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Effectiveness And Stability Analysis Of Embankment Using Lightweight Embankment On Pasuruan - Probolinggo Toll Road Project Section 4, Indonesia

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ABSTRACT

The Pasuruan-Probolinggo Section 4 Toll Road project which has a length of 12.04 km is dominated by silty clay - clay. In addition to soft soil, there are other problems in the construction of the Pasuruan - Probolinggo Section 4 toll road, namely the limited availability of embankment soil material around the project site and the location of the quarry which is quite far away. In addition, when relying on embankment material from the quarry, the weather factor will play a very important role when the weather is rainy then the activity in the quarry stops, the targeted embankment volume is not met and the progress of work on that day is not achieved. Therefore, there is a need for alternative reinforcement of embankments other than soil embankments from quarries that are safe and light enough. Based on the existing problems, this research will conduct a comparative study of toll road embankment design with 3 different types of materials, namely: Conventional soil embankment compared with lightweight embankment in the form of EPS-Geofoam material and foam mortar material. This research will use Plaxis 2D program. The results of this research will determine alternative embankment materials that can be applied to soft subgrade so that overall stability and hydrostatic uplift requirements can be met. This research is expected to be a reference in planning the construction and improvement of the subgrade of the Pasuruan-Probolinggo Section 4 toll road and other toll roads using EPS geofoam embankment and foam mortar

Keywords : Road asset management, *EPS Geofoam, foam mortar, Plaxis2D*

INTRODUCTION

The construction of the Pasuruan - Probolinggo Toll Road Section 4 was carried out to fulfill the smooth mobility of goods, services and people so that economic movement is smoother. This is due to the increasing volume of traffic on conventional roads that have been congested as well as the amont of damage to road infrastructure. According to (Suprayitno and Soemitro,2018), infrastructure asset management are knowledge, science or program to manage the infrastructure in order to be able to execute its function sustainably, effectively, and efficiently. Thus, a road should be constructed and managed using infrastructure asset management principles. In Indonesia, there are often existing conditions that require special handling on soft soils. Including the Pasuruan-Probolinggo Section 4 Toll Road project which has a length of 12.04 km which is dominated by clayey silt, as shown in **Figure 1.**

Figure 1. Pasuruan-Probolinggo Section 4 Toll Road
(PT. Waskita Karya, Project Office)

Some locations on the implementation of this toll road project have soft soil with depths ranging from 2 - 8 meters, so there are several problems that occur, including low soil bearing capacity and relatively large settlement. As a result, landslides can occur on the embankment slope and make the pavement above the embankment damaged due to the difference in settlement. Based on the cause and effect, it is necessary to improve the subgrade and reinforce the embankment of the road body. In addition to soft soil, there are other problems in the construction of the Pasuruan - Probolinggo Section 4 toll road, namely the limited availability of embankment soil material around the project site and the quarry location is quite far away.

This will result in the effectiveness of the work and implementation time. In addition, when relying on embankment material from the quarry, the weather factor will play a very important role, when the weather rains then the activity in the quarry stops, the targeted volume of embankment is not met and the progress of work on that day is not achieved. Furthermore, the quality factor of the embankment, when it rains, the quality of the embankment will be poor, the excess water content in the soil will certainly affect the shear strength of the soil and it takes time to be treated to return to the required quality. The condition and cross section of this road can be seen in **Figure 2.**

Figure 2. Condition of Pasuruan-Probolinggo Section 4 Toll Road
(PT. Waskita Karya, Project Office)

(Gunawan, 2020) conducted research which showed that using EPS (Expended Polystyrane) Geofoam significantly reduced the need for landfill. This can reduce the use of heavy equipment for digging and transporting land, saving time and construction costs. This means that EPS-Geofoam is a more environmentally friendly solution compared to landfill in general. Although construction costs using EPS-Geofoam may still be higher than conventional embankments, the significant reduction in construction time makes geofoam more effective. Apart from EPS-Geofoam, another lightweight fill material is Foam Mortar, Winurseto (2018) in his research used foam mortar on the dermoleng fly over project, Foam mortar has a light weight and high enough strength for subgrades and road pavement foundations, the bulk weight and compressive strength of the mixed soil can be planned as desired so that it can reduce the lateral pressure of the soil on a building structure, abutment, bridge foundation or reduce the weight of embankment. Research results (Shinde 2019) show that the reduction value after analysis using Plaxis 2D was found to be 180.32 mm for murum and for EPS Geofoam it was 22.52 mm. Although the basic cost of EPS Geofoam is high, taking into account other factors such as transportation costs, there is no The cost of compaction required, machinery, and material availability, make EPS Geofoam feasible and economical for long term considerations. Research results (Hidayat & Suhendra, 2011) based on calculation results using the Plaxis 2D program show that the use of geofoam as filling material for embankments provides several advantages compared to embankments using laterite soil, namely: Higher safety factor Geofoam, SF = 1,77 Laterite soil , SF = 1,10. The results of research (Atamini & Moestofa, 2018) show that the gradual comparison of the settlement that occurs between red laterite red soil piles and foam mortar light embankments, the use of foam mortar light embankments on soft soil will result in smaller settlements (<74.40%) compared to the laterite red soil option, because the foam mortar embankment can reduce the amount of settlement that occurs due to the light weight of the material.

Based on the existing problems, research is needed to determine the comparison of highway embankment design with 3 different types of materials: Conventional soil embankment compared with lightweight embankment in the form of EPS-Geofoam material and foam mortar material. Numerical modeling will be carried out in this study with the Plaxis 2D auxiliary program which is able to analyze close to the actual behavior related to Overall stability and Hydrostatic Uplift. The results of this research will determine alternative embankment materials that can be applied to soft subgrade so that overall stability and internal stability requirements can be met.

LITERATUR REVIEW

Overall Stability

For Overall Stability, the Retaining Moment (MR) and Driving Moment (MD) generated by ground movement are considered. After that, we can calculate the SF to be planned as a factor of safety for embankment stability. We first determine the minimum SF available on the embankment. The safety factor sought is a number with the height of the embankment when it reaches the critical height (Hcr), SF, Retaining Moment, and radius of collapse can be found with the Plaxis 2D tool (Adi, 2018) Then the calculation of the Driving Moment (MD) can be found through the following equation, namely

$$MD = \frac{M_R}{Sf} \quad ...(1)$$

Where :

MD = Driving Moment
MR = Resistance Moment
SF = Safety Factor

Hydrostatic Uplift (Flotation)

EPS Geofoam has a low density. The low density has the potential for lift or lift force on the embankment. Therefore, it is necessary to check the lifting force if there is flooding on both or one side of the embankment. (Arellano & Stark, 2004) as shown in **Figure 3**

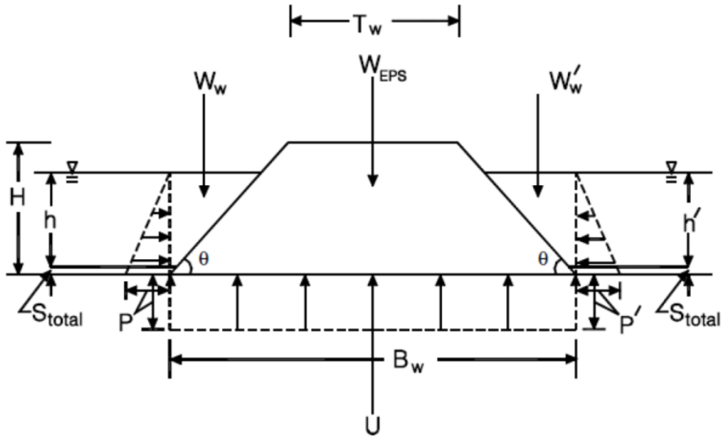

Figure 3. Hydrostatic Uplift Due to Both Sides of the Embankment Flooding (Arellano & Stark, 2004)

The safety factor value of the lifting force the equation are shown as follows :

$$FS= \frac{\Sigma N}{\Sigma U} \qquad ...(2)$$

$$\Sigma N= W_{EPS} + W_W + W'_W + Q_{REQ} \qquad ...(3)$$

$$\Sigma U= \gamma_W \times B_W \times (h + S_{total}) \qquad ...(4)$$

Where :

Σ N	= summation of normal forces = W_{EPS} + W_W +O_{REQ}
∑ U	= summation of uplift forces, U, at base of embankment
Weps	= weight of EPS-block geofoam embankment EPS
W_W	= vertical component of weight of water on the embankment
W_W ′	= vertical component of weight of water on the face of the embankment on
γ_W	= unit weight of water,
Stotal	= total settlement as defined by Equation
B_W	= bottom embankment width

Safety Factor Criteria

The slope safety factors required for soil slope stability analysis are shown in **Table 1** based on SNI 8460:2017 on Geotechnical design requirements.

Table 1. Safey Factor Criteria

No	Parameter Analisis	Safety Factor	Literature Sources
1	Overall Stability	1,5	SNI 8460:2017 Geotechnical design requirements Page 179
2	Hydrostatic Uplift	1,5	SNI 8460:2017 Geotechnical design requirements Page 179

DATA COLLECTION

Soil Data

The soil data used in this study are secondary data of embankment soil properties tests from quarries and borlogs at the construction site of the Pasuruan - Probolinggo Toll Road Section 4. The available borlog data are the results of soil investigation work covering several locations as follows:

1. Borelog data and SPT values taken at Zone 1, STA 0+600
2. Borelog data and SPT values taken at Zone 2, STA 37 + 925

In this research, several variations of soft soil depth, embankment slope and embankment height are analyzed but using three different types of quarry fill material, lightweight embankment material (EPS-Geofoam and Foam Mortar) as an alternative to the soil embankment carried out at the research site. In addition, this research will analyze the resource requirements of the equipment used. The locations reviewed in this research include: Zone 1, STA 0+600 and Zone 2, STA 37+925.

1. Depth of soft soil 2m, 4m, 6m and 8m
2. Embankment slope 1:1.5, 1:2 and upright embankment.
3. Embankment heights of 4m, 6m, 8m and 10m

Table 2. Zone 1 Subgrade Data Parameter

Parameter	STA 0+600			
	Layer 1	Layer 2	Layer 3	Layer 4
Jenis Tanah	Clayey silt	Clayey silt	Sandy Silt	Sandy rock
Material Model	Soft Soil	Soft Soil	Mohr Colloumb	Mohr Colloumb
N-SPT	2	4	35	29
γt(kN/m3)	16	15,3	17,2	17,2
γsat(kN/m3)	17	16,3	18,2	18,2
e	1,35	1,27	1,21	1,39
Cc	0,339	0,049	-	-
Cs	0,439	0,054	-	-
λ*	0,073820537	0,084083509	-	-
k*	0,01813136	0,020685692	-	-
C’ (kN/m2)	35,50	73,29	43,35	2,75
E (kN/m2)	10477,75	19292,96	271222,26	204574,60
ϕ (^{0})	20,00	20,00	35	47,00
ψ (^{0})	13,33	13,33	23,33	31,33
Kx. Ky (m/day)	0,00864	0,00864	0,00864	8,64
LL	55,04	66,63	53,89	-
PL	30,2	39,65	37,12	-
IP	24,84	26,95	16,76	-
(υ)	0,30	0,20	0,10	0,15

Table 3a. Zone 2 Subgrade Data Parameter

Parameter	STA 37+925			
	Layer 1	Layer 2	Layer 3	Layer 4
Jenis Tanah	Clayey silt	Clayey silt	Clayey silt	Silty rock
Material Model	Soft Soil	Soft Soil	Mohr Colloumb	Mohr Colloumb
N-SPT	3	8	50	52
γt(kN/m3)	19,84	17,88	15,93	17,25

Table 3b. Zone 2 Subgrade Data Parameter

Parameter	STA 37+925			
	Layer 1	Layer 2	Layer 3	Layer 4
γsat(kN/m3)	20,2	18,4	16,53	17,47
e	0,715	1,11	1,426	1,373
Cc	0,515	0,224393	-	-
Cs	0,0486445	0,039382	-	-
λ*	0,130561541	0,046237997	-	-
k*	0,02466447	0,016229961	-	-
C' (kN/m2)	25,82	17,26	20,00	20,80
E (kN/m2)	15002,13	36486,14	411676,65	378640,78
ϕ (^{0})	20,00	20,00	47,00	47,00
ψ (^{0})	13,33	13,33	31,33	31,33
Kx. Ky (m/day)	0,00864	0,00864	0,00864	8,64
LL	44,21	45,77	32,37	33,3
PL	31,25	31,19	23,85	22,31
IP	12,96	14,58	8,52	10,99
(υ)	0,30	0,20	0,10	0,10

Table 4. Embankment Material Specifications

Material	γ (kN/m3)	ν' (poisson)	C (kN/m2)	φ (^{0})	ψ (^{0})
Timbunan Quarry	19,8	0,15	5	35	23
EPS Geofoam	18,4	0,1	35	30	0
Mortar Busa Sub Base	6	0,2	60	45	0,2
Mortar Busa Base	8	0,2	60	40	0,2

Table 5. Nilai Parameter *Geotextile*

Material Perkuatan	Tensile Strenght (KN/m)	Strain (%)	E (kN/m)
Geotextile	148	19	2812

RESEARCH ANALYSIS

The analysis in this study uses two ways, namely manual analysis and analysis using modeling in Plaxis 2D software. Plaxis 2D software is used to analyze Safety Factor (SF) Overall stability and manual analysis Hydrostatic Uplift.

Safety Factor (SF) Overall stability

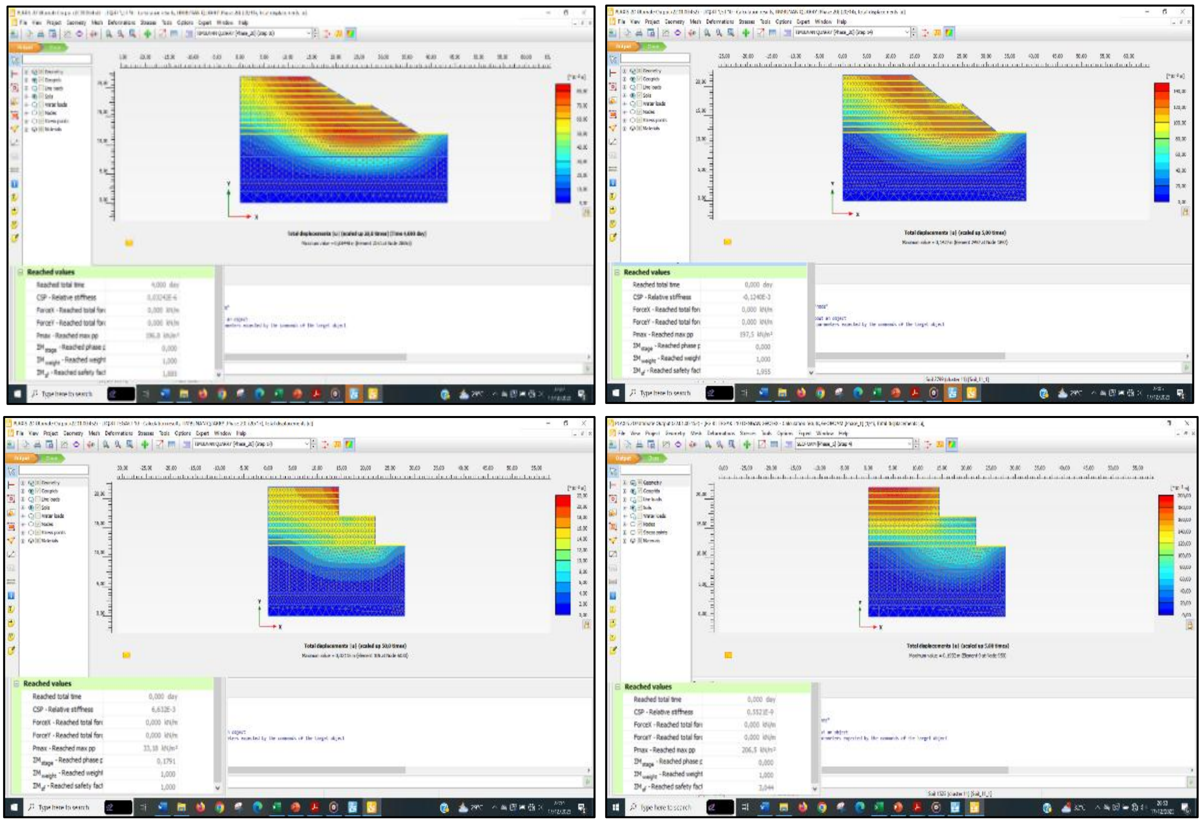

Figure 4. Modeling using Facing, Plaxis 2D

Table 6. Overall Stability Safety Factor (SF) Parameters

Variations in Embankment Material and Embankment Slope	Zone 1 STA 0+600		Zone 2 STA 37+925	
	Without Facing	With Facing	Without Facing	With Facing
Quarry Land 1:2	0,98	2,29	1,40	2,27
Quarry Land 1:1,5	1,30	2,35	0,34	1,95
Upright Quarry Land	0,16	0,42	0,05	0,18
Geofoam EPS 1:2	2,89	3,44	3,59	8,69
Geofoam EPS 1:1,5	2,73	3,22	3,07	7,92
Upright Geofoam EPS	1,44	3,02	1,43	3,04
Foam Mortar 1:2	12,34	11,95	25,16	26,19
Foam Mortar 1:1,5	11,68	11,32	18,16	19,01
Upright Foam Mortar	11,01	10,98	17,60	17,40

Based on **Table 6** related to the slope of the embankment, it can be seen that the steeper the slope, the Safety Factor (SF) for the Overall Stability parameter will experience an average decrease of 87%. In variations in vertical slope with quarry embankments, the safety factor value is below ≤ 1.5 so that experienced collapse. If you want to continue using this material, it is recommended to add reinforcement to the retaining walls. Furthermore, regarding the use of facing in general, the use of facing can increase the Safety Factor (SF) value by 35%. In general, related to the stability of the use of lightweight embankment materials, it can be seen that the Safety Factor (SF) value of Geofoam EPS is 54% greater than that of Quarry Soil, then Foam Mortar has a Safety Factor (SF) 69% greater than Geofoam EPS.

Hydrostatic Uplift

Table 7. Hydrostatic Uplift

Symbol	Formula	Value	Unit
γ embankment	Specific gravity of embankment soil	19,8	kN/m3
A	Embankment area	147,6	m2
Wtimb	Embankment Weight (γ timbunan x A)	2922,48	kN/m2
Ww	Vertical Component Left Water Weight (0,5 x (h+Stot)) x(h+Stot) x γ w)	55,960	kN/m
W'w	Vertical Component Right Water Weight (0,5 x (h+Stot)) x(h+Stot) x γ w)	55,960	kN/m
Σ Resistance	Total resistance force ($WEPS + WW + W'W$) (Equation 3)	3034,401	kN/m
Symbol	**Formula**	**Value**	**Unit**
h	Water level	3	m
γ w	Weight of water volume	9,81	kN/m3
Bw	Bottom width of embankment	44,9	m
Stotal	Total Settlement	0,378	m
Σ Workingload	Total Workingload ($\gamma W \times B$w $\times$ ($h + Stotal$)) (Equation 4)	1487,77	kN/m
SF	**Σ Resistance / Σ Workingload (Equation 2)**	2,04	

Furthermore, the analysis is carried out for the three types of materials used Quarry Soil, EPS Geofoam and Foam Mortar. Then the resume of the results of the comparison of the three materials with a slope variation of 1: 2 assuming the smallest Safety Factor value obtained is as follows can be seen in **Table 8** and **Table 9.**

Table 8. Hydrostatic Uplift Zona 1

Variations in Embankment Material and Embankment Slope	**Zone 1 STA 0+600**			
	H = 4m	**H = 6m**	**H = 8m**	**H = 10m**
Quarry Land 1:2	1,87	2,58	3,25	3,79
Quarry Land 1:1,5	1,95	2,71	3,42	3,96
Upright Quarry Land	2,36	3,05	3,81	4,59
Geofoam EPS 1:2	1,74	2,41	3,03	3,54
Geofoam EPS 1:1,5	1,82	2,53	3,19	3,70
Upright Geofoam EPS	2,19	2,84	3,55	4,28
Foam Mortar 1:2	0,76	1,03	1,28	1,49
Foam Mortar 1:1,5	0,80	1,08	1,35	1,56
Upright Foam Mortar	0,98	1,23	1,51	1,81

Table 9. Hydrostatic Uplift Zona 2

Variations in Embankment Material and Embankment Slope	**Zone 2 STA 37+925**			
	H = 4m	**H = 6m**	**H = 8m**	**H = 10m**
Quarry Land 1:2	2,04	2,84	3,58	4,19
Quarry Land 1:1,5	2,12	2,97	3,76	4,37
Upright Quarry Land	2,51	3,25	4,16	5,03
Geofoam EPS 1:2	1,90	2,64	3,34	3,90
Geofoam EPS 1:1,5	1,98	2,77	3,51	4,08
Upright Geofoam EPS	2,33	3,03	3,88	4,69
Foam Mortar 1:2	0,80	1,09	1,37	1,59
Foam Mortar 1:1,5	0,84	1,15	1,44	1,66
Upright Foam Mortar	1,00	1,26	1,60	1,92

Based on **Tables 8 and 9**, it can be seen that the more gentle the slope, the Safety Factor will experience an average decrease of 16%, this is likely to occur because the area of the embankment that is in direct contact with the soft soil of the 1:2 slope embankment is wider than the 1:1.5 embankment and upright embankment. Making the divider factor on the driving force is greater so that the Safety Factor is smaller than other embankment slopes. As for the height of the embankment, the higher the embankment, the Safety Factor increases by about 50%, this is likely due to the additional weight of the embankment in the variation of embankment material used with the three different types of embankment material. Based on Tables 8 and 9 it can be seen that Quarry Soil has the highest Safety Factor followed by EPS Geofoam and Foam Mortar. Foam Mortar has the smallest Safety Factor compared to Quarry Soil and EPS Gofoam, this is likely due to the specific gravity of the Foam Mortar material being lighter than the other materials. If you still want to use Foam Mortar, it is recommended to use more height to increase the weight of the embankment itself so that it reaches the required Safety Factor or by adding reinforcement structures to the embankment.

CONCLUSIONS

Based on the result of modeling analysis, it can be concluded that:

1. The stability of the existing embankment on the Pasuruan - Probolinggo Toll Road Project Section 4 with a gemoetric soft soil depth of 8m, a slope of 1:1.5 and an embankment height of 10m has a Safety Factor Overall Stability of $2.35 \geq 1.5$ and a Safety Factor Hydrostatic Uplift of $3.96 \geq 1.5$.
2. The most effective and stable type of facing for handling high embankment using lightweight embankment (EPS-Geofoam and Foam Mortar) is geotextile reinforcement. With an average increase in Safety Factor (SF) Overall Stability of 35%.
3. The most effective and stable use of lightweight backfill material is EPS Geofoam material.

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