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Comparison Study of Embankment Filled with Selected Material and Foamed Mortar on Toll Road

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ABSTRACT The road studied was planned to be constructed on an embankment with a height ranging from 3 to 12 meters. It also has compressible soil conditions at a thickness of ± 10 meters and an average N-SPT value ranging from 5 to 12 which indicates a relatively large soil compression. Therefore, it is necessary to design a road embankment that meets the standard safety factor by using lightweight materials to minimize the occurrence of subgrade compression. The effect of gravel and foam mortar materials on the settlement and stability of the embankment was determined using 4 combinations including 100% gravel, 25% foam mortar with 75% gravel, 50% foam mortar with 50% gravel, and 75% foam mortar and 25% gravel. The findings showed that the combination with higher content of foam mortar has a smaller settlement and overall stability considered to be safe. It was discovered that the combination of 75% foam mortar and 25% gravel was able to reduce the settlement up to 0.6 times and increase the average safety factor up to 1.46 times. This combination was found to have the best results with consolidation settlement (Sc) of 1,24 m and Safety Factor (SF) of 1,383 for STA 414+525 while the values for STA 424+576 were 0,42 m and 2,78, respectively.

KEYWORDS Soft Soil; lightweight material; Embankment; Settlement

1 INTRODUCTION

The continuous population growth has led to an increase in the number of goods required by the people, thereby leading to the need for appropriate distribution channels. An example of these channels is the land route which is observed to have led to an increment in the use of land transportation modes. This means the required infrastructure needs to be enhanced in order to facilitate distribution and connect the growth center area with the surrounding area. This is considered one of the methods to improve the economy of a region.

The construction of toll road transportation infrastructure is expected to improve the regional economy and support the mobility and accessibility of land routes. The obstacle often encountered in the process is the existing soft ground with the potential to cause problems such as large settlements and low bearing capacity. This is the reason it is necessary to pay attention to the stability of the embankment with the potential for large compression and landslides. Therefore, several studies were conducted on light embankment technology such as foam mortar. For example, Hidayat *et al.* (2016) stated that cohesive soil which is a local material can be mixed with foam in order to achieve an expansion of the initial volume by four times to reduce the material required and the importation of stockpile materials from other locations. Lightweight foam mortar embankment is the innovation currently being applied as a substitute for ordinary materials such as granular soil in the construction of toll roads in Indonesia due to its ability to minimize compression caused by embankment loads on the subgrade. This material is made up of a mixture of cement, sand, water, and foam mortar. It is also easier to work with the material, thereby speeding up the execution time of the project. Another study by Marradi *et al.* (2012) focused on the possibility of achieving adequate performance through the innovative application of lightweight materials in airport pavement subgrades and embankments using both natural and/or materials derived from an industrial process. Some preliminary results were obtained by comparing the natural and geofoam lightweight materials.

Kadela *et al.* (2017) conducted laboratory tests on foam concrete and numerical simulations for pavement on the sub-base layer of the road constructed on a soft subgrade using different densities of foam mortar ranging from 500 to1300 kg/m3. The focus was on density, porosity, compressive strength, and flexural strength. The numerical simulations showed that the maximum tensile stress at the bottom of the subbase layer zone for the pavement structure KR5 and subgrade type G1÷G4 is lower than the flexural strength of foam concrete with a density of 860 - 1060 kg/m^3. This indicates the potential of foam mortar as a subbase material to construct pavement structures.

Tharakarama *et al.* (2017) also stated that foamed concrete is a versatile material consisting mainly of cement-based mortar mixed with at least 20-25% by volume of air. It is a no-load structural element having a lower strength than conventional concrete. The study was conducted to reduce the density of the concrete using the optimum foam content and provided an overview of foamed concrete with a focus on its constituents, production, engineering properties, and uses. The test results from the experiment showed that 1200 kg/m^3 is the optimal density to reduce up to 40% density compared to conventional concrete.

Hidayat *et al*. (2016) used PLAXIS modeling to determine the effect of light embankment technology on loads when compared to conventional methods. The technology was discovered to have the ability to reduce embankment loads because it is light in weight, high enough for subgrade strength, fill weight, and the possibility of designing its compressive strength as desired towards reducing the impact of settlement on the road above. Hidayat *et al.* (2016) also showed that the use of lightweight materials with foam mortar as embankment filling material provides several advantages such as its lower deformation when compared to conventional embankments. The foam mortar used in the study has an elasticity modulus of 892634,5 kN/m^2, unit weight of 6 kN/m^3, and void ratio of 0,2 while the convention embankment with granular material has a unit weight of 17 kN/m^3, cohesion of 10 kN/m^2, friction angle of 25^0, and Young modulus of 9000 kN/m^2. Moreover, the ground settlement due to weight self of conventional embankment was recorded to be 6810 mm, while the light embankment due to uniform load produced 39.9 mm and concentrated load was 98.3 mm. According to Sheng *et al.* (2020), the foamed light soil embankment wall has the ability to provide full play to the lightness of the foamed light soil and effectively solve the problem of uneven settlement associated with the widened roadbed as indicated by its value of only 3.67 cm after 3 months of the construction. It was also discovered that the maximum horizontal displacement was only 36 mm within 5 months after the construction.

Fadilah *et al.* (2017) compared the occurrence of settlement for the embankments constructed using granular soil and lightweight foam mortar and the results showed that those with lightweight materials were able to reduce the amount of settlement by up to 18,78%. They also have approximately 2,9 times the safety factor compared to the granular soil embankment due to their rigid nature such as concrete which increased the stability of the embankment. Moreover, the PLAXIS analysis conducted using the soft soil model also produced results that are in accordance with the conditions observed in the field and this means there is a possibility of a decline in the embankment in the following years.

These previous studies showed that the stability of an embankment can be maintained using reinforcement with geotextiles. The application of the geotextile is to avoid road damage due to land subsidence, landslides, and other factors. Meanwhile, the choice of foam mortar is intended to maintain the stability of the embankment and reduce the associated load. This study compares the stability and settlement of the embankment constructed using granular materials reinforced with geotextiles and lightweight materials in the form of foam mortar.

2 METHODS

2.1 The Study Area and Soil Data

The Batang-Semarang STA 414+525 and STA 424+576 toll roads being constructed were used as the study area. The STA 414+525 has a design embankment height of 11.5 meters while STA 424+576 has 3.1 meters as indicated in Figure.1. The location has a soft soil depth of 12 meters with an N-SPT value below 10 as shown in Figure 2 while the stratigraphy of soil is presented in Figures 3 and 4 as well as Tables 1 and 2.

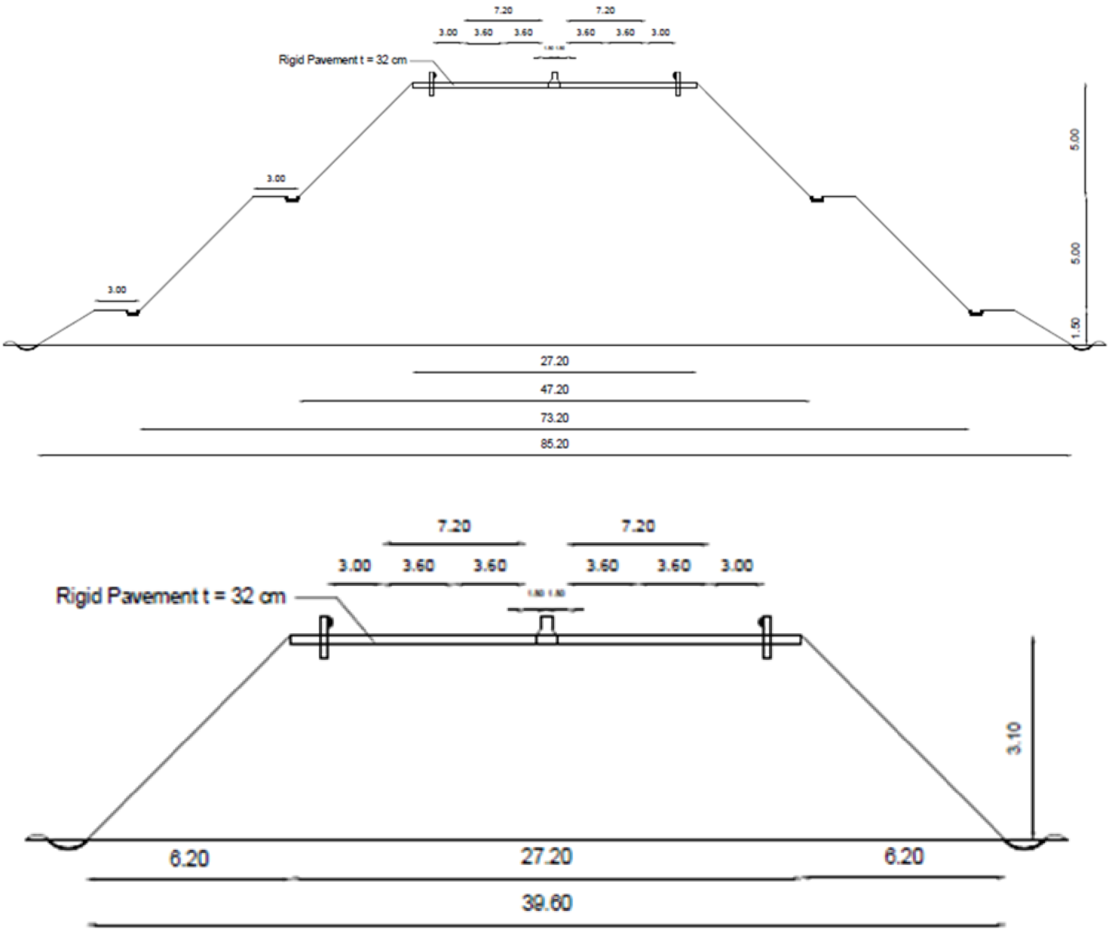

Figure 1. Cross Section of Road embankment for STA 414+525 and STA 424+576 (Source: PT Waskita Karya).

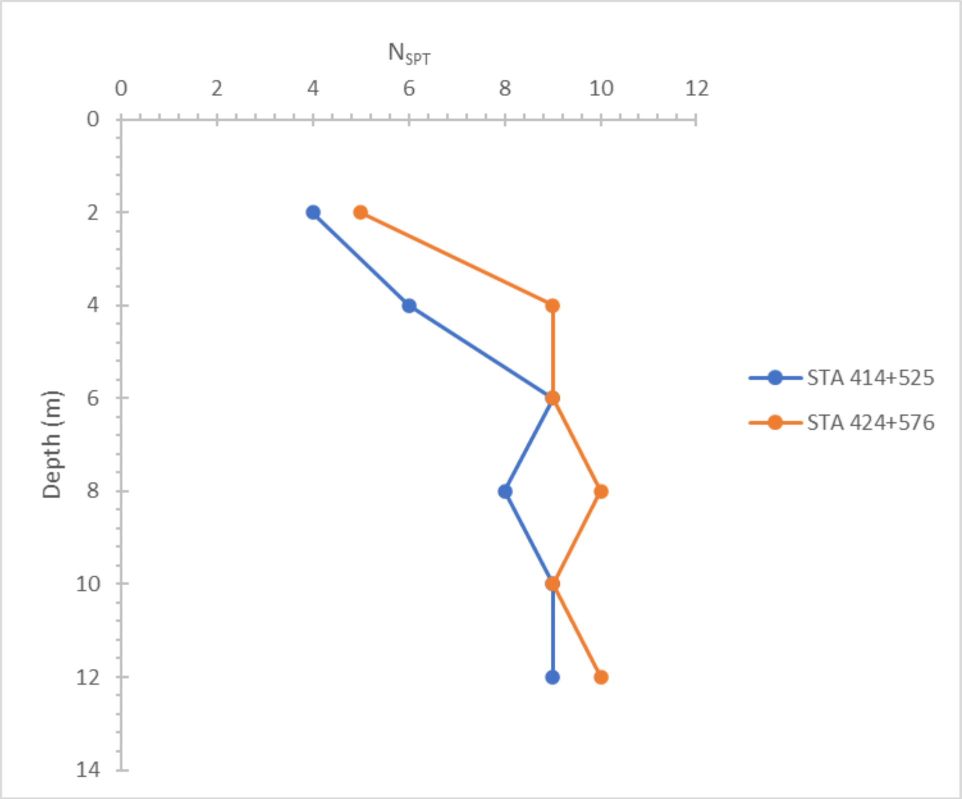

Figure 2. Combination of NSPT vs Depth (m) for STA 414+525 and STA 424+576

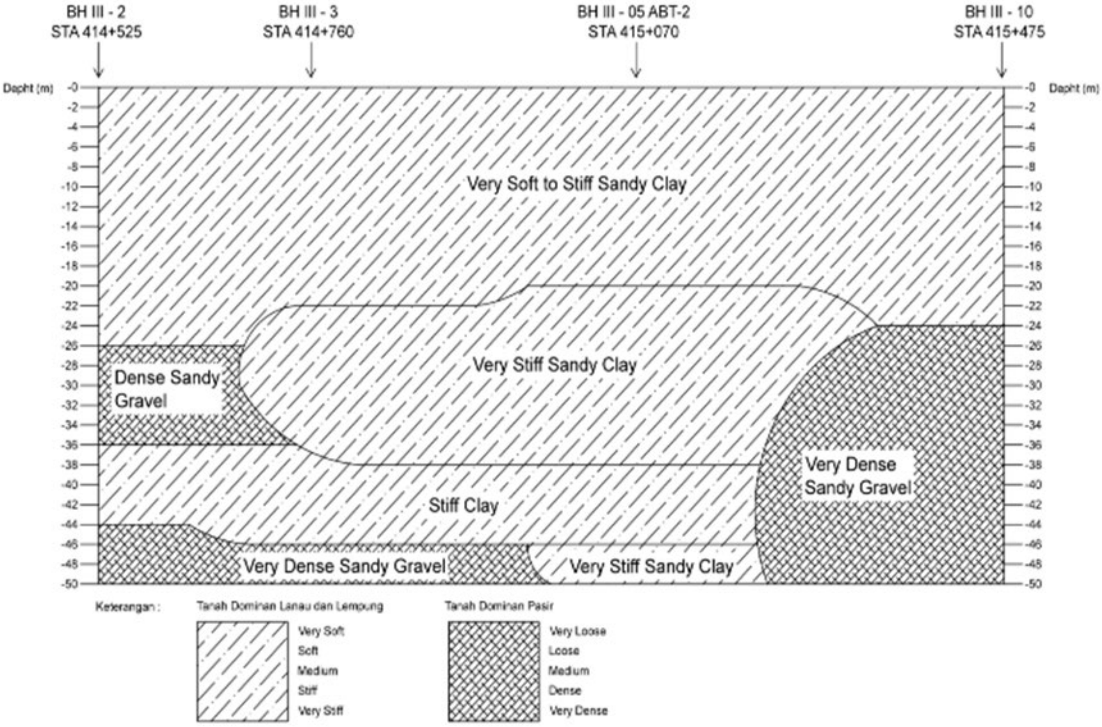

Figure 3. Sketch of Soil Stratigraphy Data for STA 414+525 – STA 415+475

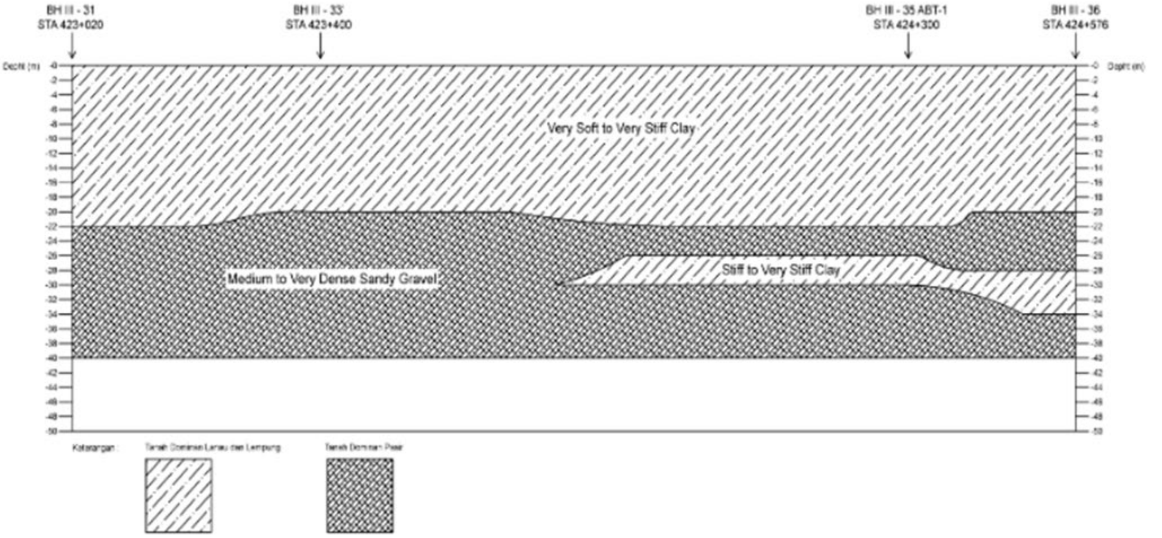

Figure 4. Sketch of Soil Stratigraphy Data for STA 423+020 - STA 424+575

The soil properties obtained from field and laboratory tests to calculate settlement and overall stability are presented in Tables 1 and 2 for STA 415+525 and STA 424+576, respectively.

Table 1. Mechanical and Physical Properties of the soil at Sta 415+525

Depth (m)	NSPT	Type of Soil	e	γdry (t/m3)	γsat (t/m3)	Cs	Cc	Cv (cm2/s)	Φ	C' (t/m2)	Cu (t/m2)	LL (%)	PI (%)	PL (%)
0 – 2	4	Soft Clay	2,38	0,8	1,5	0,127	0,633	0,0002	0	0,55	0,83	95%	55%	40%
2 – 12	8	Medium Clay	1,862	0,95	1,598	0,0956	0,4776	0,0004134	0	0,986	1,48	77%	41%	35%

Table 2. Mechanical and Physical Properties of Soil at Sta 424+576

Depth (m)	NSPT	Type of Soil	e	γdry (t/m3)	γsat (t/m3)	Cs	Cc	Cv (cm2/s)	Φ	C' (t/m2)	Cu (t/m2)	LL (%)	PI (%)	PL (%)
0 - 2	5	Soft Clay	2,27	0,83	1,52	0,12	0,6	0,000229	0	0,56	0,84	96%	55%	41%
2 - 12	9	Medium Clay	1,714	0,996	1,628	0,0866	0,4332	0,0004888	0	1,014	1,522	74%	39%	35%

2.2 Methodology

The embankment materials were divided into 4 types which include the use of the ordinary materials in the form of granular soil as well as a quarter, half, and three-quarter of the embankment height using lightweight materials. Moreover, the foam mortar was applied to the road embankments in two layers which include the base and subbase as shown in Figure 5. The effect of the variations of the embankment materials on the settlement and stability of the existing embankment was subsequently determined. Meanwhile, the embankment materials used are presented in Table 3.

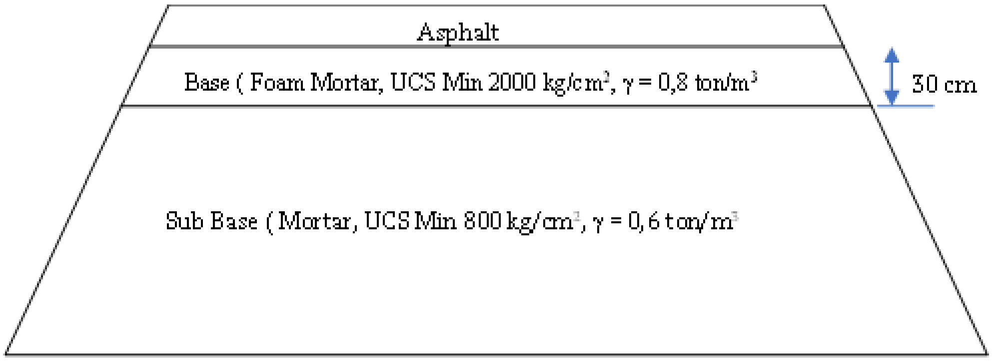

Figure 5. Layers of foam mortar on the road embankment (Source: Pusjatan Foam Corrugated-Mortar Technology (CMP))

The embankment parameters for granular soil were obtained from the test results while those for foam mortar were from the previous study by Pusjatan and presented in the following Table 3.

Table 3. Embankment Parameters

Embankment Parameter	Unit	Granular soil	Foam Mortar	
			Base	Subbase
γ	(t/m^3)	1,85	0,8	0,6
C	(t/m^2)	0	0	0
Φ	o	30	40	45

The loads used in this study include:

a. Pavement Load (Pavement)

The pavement was planned to be a flexible pavement/asphalt with a thickness of 32 cm and volume weight of 2.2 t/m3.

b. Traffic Load (qLL)

The traffic load was planned to have a volume weight of 1 t/m3.

The pavement and traffic loads were combined into a uniform load used in the embankment slope stability analysis modeling through the limit equilibrium method. The soil data parameters used to analyze the slope stability safety number in the XSTABL program are □, c, and □. Meanwhile, the XSTABL analysis using the Mohr-Coulomb soil model type and the geometric modeling embankment are indicated in Figure 6.

The embankment settlement analyzed and calculated in this study is the consolidated type which is reviewed in the middle of the embankment where the settlement is considered to be the largest.

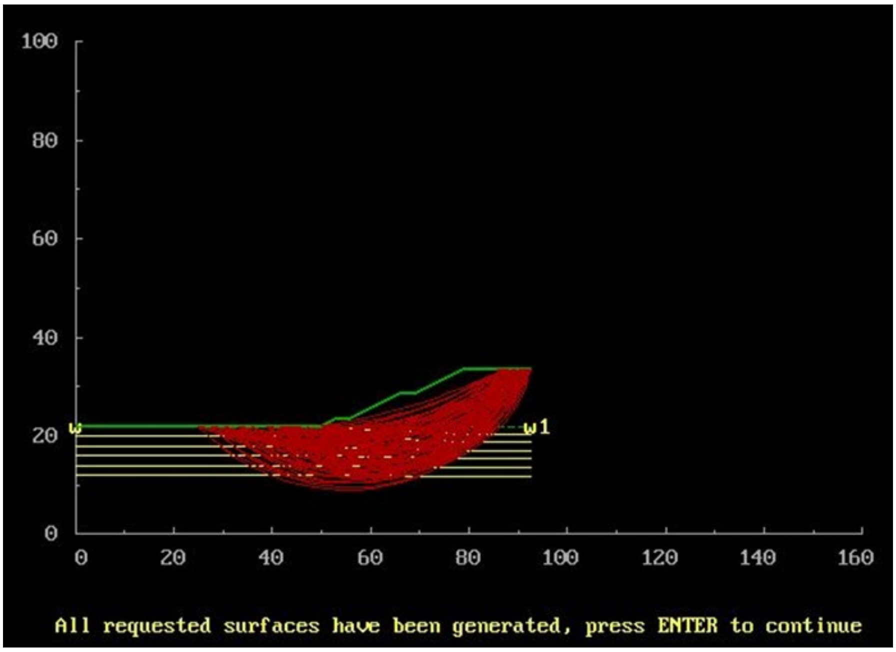

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Figure 6. Analysis of Granular Soil Landslides using the XSTABL program

The initial embankment height (Hinitial) at the time of implementation tends to be different from the final embankment height (Hfinal). It is also important to note the amount of compression occurring in the subgrade layer. Therefore, the initial and final embankment heights were determined using the following equation.

$$H_{initial} = \left(q + (S_c \times \gamma_{embankment}) + (S_c \times \gamma'_{embankment})\right) \times \gamma_{embankment} \qquad (1)$$

$$H_{final} = H_{initial} - S_c \qquad (2)$$

If $\gamma_{sat} = \gamma_{embankment}$, then

$$q = H_{initial} \times \gamma_{emabnkment} - S_c \times \gamma_w \qquad (3)$$

Then

$$H_{initial} = \frac{q \times S_c \times \gamma_w}{\gamma_{embankment}} \qquad (4)$$

Where

H_{final} = Final embankment height (m)

$H_{initial}$ = Initial embankment height (m)

Sc = Total consolidation settlement due to embankment

$\gamma'_{embankment}$ = Effective unit weight of embankment's material

3 RESULTS

3.1 Embankment Height

The thickness of the soft ground soil at STA 414+525 was found to be 12 m and was applied to design the initial embankment height in order to anticipate the settlement. Hinitial was observed to be higher than Hfinal planned as indicated in Figures 7 to 10 based on the variations of the embankment materials used.

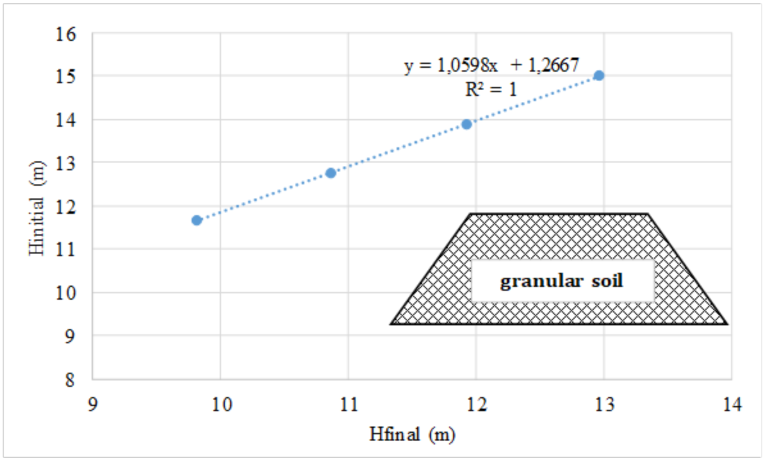

Figure 7. $H_{initial}$ (m) vs H_{final} (m) relationship for granular fill materials

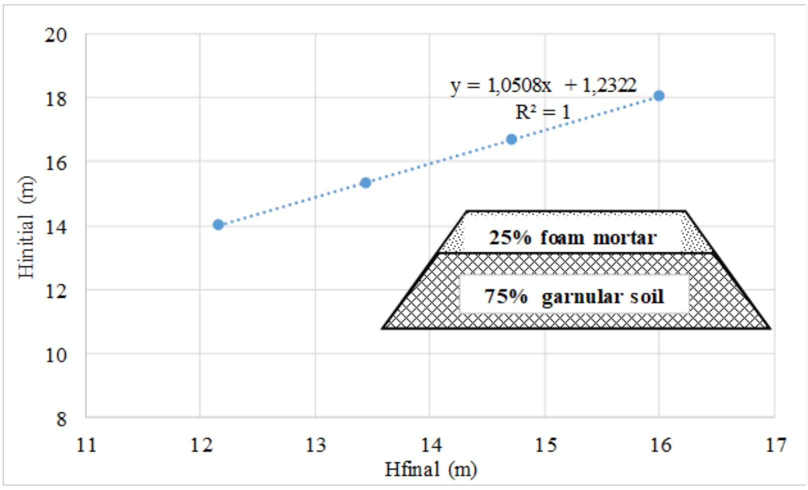

Figure 8. $H_{initial}$ (m) vs H_{final} (m) relationship for 25% foam mortar and 75% granular soil

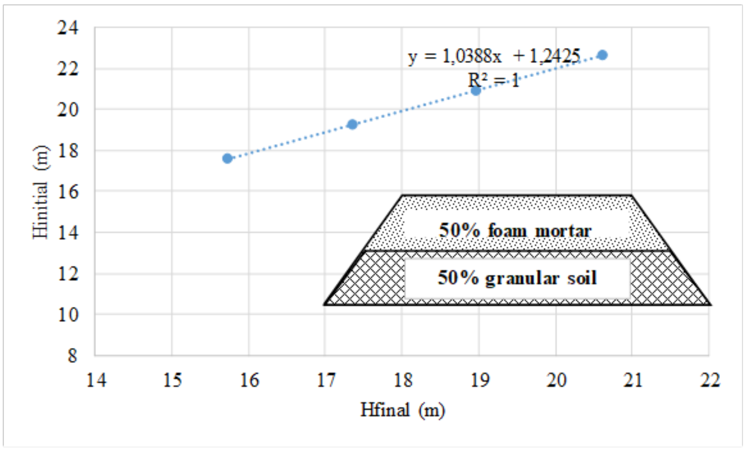

Figure 9. $H_{initial}$l (m) vs H_{final} (m) relationship for 50% foam mortar and 50% granular soil

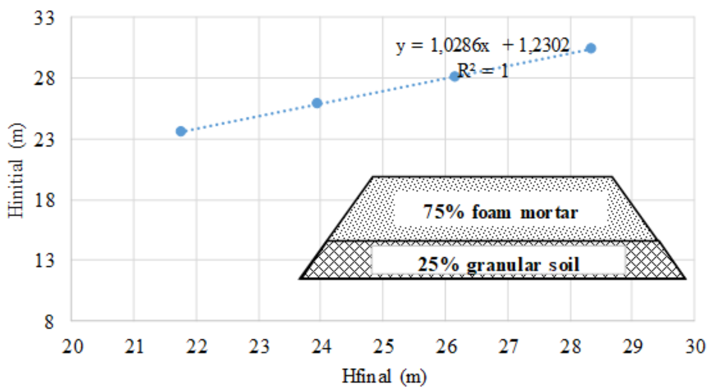

Figure 10. $H_{initial}$ (m) vs H_{final} (m) relationship for 75% foam mortar and 25% granular soil

The information from the figures showed that the embarkment with a greater percentage of granular materials required higher $H_{initial}$. Moreover, the soil compression with the foam mortar was smaller than the granular soil. A similar trend was also observed with the $H_{initial}$ such that the embankments with different variations of foam mortar were discovered to have a lower height than those with granular soils.

3.2 Settlement

The determination of the initial embankment height was followed by the analysis of the settlement based on the combination of the materials and the results are presented in Figures 11 to 14. It is important to restate that the consolidation settlement was calculated at the middle of the embankment width where the largest decrease usually occurs.

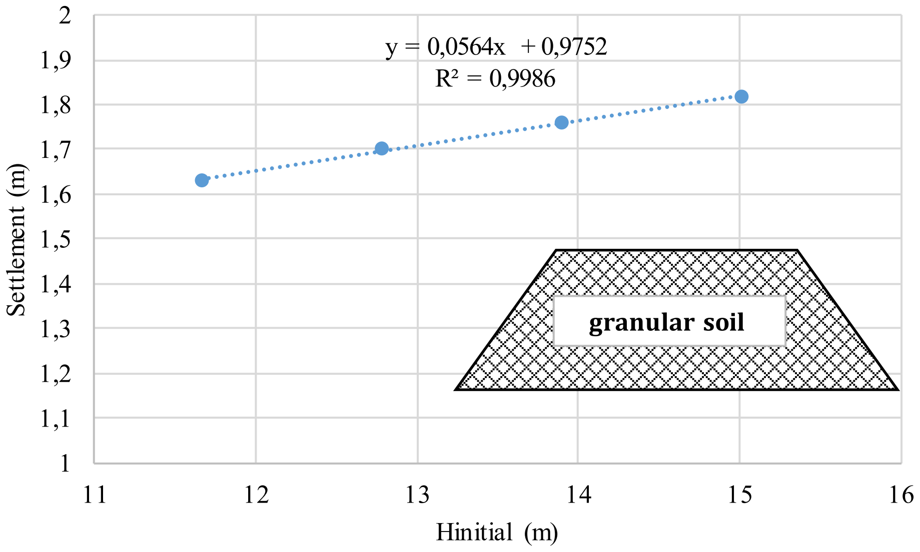

Figure 11. $H_{initial}$ (m) vs Settlement (m) relationship for granular fill materials

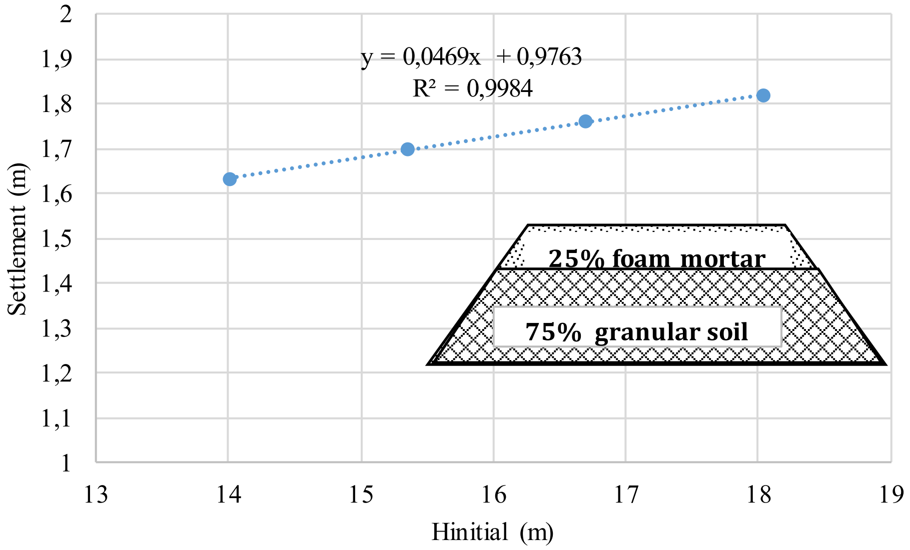

Figure 12. $H_{initial}$ (m) vs Settlement (m) relationship for 25% foam mortar and 75% granular soil

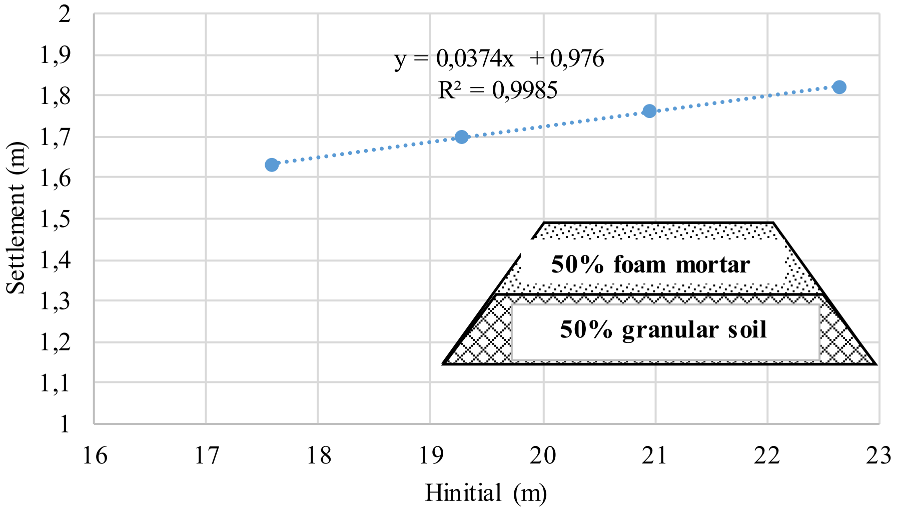

Figure 13. $H_{initial}$ (m) vs Settlement (m) relationship for 50% foam mortar and 50% granular soil

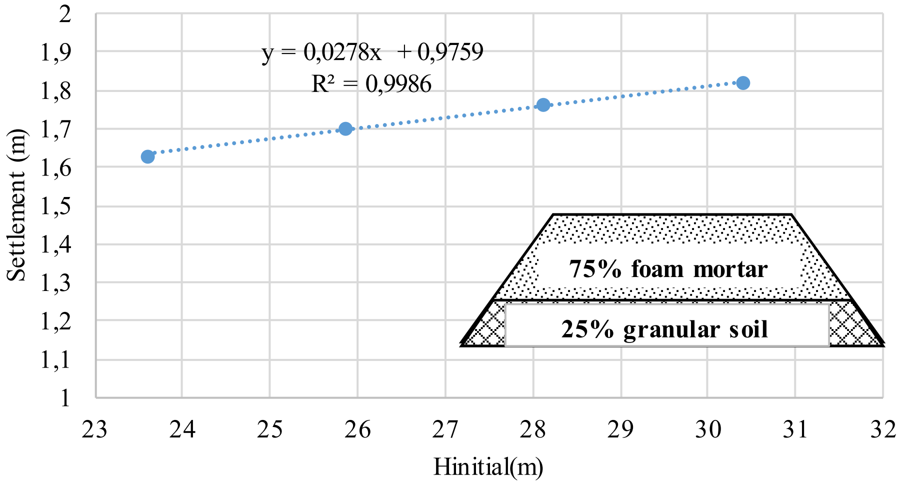

Figure 14. $H_{initial}$ (m) vs Settlement (m) relationship for 75% foam mortar and 25% granular soil

The figures show that the greater percentage of granular embankment material produced the highest settlement. The foam mortar material with a smaller volume weight produced a smaller soil compression when compared to the granular soil material. Moreover, the foam mortar material also has the property of being able to expand and condense itself to reduce the quantity required. This is presented more clearly in the results obtained from combining different variations of granular soil and foam mortar at STA 414+525 and STA 424+576 in Tables 4 and 5. It was also discovered from Table 6 when $H_{initial}$ was used as constant while the embankment materials were varied that the sample with the highest percentage of foam mortar had the smallest settlement.

Table 4. $H_{initial}$ and Settlement for different variations of embankment materials at STA 414+525

Hinitial (m)	Variation of Embankment			
	Granular Material Embankment	25% Foam Mortar 75% Granular	50% Foam Mortar 50% Granular	75% Foam Mortar 25% Granular
Hinitial Total (m)	13,46	13,32	13,14	12,96
Hinitial of Granular (m)	13,46	10	6,6	3,25
Hinisial Subbase Mortar (m)	0	3,12	6,35	9,5
Hinitial Base Mortar (m)	0	0,2	0,2	0,2
Sc (m)	1,74	1,6	1,42	1,24

Table 5. $H_{initial}$ and Settlement for different variations of embankment materials at STA 424+576

Hinitial (m)	Variation of Embankment			
	Granular Material Embankment	25% Foam Mortar	50% Foam Mortar	75% Foam Mortar

		75% Granular	50% Granular	25% Granular
Hinitial Total (m)	4,18	4,05	3,9	3,74
Hinitial of Granular (m)	4,18	3,04	1,95	0,94
Hinisial Subbase Mortar (m)	0	0,81	1,75	2,61
Hinitial Base Mortar (m)	0	0,2	0,2	0,2
Sc (m)	0,86	0,73	0,58	0,42

Table 6. Relationship between $H_{initial}$ and Settlement for different Variations of Embankment Materials

Variation of Embankment	STA 424+576		STA 424+576	
	Hinitial (m)	Sc (m)	Hinitial (m)	Sc (m)
Granular Material Embankment	13,46	1,734344	4,18	1,210952
25% Foam Mortar 75% Granular	13,46	1,607574	4,18	1,172342
50% Foam Mortar 50% Granular	13,46	1,479404	4,18	1,132332
75% Foam Mortar 25% Granular	13,46	1,350088	4,18	1,092104

3.3 Overall Stability of the Embankment

The determination of the settlement to plan the toll road on soft soil was followed by the assessment of the overall stability of the embankment. This is to ensure the embankment height satisfies the stability requirements. It also determines the possibility of introducing reinforcement in the embankment or improving the soil when the embankment height is discovered not to have met the appropriate requirement.

The findings showed that the use of more granular soil than foam mortar in the embankment reduced the safety factor. However, the safety factor was observed to be increasing as the percentage of foam mortar increased as shown in Tables 7 and 8.

Table 7. $H_{initial}$ and SF for different variations of embankment materials at Sta 414+525

Variation of Embankment	H_{final} m	SF
Granular Embankment	11,5	1,019
25% Foam Mortar 75% Granular	11,5	1,066
50% Foam Mortar 50% Granular	11,5	1,143
75% Foam Mortar 25% Granular	11,5	1,383

Table 8. $H_{initial}$ and SF for different variations of embankment materials at Sta 424+576

Variation of Embankment	H_{final} m	SF
Granular Embankment	3,1	1,783
25% Foam Mortar 75% Granular	3,1	1,924
50% Foam Mortar 50% Granular	3,1	2,292
75% Foam Mortar 25% Granular	3,1	2,782

The STA 414+525 requires a relatively high embankment height of 11.5 m and the safety factor for overall stability was observed to be below 1.5. It is recommended that geotextile be used as reinforcement or PVD be installed to speed up the completion time of the consolidation settlement. This is further expected to increase the subgrade parameters with the hope of enhancing the safety value for overall stability. Meanwhile, there is no need for any reinforcement or soil improvement in STA 424+576 because its embankment height is relatively not too high and the safety value for overall stability is more than 1.5.

4 DISCUSSION

The results of the final embankment height, settlement, and overall stability are in line with those presented in previous studies. It was discovered that the lightweight foam mortar has the ability to reduce the initial embankment height by up to 3,7% in STA 414+525 and 10,53% in STA424+576 as shown in Table 9. Furthermore, the settlement was observed to reduce to 28,74% in STA 414+525 and 51,16% in STA424+576 using lightweight materials. It was also discovered in Table 10 that the SF increased from 4,61% to 56% due to the use of lightweight materials.

Table 9. Decreasing H_{inital} and Sc for different variations of embankment materials at Sta 424+576 & Sta 424+576

Variation of Embankment	STA 414+525				STA 424+576			
	$H_{initial}$ Total	% Decrease $H_{initial}$	Sc	% Decrease Sc	$H_{initial}$ Total	% Decrease $H_{initial}$	Sc	% Decrease Sc
	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
Granular Material Embankment	13,46	0	1,74	0	4,18	0	0,86	0
25% Foam Mortar 75% Granular	13,32	1,04	1,6	8,05	4,05	3,11	0,73	15,12
50% Foam Mortar 50% Granular	13,14	2,38	1,42	18,39	3,9	6,70	0,58	32,56
75% Foam Mortar 25% Granular	12,96	3,71	1,24	28,74	3,74	10,53	0,42	51,16

Table 10. Increasing SF for different variations of embankment materials at Sta 424+576 & Sta 424+576

Variation of Embankment	STA 414+525		STA 424+576	
	SF	% Increasing SF	SF	% Increasing SF
Granular Material Embankment	1,019	0	1,783	0
25% Foam Mortar 75% Granular	1,066	4,61	1,924	7,91
50% Foam Mortar 50% Granular	1,143	12,17	2,292	28,55
75% Foam Mortar 25% Granular	1,383	35,72	2,782	56,03

5 CONCLUSION

The conclusion from the analyses conducted are stated as follows:

1. Foam mortar and granular soil can be combined as an alternative to the use of embankment material in the process of constructing roads on soft soil. A greater volume of foam mortar compared to granular soil was observed to have led to shorter initial embankment height requirement, smaller settlement occurrence, and safer stability.

2. The overall stability of the STA 41+525 is lesser than the safety factor requirements for overall stability and this means the STA requires strengthening or soil improvement. Further incestigation is required to determine the level of reinforcement or soil improvement needed using the same variations of embankment materials used in this study.

3. A softer subgrade requires a higher percentage of foam mortar compared to the granular soil in order to reduce the settlement and higher initial fill height.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

ACKNOWLEDGMENTS

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