International Journal of Civil Engineering and Infrastructure
Vol. 1, No. 1, March 2023

THE EFFECT OF USING FOAM MORTAR AS AN ALTERNATIVE BACKFILL MATERIAL ON SHEET PILE WALLS ON SLOPES

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Received January 02, 2023 | Accepted February 23, 2023

ABSTRACT

Foam Mortar is one of the newest technologies in road and Bridge. The density of foam mortar is only about 40% of the soil or rock, making it a lightweight fill material that significantly reduces lateral and vertical pressure when used as a retaining wall backfilling material. This paper aims to analyze the effect of using foam mortar as backfill material on the performance of sheet pile retaining wall relating to safety factor, bending moment, and sheet pile displacement. Comparative analysis using soil and foam mortar as backfill material is also studied. The modeling is carried out using finite element software with loose sand and foam mortar as the comparative backfill material parameters, and using simple slope model with variations in slope ratio (1:1.5; 1:2; and 1:3) and variations in backfill height (1m , 2m, 3m and 4m). Results showed that the effectiveness of the foam mortar increased with the increase in the steepness and the height of the backfill material. The analysis results also showed that the greatest increase in the value of the safety factor occurred at backfill height of 4m with a slope ratio of 1:3 to 28.89%, the greatest reduction value in deflection occurred at backfill height of 4m with a slope ratio of 1:3 to 96.2%, and the greatest reduction value in bending moment occurred at backfilling height of 4m with a slope ratio of 1:1.5 to 89.73%..

Keywords: *Foam mortar, sheet pile, safety factor, displacement, bending moment*

1. INTRODUCTION

Landslides are a common disaster in Indonesia. In general, slope failure is caused by high rainfall intensity, where infiltration of rainwater onto the slopes causes an increase in pore water pressure and reduces the shear strength of the soil so that the slopes become more prone to landslides. Moreover, deforestation, poor design construction, hydropower projects as human activities also have added up the landslide event (Chakraborty & Rathod, 2020).

Slope stability analysis is crucial in the mitigation and handling of landslide susceptibility. The aim in knowing slope stability is to find the value of the safety factor for the landslide area (Pourkhosravani & Kalantari, 2017). To prevent such a landslide occurring, it generally can be handled in several ways such as reducing slope loads and strengthening slopes.

In reducing the load on slopes, many ways have been developed, one of them is material called foam mortar. Foam mortar technology as a lightweight material to alternative backfill is currently widely recommended in many areas in Indonesia. The advantage of its use is that it has a density of about 40% which is useful for reducing soil loads on unstable soil conditions such as slopes that are prone to landslides due to high rainfall, soft soils, and peat soils. In slope reinforcement, sheet pile is also a soil retaining material that is commonly used to strengthen soil resistance on slopes. The mechanism is to bypass the failure plane and divert the failure plane on the slope to sheet pile.

The aim of this paper is to determine the effectiveness of foam mortar used as a backfill material on the performance of sheet walls. the objectives was achieved by a series of numerical analyses comparing homogeneous soil slopes with foam mortar and loose sand as backfilling materials and combinations of backfill height variables and slope ratio to the performance values of the sheet pile in the form of safety factor, displacement value, and its bending moment. The increase rate of the comparison of loose sand and foam mortar is also studied.

2. LITERATURE REVIEW

Slope Stability

Slope stability is an essential factor and is frequently encountered in the field to fulfil the requirements for road construction, and this is related to road user safety and equipment safety. The vulnerable slope is often found in excavation and backfilling which exposes variations in geological layers and can increase the weathering level. It often occurs as a landslide due to high intensity of rain or changes in land use which cause slope stability more prone or areas of weakening occur. In calculating slope stability and bearing capacity, there are soil shear strength properties, including the friction angle (ø) and cohesion (c) (Wicaksono & Iqbal, 2020).

Foam Mortar

Foam mortar is a lightweight material with a mixture of cement, water, fine aggregate and foam with a certain target compressive strength value to be achieved. Foam mortar has a certain density value ranging from 0.6 kN/m3 - 0.8 kN/m3, while soil embankment ranges from 1.6 kN/m3 - 1.8 kN/m3. Some advantages and functions of foam mortar (Febrianto, 2010; Iqbal, 2012) is reducing embankment loads and has adequate bearing capacity which is excellent to be used as a road pavement subgrade, reducing the lateral pressure on the retaining wall, and has self-compacting ability. There is two type of mortar foam with density of 0.6 kN/m3 at 14 days of age with compressive strength of 800 kPa, and density of 0.8 kN/m3 at 14 days of age with compressive strength of 2000 kPa

Finite Element Method

Finite element methods (FEM) or numerical analysis provide reasonable approximations to the “correct” or “exact” mathematical solutions of the slope stability equations. They are more sophisticated and complicated than limit equilibrium methods, which take into account deformations (strains) and not only forces (stresses) (Pourkhosravani & Kalantari, 2017). In geotechnical problems, the FEM can help simulate the physical behavior of soil materials or structures by using tools inside without simplifying the problem. The FEM is currently used as a reference for slope stability analysis solutions that are often used in the last 20 years.

Safety Factor

The factor of safety (FoS) practically defines a slope as stable (FoS>1) or unstable (F0S<1). In the process, knowing the lowest factor of safety in the analysis can estimate the potential for failure areas that are prone to occur. However, safety factors are applied to calculate and mitigate uncertainties in soil conditions, soil geometry, load conditions (static and dynamic), stability analysis methods, and restraint soil movement to an acceptable level (Bilgin, 2010).

3. MATERIAL AND METHODE

Design Procedure

The most common way to design sheet pile walls nowadays is to use the limit equilibrium approach. This method relies on the active and passive earth pressures that are related to the failure condition based on the Mohr–Coulomb failure criterion. The depth of wall penetration, the force of the anchor, and the choice of pile section depend on the balance of force and moment using the lateral earth pressures. The passive pressures are multiplied by a factor of safety when calculating the lateral earth pressures. The factor of safety accounts for the uncertainties in soil conditions, the stability analysis method, the loading conditions, and also limits soil movements to a reasonable level.

As computing technology improves, continuum mechanics numerical methods have become more popular for analyzing and designing sheet piles. The finite element method is the main numerical method used, but the finite difference method is also applied. Researchers have used the finite element method to investigate and explain how cantilever, braced, and anchored sheet pile walls behave under static and dynamic loading conditions.

The finite element method has been utilized by writers to study and understand the behavior of cantilever sheet pile walls under several conditions.

Wall And Soil Profiles Model

This study selected three different angles of slope to determine the effect of slope on the behaviour of sheet piles. Previous studies have examined the behaviour of retaining walls with mortar and relatively no lateral pressure on flat planes. Numerical modelling and analyses were performed for these three angles of slope with soil profile combinations.

This study considered two different soil types: medium dense sand and loose sand. The paper uses one-letter code designations to refer to the soil types. The letter codes “D” and ‘‘L” represent medium dense sand and loose sand, respectively. Table 1 provides the properties selected for the two soil types, which are an average of typical representative ranges reported. For example, the modulus of elasticity is an average value selected from the typical range given by Kulhawy and Mayne and is representative of secant moduli within common design stress levels. For mortar foam material properties, refer to previous research (Hidayat, 2016) shown in table 2.

Table 1. Soil Properties (Bilgin, 2010)

Property	***Medium Dense Sand (D)***	***Lose Sand (L)***
Material Type	Mohr Coulomb	Mohr Coulomb
Saturated unit weight (kN/m³)	18	16
Unsaturated unit weight (kN/m³)	17	16
Friction angle (°)	36	30
Cohesion (kPa)	0,3	0,3
Dilatancy angle (°)	6	0
Modulus of elasticity (kPa)	35.000	15.000
Poisson’s ratio	0,28	0,20
Interface strength	0,65	0,67

Table 2. Mortar Foam Properties

Property	***Mortar Foam***
Material Type	Linear Elastic
Saturated unit weight (kN/m^3)	6
Unsaturated unit weight (kN/m^3)	6
Void Ratio	0.2
Modulus of elasticity (kPa)	892.634,5

Table 3. Sheet Pile Properties

Property	***Sheet Pile***
EA (kN/m^3)	9,7E7
EI (kNm^2/m)	2,08E5
W (kN/m/m)	3,40
Poisson's ratio	0,35
Mp (kNm/m)	1E15
Np (kN/m)	1E15

Slope models are made as a simple slope with variations in vertical to horizontal ratios of 1:1, 1:2 and 1:3. Loose sand and mortar foam is used for backfill soil behind the sheet pile, while medium dense sand is used as foundation soil on slope. The wall height is 12 m, with free standing 4 m.

Finite Element Analysis

The finite element modelling modelled as two-dimensional plane strain analysis and analyses were carried out using PLAXIS. PLAXIS has been used successfully to model and analyse various types of retaining wall structures under different loading conditions. The predicted performance of the walls by PLAXIS was verified by field measurements.

Soil layers were modeled using 15-node triangular elements. The 15-node elements provide a fourth order interpolation for displacements and the numerical integration involves 12 stress points. The sheet pile wall was modeled by using five-node elastic plate elements.

The Mohr-Coulomb material model, also known as the linear elastic perfectly-plastic model, is used as the constitutive model of the soil. The Mohr–Coulomb model has been successfully used for granular soils and was therefore employed in this study to model the stress–strain behavior of sands. The parameters needed for the Mohr–Coulomb model are the Young's modulus, E, and Poisson's ratio, m, for the elastic strain component of the soil behavior. The effective strength parameters cohesion, c0, and friction angle, ϕ , as well as the dilatancy angle, w, are needed for the plastic strain component of the soil behavior. Table 1 provides the properties selected for the two soil types.

Construction method was simulated by adding sheet pile walls and adding soil in lifts for backfill. total soil height added was performed in four steps, and thickness of the backfill added was equal to one-four of total wall height for each step. This resulted in 1 m thick backfill for 4 m-high walls respectively. The analyses were performed for both soil and mortar foam backfill condition and the results were compared. Due to cohesionless soils, analyses were performed considering fully drained conditions.

Safety analysis in Plaxis uses a so-called phi/c reduction method in which the strength of the soil materials will be reduced with a factor ΣMsf until either failure is reached for a stable value of ΣMsf, or the maximum number of calculation steps is reached. The total multiplier ΣMsf is used to define the value of the soil strength parameters at a given stage in the analysis:

$$\Sigma Msf = \frac{\tan \varphi_{input}}{\tan \varphi_{reduced}} = \frac{c_{input}}{c_{reduced}}$$

Where the strength parameters with the subscript 'input' refer to the properties entered in the material sets and parameters with the subscript 'reduced' refer to the reduced values used in the analysis. Σ Msf is set to 1.0 at the start of a calculation to set all material strengths to their input values. The principal results of a Safety calculation are the failure mechanism and the corresponding ΣMsf, which is the safety factor. The strength reduction method, as adopted in a Safety calculation, gives similar safety factors as obtained from conventional stability analysis based on the Limit Equilibrium Method (LEM) slip-circle analysis (Brinkgreve, R.B.J., Bakker, H.L., 1991).

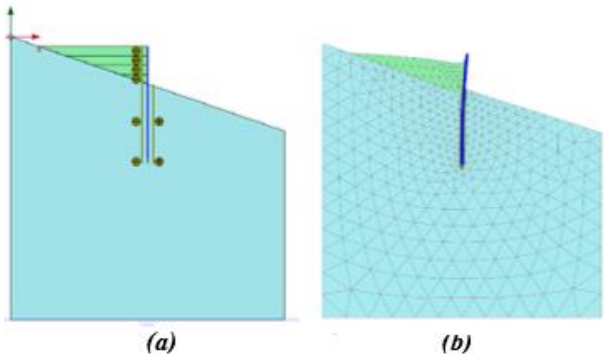

Figure 1. Finite Element Model (a) embedded sheet pile; (b) deformed sheet pile in PLAXIS

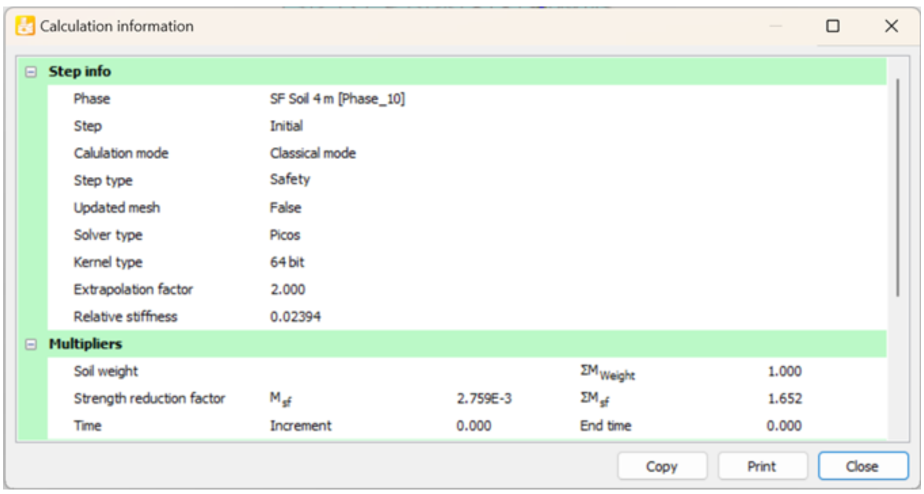

Figure 2. Safety factor analysis result

4. RESULTS AND ANALYSIS

A series of comparative numerical analysis of sheet piles and foam mortar in evaluating sheet pile performance has been carried out. The results of the analysis and summary have been discussed below.

Evaluation of Sheet Pile Safety Factor for Variations in Slope Ratio and Backfill Height

Based on the safety factor curve in figure 3, the highest safety factor from backfill soil material with a slope ratio of 1:1.5, 1:2, and 1:3 is achieved at a height of 1 m with values of 1,142, 1,540, and 2,235 respectively. When viewed from the increase in the backfill height, the factor of safety on each slope ratio has a similar decreasing pattern, especially the significant decrease in the safety factor is shown at the backfill heights of 3m and 4m. while the safety factor of the soil material backfill at variations in backfill height from 1 m to 4 m with a slope ratio of 1: 1.5, 1: 2, and 1: 3 does not provide a significant difference from each of the resulting safety factor values or is relatively stable with values 1.14, 1.53, and 2.3 respectively

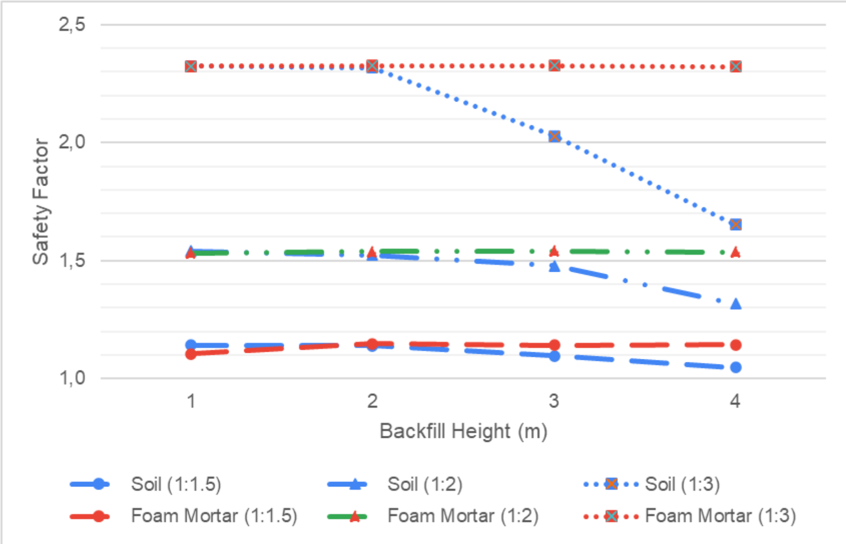

Figure 3 Effect of backfill height and slope ratio variation to safety factor

In the curve of the increase rate in the value of the safety factor using foam mortar, it can be seen in Figure 4 that the higher the backfill height that burdens the sheet pile, the higher the increase rate in the safety factor. When viewed from the value of the increase rate, the effectiveness of foam mortar as an alternative to landfill gives the greatest increase in safety factor obtained 8.47%, 14.26%, and 28.89% based on each slope of 1:1.5, 1:2, and 1:3 respectively. However, there is no difference in increased safety factor on slopes ratio of 1:2 and 1:3 with backfill height of 1 m to 2 m.

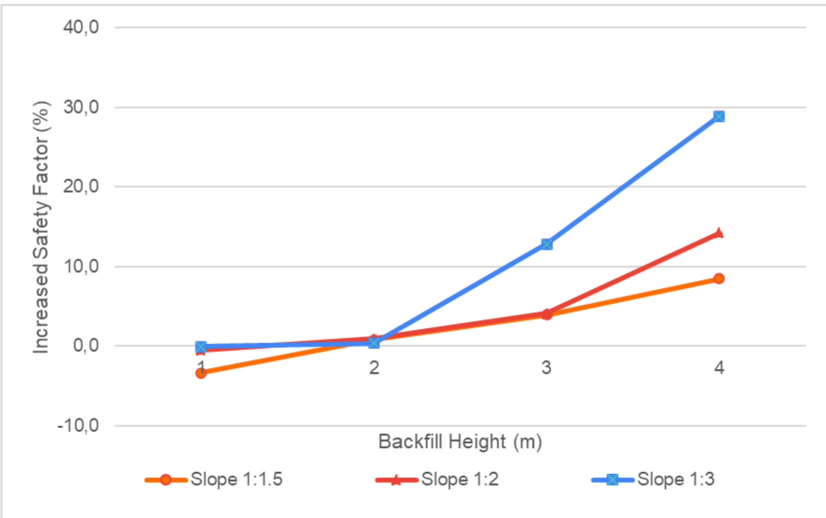

Figure 4 Increase rate in the the safety factor by using foam mortar

Evaluation of Sheet Pile Bending Moment for the Variations in Slope Ratio and Backfill Height

From figure 5, it can be seen that the loose sand and foam mortar backfills have different patterns, the bending moment curve with loose sand shows an increase in the value of the bending moment or lateral pressure that burdens the sheet pile so that the greater the backfill height the greater the lateral pressure on the sheet pile. Based on its value, the greatest bending moment is achieved at the backfill height of 4 m with values of 158.2kNm, 101.2kNm and

85.76kNm on each slope ratio of 1:1.5, 1:2 and 1:3. It is different with the pattern of the lateral pressure curve of the foam mortar which has an increasing pattern in similar direction as the increase in backfill height, but the amount of bending moment given does not show a significant value to burden the sheet pile. The highest moment values given by the foam mortar material are 16.25kNm, 18.4kNm and 27.63kNm with slopes of 1:1.5, 1:2 and 1:3, respectively.

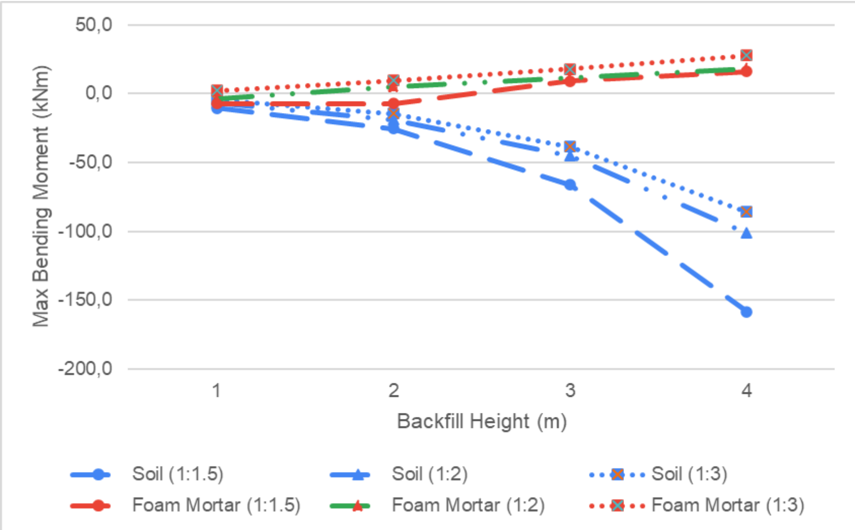

Figure 5 Effect of backfill height and slope ratio variation to bending moment

Based on the bending moment reduction value shown in figure 6, the contribution of the mortar in reducing the moment load or lateral pressure is excellent. It is shown that the greater the backfill height results in the increase of the bending moment reduction rate which produces 89.73%, 81.82%, and 67.78% on the slopes of 1:1.5, 1:2, and 1:3 respectively. Further research on backfill height variations is needed to see the asymptotic point of the effectiveness of foam mortar as an alternative to lightweight backfill material.

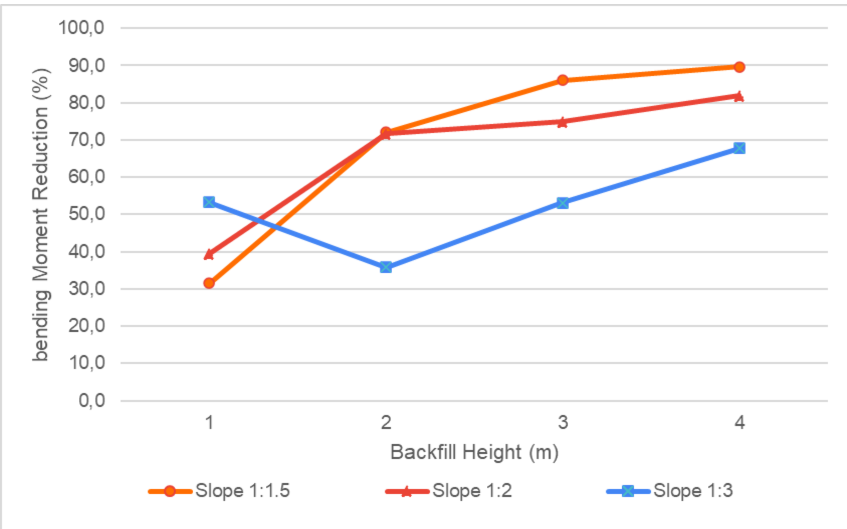

Figure 6. Bending moment reduction rate by using foam mortar

Evaluation of Sheet Pile Displacement for the Variations in Slope Ratio and Backfill Height

Based on Figure 7, it shows a pattern which states that the higher backfill burdening the sheet pile, the higher sheet pile displacement. The highest displacement values on slopes ratio of 1:1.5, 1:2, and 1:3 with loose sand backfill material were achieved at a height of 4 m with values of 42.53mm, 16.55mm and 11.48mm respectively. The highest displacement value of foam mortar embankment material with slopes of 1:1.5, 1:2, and 1:3 was achieved at a backfill height of 4 m with values of 5.52mm, 1.64mm, and 0.436mm respectively.

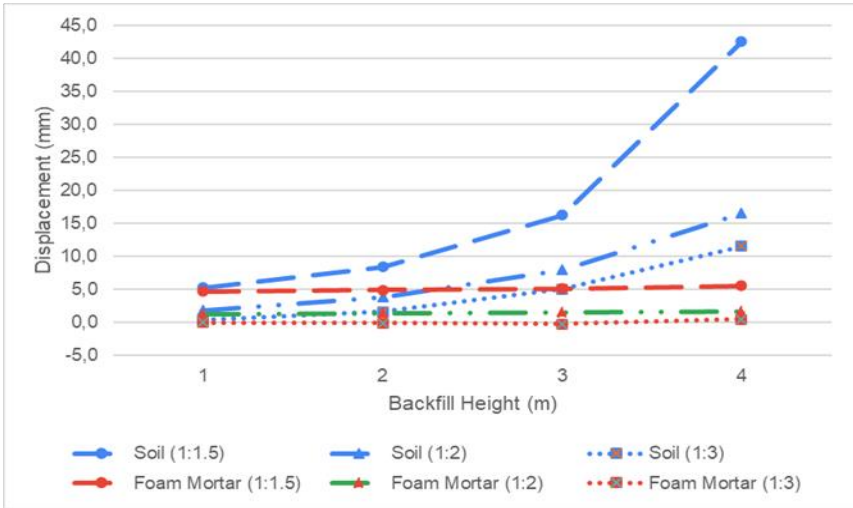

Figure 7. Effect of backfill height and slope ratio variation to sheet pile displacement

Figure 8 shows the sheet pile displacement reduction rate by using foam mortar. In detail, it can be seen that at certain backfill height, the percentage reduction curve for each slope variation gives an asymptote value, so further research needs to be considered. It also shows a consistent increase in percentage value with increasing slope and embankment height. based on its value, at a slope of 1:1.5, 1:2, and 1:3 with a height of 4 m it has achieved the highest effectiveness of the foam mortar alternative material from the percentage value of the transfer value with details of 87.03%, 90.07% and 96.20% respectively .

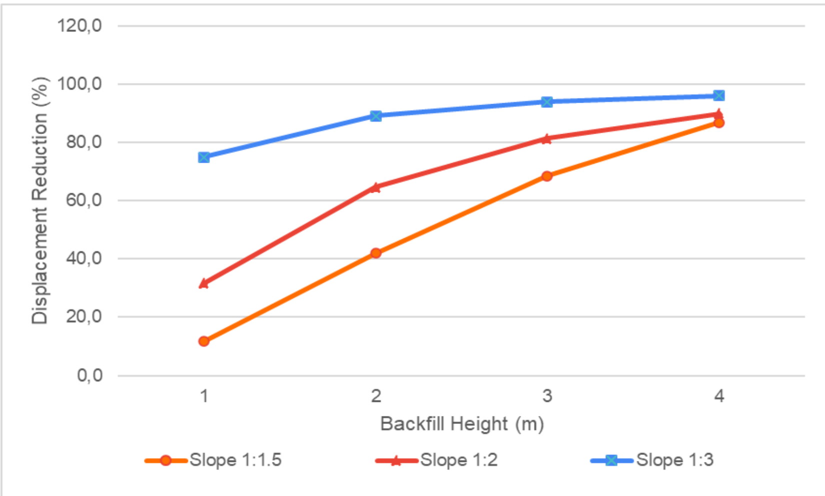

Figure 8. Sheet pile displacement reduction rate by using foam mortar

5. CONCLUSION

The effects of using foam mortar as an alternative backfill material for sheet wall are determined in 2D finite element analysis which explains the effect of variations in slope ratio and backfill height on safety factor, sheet pile displacement, and bending moment values. Conclusions are summarized below:

1. Foam mortar can maintain a sustained safety factor with an increase in backfill height from 1 m to 4 m compared to loose sand with a decreased safety factor. On slope ratio variations, slopes with slope ratio of 1: 3 have a high safety factor because of their gentle slope, and based on the increase rate analysis of the safety factor, the highest safety factor is achieved at a backfill height of 4 m and a slope ratio of 1: 3 of 28.89%
2. Foam mortar has low lateral pressure or bending moment values. This is due to the density of foam mortar 0.6 kN/m3 - 0.8 kN/m3, while the backfill soil ranges from 1.6 kN/m3 - 1.8 kN/m3. It is also proven that foam mortar can provide a reduction factor at the bending moment with a backfill height of 4 m and a slope ratio of 1:1.15 of 89.73% compared to loose sand.
3. Foam mortar can reduce the displacement value on sheet pile. The results of numerical analysis show that the steeper the slope and the backfill height, the greater the displacement value. However, with foam mortar, the displacement value of the sheet pile shown due to the backfill is low. Then when compared, the reduction rate of foam mortar has a high value where the bending moment at a backfill height of 4 m and a slope ratio of 1:1.5 reaches 89.73%..

REFERENCES

[1] Bilgin, O. (2010). Numerical studies of anchored sheet pile wall behavior constructed in cut and fill conditions. *Computers and Geotechnics*, 37(2010):399-407

[2] Brinkgreve, R.B.J., Bakker, H.L. (1991). Non-linear finite element analysis of safety factors. In Proc. 7th Int.

[3] Conf. on Comp. Methods and Advances in Geomechanics. Cairns, Australia, 1117–1122.

[4] Chakraborty, M., Rathod, P. (2020). A Review on Slope Stability Analysis. Parul University International Conference on Engineering & Technology (PICET-2020):Smart Electronics

[5] El-kady, M.S., Alzara, M.A., Farouk, MA. (2018). Reduction of lateral earth pressure using Geo-foam blocks. Innovative Infrastructure Solutions, 3:40. https://doi.org/10.1007/s41062-018-0145-4

[6] Soong, TT and Dargush, GF (1997). "Passive Energy Dissipation Systems in Structural Engineering". John Wiley & Sons, Chichester, England.

[7] Febrijanto, R. (2009). Laporan Akhir Kajian dan Pengawasan Uji Coba Skala Penuh Timbunan Badan Jalan Dengan Material Ringan. Laporan Penelitian Pusat Penelitian dan Pengembangan Jalan dan Jembatan, Departemen Pekerjaan Umum.

[8] Hidayat, D., Purwana, Y. M., Pramesti, F.P. (2016) Analisis Material Ringan dengan Mortar Busa Pada Konstruksi Timbunan Jalan. Seminar Nasional Sains dan Teknologi 2016: Jakarta

[9] Iqbal, M. (2012). Kajian Penanganan Tanah Lunak dengan Timbunan Jalan Mortar Busa. Pusat Penelitian dan Pengembangan Jalan dan Jembatan: Bandung

[10] Patil, H., Deshmukh., Salunke, P., Analysis of sheet pile in dense and

loose soil using finite element method. Material Today: Procedeedings

[11] Pourkhosravani, A., Kalantari, B. (2011). A Review of Current Methods for Slope Stability Evaluation. Electronic Journal of Geotechnical Engineering, 16(2011)

[12] Wicaksono, S; Iqbal, M. (2020). Effectiveness of Foamed Mortar Light Weight Fills As An Approach Bridge Fill On Sheet-Pile Structures. Jurnal Jalan-Jembatan, 37(2020):87-101