that need to be used. This study used concrete panel, strip footing and anchor to design the mechanically stabilized earth wall (MSE wall) retained soil and also the foundation soil. The height of the concrete panel that used was 9m, 300mm x 1000mm of strip footing and 8.7m of anchor with 0.75m both of horizontal and the vertical spacing. In this study, MSE wall with height of 9m was designed and analyzed under the different loads condition. Figure 6 showed the design of MSE wall in PLAXIS software.

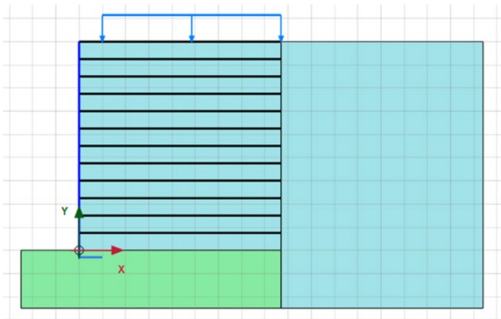

Fig. 6 - Design of the MSE wall using PLAXIS

1.2.3 Analysing the Model of MSE Wall

The design of MSE walls was mesh in the PLAXIS using different loads. The uniform loads that used in this study was 0 kN/m, 25kN/m3, 50 kN/m2 and 75 kN/m2 and 100 kN/m2. The design deformation and the total displacement maximum value had been analysed. The uniforms loads started from 0 kN/m2 to 100 kN/m2 on the same model and parameter. The deformation of surcharge was determined by the analyzing the model of MSE wall in PLAXIS. Lastly, the Factor of safety had been analysed from the the graph that obtained from the analyzing of MSE walls model.

1.3 Results and Discussion

In this study, different loads are used in order to determine the surcharge and the factor of safety (FOS) of MSE wall. The model of MSE walls with 9m height, concrete panel, strip footing and anchor were analyzed to determine the deformation and the factor of safety (FOS). Table 3 presented the geotechnical parameter that used in this study that was extracted from Senai City Airport soil investigation report.

Table 3 - The soil parameters of MSE walls

Soil Data	Concrete Panel and Strip Footing	Retained Soil	Anchor	Foundation Soil
Cohesion, kn/m²	-	0	-	5
Friction Angle, Degree	-	30	-	32
Unit Weight, Kn/m³	-	20	-	18
Young Modulus, e, (kN/m2)	-	13000	-	34000
Poisson Ratio, v	-	0.3	-	0.33
Lateral Earth Pressure Coefficient, K	-	0.333	-	0.333
EA (kN/m)	6x10^6	-	5.7x10^5	-
EI (kNm²/m)	11000	-	-	-
W (kN)	38	-	-	-

The MSE wall had been model in order to determine the behavior of the MSE wall under different loads condition. Figure 4.1 shows the deformation of the MSE walls at 0 kN/m². The total displacement of the MSE walls when 0 kN/m² affected on it had showed in Figure 7, the soil pushed the concrete panel and collapse at the maximum value 0.4536m.

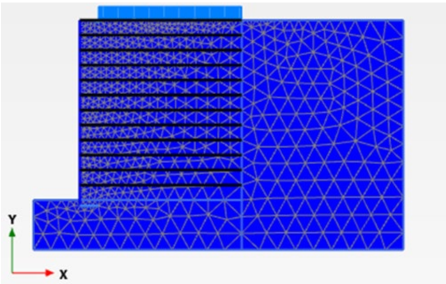

Fig. 7 - Displacement and deformation of MSE wall for 0 kN/m² at maximum value of 0.4536m

In figure 8, it showed the mesh deformation of the MSE wall when 25 kN/m² affected on it. Next, in Figure 8, the small change of displacement compared to the design in figure 7. In figure 8, the total displacement for the design was 0.4714m.

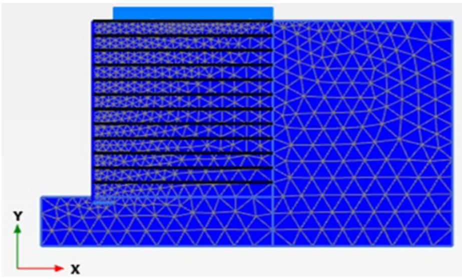

Fig. 8 - Displacement and deformation of the MSE wall for 25 kN/m² at maximum value 0.4714m

Figure 9 showed huge deformation compared to the figure 4.3. The maximum deformation was at the top of the wall against the concrete panel. Next, figure 9 shows the huge total displacement when 50 kN/m² loads affected on it compared to the Figure 9. The total displacement for this design was 0.5267m.

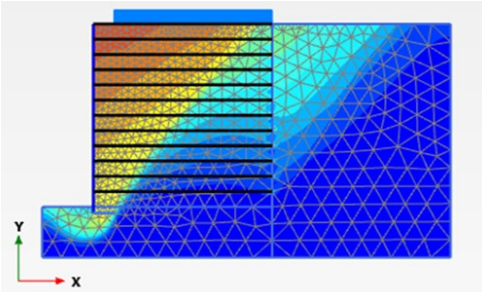

Fig. 9 - Displacement and deformation of the MSE wall for 50 kN/m² at maximum value 0.5267m

In Figure 10, the total displacement was very huge compared to the Figure 9 when it was run by the PLAXIS software. The maximum value of displacement that was obtained was 18.88m which is very huge compared to the results before.

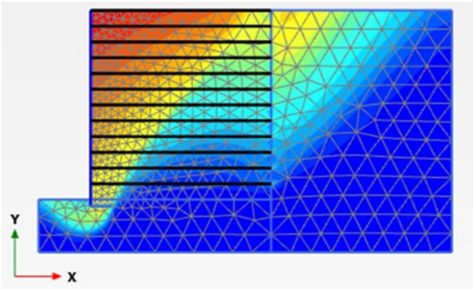

Fig. 10 - Displacement and deformation of the MSE wall for 75 kN/m² at maximum value 18.88m

In Figure 11, the maximum value of displacement that was obtained was 19.23m which is very huge compared to the results before. It tends to the soil body collapse and push away the concrete panel when the loads of 100 kN/m² affected on the structure of MSE wall. In this study, the surcharge will increase when the loads were increased.

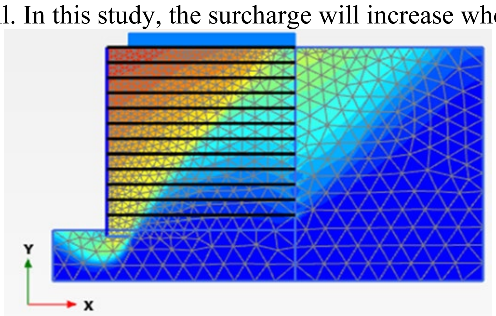

Fig. 11 - Displacement and deformation of the MSE wall for 100 kN/m² at maximum value 19.23m

In this study, the Factor of Safety was analyzed from various value of Uniform loads that affected on the MSE wall using PLAXIS. The summary of Factor of Safety was shown in the Table 4 as the result of Factor of Safety (FOS) against the uniform loads.

Table 4 - The summary of Uniform Loads (kN/m²) and their FOS

Uniform Loads (kN/m²)	Factor of Safety (FOS)
0	1.145
25	1.129
50	1.108
75	0.966
100	0.884

Figure 4 showed the Factor of Safety (FOS) for 0 kN/m² load that was the highest compared to 25 kN/m², 50 kN/m², 75 kN/m² and 100 kN/m². In this study, it can be observed that when the loads that affected on the MSE walls increase, the Factor of Safety (FOS) will be decrease.

Fig. 12 - Uniform Load (kN/m²) vs Factor of Safety (FOS)

1.4 Conclusion

This paper presents the analyzing of the MSE walls to determine the deformation, surcharge and also the factor of safety (FOS). Different loads that had affected on the MSE walls given the different deformation of MSE walls. The design success to be analyzed in the PLAXIS software. The design of the MSE walls was not achieved the criteria due to some of the soil parameter were collected from previous study due to the limitation in soil investigation report at Senai City Airport. The design showed the highest deformation of the mesh for the design when the 75 kN/m² and 100 kN/m² were applied on the MSE wall structure. In order to obtain the best deformation of the 75 kN/m² and 100 kN/m² of the loads, the parameter of the MSE walls need to be changed. The highest deformation was when 100 kN/m² loads affected on the model which was 19.23m total displacement. Furthermore, the factor of safety had been analysed using the PLAXIS software and the graph of factor of safety had been obtained from it. It can be explained that the deformation at the 100 kN/m² was the highest compared to the deformation at 0 kN/m². The different of surcharge also can be observed in this study from the different uniform loads. The highest factor of safety was 1.145 and the lowest factor of safety obtained was 0.884. The factor of safety decrease when the loads increased. Parameter that leads to the best design performance need to be determine in order to achieved a good result. Hence, this study helped us determined the optimum FOS and the surcharge of the MSE walls when the loads affected on the design.

Acknowledgement

I would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tuun Hussein Onn Malaysia for its support.

References

Bourgeois, E., Corfdir, A., & Chau, T. L. (2013). Analysis of long-term deformations of MSE walls based on various corrosion scenarios. *Soils and foundations*, *53*(2), 259-271.

Sadat, M. R., Huang, J., Bin-Shafique, S., & Rezaeimalek, S. (2018). Study of the behavior of mechanically stabilized earth (MSE) walls subjected to differential settlements. *Geotextiles and Geomembranes*, *46*(1), 77-90.

Rajagopal, G., & Thiyyakkandi, S. (2021). Numerical evaluation of the performance of back-to-back MSE walls with hybrid select-marginal fill zones. Transportation

Allen, T., Christopher, B., Elias, V., & DeMaggio, J. (2001). Development of the simplified method for internal stability design of mechanically stabilized earth walls (No. WA-RD 513.1,). The Department.

Rabie, M. (2016). Performance of hybrid MSE/Soil Nail walls using numerical analysis and limit equilibrium approaches. *HBRC journal*, *12*(1), 63-70.

Luo, N., Bathurst, R. J., & Javankhoshdel, S. (2016). Probabilistic stability analysis of simple reinforced slopes by finite element method. Computers and Geotechnics, 77, 45–55. https://doi.org/10.1016/j.compgeo.2016.04.001

Abdelouhab, A., Dias, D., & Freitag, N. (2011). Numerical analysis of the behaviour of mechanically stabilized earth walls reinforced with different types of strips. Geotextiles and Geomembranes, 29(2), 116-129.

Jalali, M., Hasan Golmaei, S., Borthwick, A., Khalegh, M., Ahmadi, Z., & Moradi, R. (2012). Using Finite Element method for Pile-Soil Interface (through PLAXIS and ANSYS). Journal of Civil Engineering and Construction Technology, 3(10), 256–272. https://doi.org/10.5897/JCECT12.024

Nagel, J. (2012). Introduction to the Finite Element Method. https://my.eng.utah.edu/~ece6340/LECTURES/Apr2/Nagel_FEM.pdf

Manna, B., Rawat, S., Zodinpuii, R., & Sharma, K. G. (2014). Effect of surcharge load on stability of slopes-testing and analysis. Electronic journal of geotechnical engineering, 19, 3397-3410.