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GEOFOAM MATERIALS UTILIZATION FOR BRIDGE ABUTMENT EMBANKMENT OF THE TRANS SUMATRA TOLL ROAD: A CASE STUDY

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ABSTRACT. In the archipelago of 17,508 islands, the road network system is a fundamental need to connect people and stimulate industrial growth in Indonesia. Geofoam technology has been used as a substitute for landfills in several areas that require high stability and carrying capacity to improve the quality and safety of toll roads. Geofoam has several advantages that make it very effective in constructing toll roads. The paper examines Geofoam's performance as a replacement fill material for approach bridge construction for the case location Trans Sumatra Toll Road Project Simpang Indralaya – Prabumulih Zone 6 STA 59 + 425. In addition, this study provides a case study and a brief overview of geofoam materials. Several implementation techniques are demonstrated, and some field-related challenges and solutions are discussed. FEM analysis through Plaxis was utilized to yield SF value and displacement output. The analysis results show that the safe number (SF) owned by the geofoam embankment produces a value above 2 for longitudinal and transverse cuts, which meets the safety requirement; the SF value offers 2.602 and 2.059 for cross-section analysis, while 2.955 and 3.306 for long section analysis. These results have the potential contribution of geofoam to sustainability projects, although the engineer should be able to cover the unexpected matters during the construction process.

Keywords: Abutment, Case study, Geofoam, Safety factor.

1. INTRODUCTION

In the archipelago of 17,508 islands, the road construction system is a fundamental demand to connect people and businesses with jobs, services, and markets, reduce logistics costs, and stimulate industrial growth in Indonesia. In response to these needs, the Government has placed high connectivity as one of the top priorities. In addition, according to Indonesia Presidential Regulation No. 100 of 2014, later amended by Presidential Regulation No. 131 of 2022, the Government mandated Hutama Karya to build and develop the Trans-Sumatra Toll Road. This toll road will connect Lampung and Aceh through 24 different road sections with a total length of 2,840 km, and phase will be fully operational in 2024. The Indralaya - Muara Enim Junction section of the Indralaya - Prabumulih Junction is part of the Trans-Sumatra toll road network, which is planned to connect Ogan Ilir Regency, Muara Enim Regency, and Prabumulih City.

Geofoam technology has been used as a substitute for landfills in several areas that require high stability and carrying capacity to improve the quality and safety of toll roads. Geofoam, made from recycled materials and has a long service life, can reduce structural loads, speed up the construction process, and help reduce negative impacts on the environment, such as soil erosion and changes in water flow. Using geofoam, construction projects become more environmentally friendly and contribute to sustainability efforts. Moreover, Geofoam has several advantages that make it very effective in constructing toll roads. Some of these advantages include lightweight, durable load, reduced use of other more expensive construction materials, speed up the construction process because it does not take a long time to install and is not delayed by weather conditions, has enough compressive strength to withstand the weight of the vehicle and high stability, so it can be used in large construction projects such as toll road construction [1].

Incorporating Geofoam Expanded Polystyrene (EPS) represents a significant advancement in engineering applications for building contemporary infrastructure [2]. One kind of expanded polystyrene (EPS) produced from polystyrene, a crude oil by productFge, is called geofoam. It is made of polystyrene beads that have already been expanded and are expanded with an expanding agent [3]. Expanded polystyrene (EPS) and extruded polystyrene (XPS) are the raw materials used to make geofoam, which is increasingly used in various geotechnical engineering applications because it is highly compressive and tolerant of harsh environments [4]. Expanded Polystyrene (EPS) Geofoam has been a successful construction material in geotechnical engineering for forty years. Its many uses include compressible inclusion in retaining walls and lightweight fill material in embankments [5].

Using geofoam as a filler for embankments over soft soils requires less construction time than conventional ground improvement methods like sand drains and stone columns and is also used for rockfall prevention[6, 7].

Stakeholders can expedite adopting and optimizing EPS Geofoam solutions by utilizing new technologies, fostering industry-academic relationships, and utilizing multidisciplinary methods. This may prompt the investigation of fresh directions in creating sustainable infrastructure. This can improve construction efficiency, reduce costs, and speed up project completion time. However, the detailed analysis of EPS Geofoam must be conducted in a particular location, especially the main project for Indonesia's strategic project. In certain zone sections of Trans Sumatra Toll Road Simpang Indralaya – Prabumulih Zona 6 STA 59+425, the embankment fill utilizes the EPS Geofoam. Further examination of the safety factor of embankment, obstacles, and challenges must be assessed to minimize the harmful damage.

This research aims to examine the performance of Geofoam as a replacement fill material for embankment for toll road construction. This paper provides a case study and a brief overview of geofoam materials in Indonesia's strategic project. In case studies, the location of the geofoam installation is displayed first. Several implementation techniques are demonstrated, and some field-related challenges and solutions are discussed. Furthermore, this study is also expected to provide essential information on a similar project that takes advantage of EPS geofoam as fill material.

2. RESEARCH SIGNIFICANCE

The investigation of geofoam performance under a particular load with FEM simulation, as well as the benefits and drawbacks of the construction process, will be the basic valuable information for construction projects in Indonesia. The result of embankment stability, the obstacles, and the field problems in case studies offer new challenges in similar projects. In addition, the advantages of this method will be as essential knowledge for prospect design in embankment Toll Roads. The findings of this investigation provide significant details about the applicability of the EPS Geofoam technology and help define its development strategy.

3. LITERATURE REVIEW

3.1 The Role of Abutment in Toll Road Construction

Earth-retaining structures called abutments are made to allow free passage for vehicles to and from the bridge. Additionally, bridge abutments are cost-effective in withstanding inertial loads created during ground excitations [8]. Abutments have an important role in the construction of toll roads because they function as a bridge understructure that bears all the loads that work on the bridge's upper building and passes the load to the foundation. The abutment is a soil holder for approach piles and ensures soil stability.

3.2 Development of the Utilization of Geofoam in Construction

EPS Geofoam was used in a backfill bridge project in Oslo, Norway, in 1972 to lessen settlement. The effective application of EPS Geofoam marks the start of dissemination at conferences addressing research and project outcomes [9]. Since then, EPS Geofoam has been used extensively in civil construction projects due to its lightweight nature and relatively high strength. Some recent research on EPS Geofoam applications: slope stabilization [10, 11], sub-base fill material [12, 13], embankments [14] [15, 16], earth retaining structures [17-19], bridges approaches and abutments [20], buried pipes [21] [22], seismic buffers [23, 24], dynamic and cyclic buffer [25-[27].

In a variety of civil engineering applications, EPS-geofoam has the following benefits [28]: (1) incredibly lightweight, minimizes lateral or bearing loads; (2) predictable engineered performance; (3) adaptability to different weather conditions; (4) maximizes installation efficiency; (5) available in different densities to meet strength requirements; and (5) offers cost-effective measures. The application and design of EPS geofoam require careful consideration of several factors. These include UV protection, solvent and fire risk, environmental hazard, insulation, permafrost regions, and fixing while placing [29].

4. METHODS

4.1 Description of the Location of the Project and Geological Conditions

The location of the Simpang Indralaya – Muara Enim Toll Road is in South Sumatra Province Sta. 0+000 to Sta. 64+500, administratively passing through 2 districts and 1 city, namely Ogan Ilir Regency, Muara Enim Regency and Prabumulih City has been presented in Fig. 1. The section IV.1 has begun from Muara Enim to Indralaya area, all the location is in South sumatra province, Indonesia

Regarding the geological aspect, Ogan Ilir Regency consists of five geological formations, namely the Alluvial Formation, the lower member Palembang Formation, the middle member Palembang Formation, the upper member Palembang Formation, and the Tugu Mulyo Young volcanic material Formation. This district does not encounter complex geological structures such as faults, folds, and soil instability. Based on these geological conditions, it can be stated that the entire Ogan Ilir area is safe from the possibility of landslides or geological activities, especially earthquakes.

In terms of soil subgrade, the parameters are dominated by clay materials analyzed by Unified soil classification system, with the maximum percentage of clay around 50-75% in each borehole. The SPT location is separated into 2 locations. The details of soil subgrades have presented in Table 1.

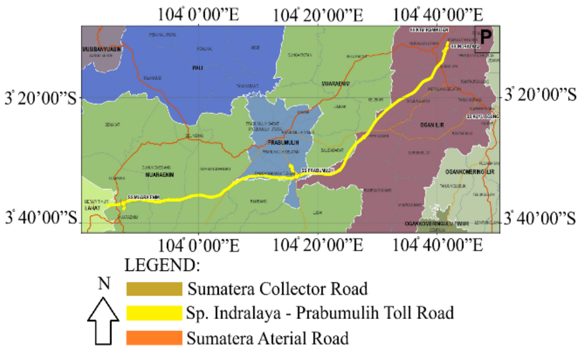

Fig.1 Project location of the Toll Road Project Site

Table 1. Results of soil investigation

Boreholes	BH 118			BH 119		
Depth (m)	1.5	3.5	7.5	3.5	7.5	11.5
γ (kN/m^3)	18.2	17.8	19.3	17.9	18.3	19.2
c (kg/m^2)	0.44			0.45		
ϕ (^{0})	9.73			9.89		
Gs	2.32	2.35	2.40	2.36	2.45	2.39
Soil Classification	Clay	Clay	Clay	Clay	Clay	Clay

4.2 Considerations for Geofoam as Abutment Materials

The selection of geofoam for abutment in the Trans-Sumatra toll road project is based on the following reasons. Because of its low weight and high compressive resistance for supporting loads, EPS-geofoam is an appropriate substitute material for conventional earthen materials to protect against overloading to underlying soils and adjacent structures. Because EPS-geofoam is simple to handle and doesn't require special equipment, using it in construction saves time. Because EPS-geofoam is an engineered product and arrives on site having undergone rigorous quality control (QC) testing, its use does not require time-consuming QC testing. EPS-geofoam is produced in blocks that can be cut into various sizes, shapes, and compressive resistances to meet specific needs [30]. The technical specifications of the geofoam refer to [31], as shown in Table 2.

Preliminary assessment for analyzing of the loading calculation for the selection of geofoam type have described as compressive force from the external load, the detail is shown as follow:

Pavement load = 0,55 m x 2,2 t/m3 = 1,21 t/m^2
Soil load on geofoam = 1 m x 1,6 t/m^2
Class 1 Road for Vehicle Load 1 = 1,5 t/m^2

The total load received by the geofoam is 4.31 t/m^2. To minimize deformation, the elongation of the geofoam is limited to 1%, so the appropriate type is Geofoam EPS 22, which has a compressive strength of 50 kPa (5 t/m^2).

Table 2. General Specifications of Geofoam

Type	**EPS 12**	**EPS 15**	**EPS 19**	**EPS 22**	**EPS 29**	**EPS 39**	**EPS 46**
Density, min. kg/m3	11.2	14.4	18.4	21.6	28.8	38.4	45.7
Compressive resistance at 1% strain, min., kPa	15	25	40	50	75	103	128
Compressive resistance at 5% strain min., kPa	35	55	90	115	170	241	300
Compressive resistance at 10% strain min., kPa	40	70	110	135	200	276	345

The initial load calculation is applied in Finite Element Model through Plaxis software to define the safety factor as well as the possibility of displacement of the model.

The finite element model through Plaxis has been modeled with the embankment geometry in cross and long sections. The 10m width of the top embankment with 2-step traps in counterweight was modeled. The external load was applied in the center of the embankment. In the long-section model, the external load was applied at the top of the substructure (abutment). The Mohr-Coulomb with Linear-Elastic Perfectly-Plastic model is the constitutive material used in this analysis. The output is the safety factor and displacement for geofoam as a replacement material for embankment.

All geofoams specification has been provided in Table 2. The range of specifications has been created and filled into the Plaxis model to generate the minimum SF and maximum displacement as the conservative construction design.

5. RESULT AND DISCUSSION

5.1 EPS Embankment Desain

The use of Geofoam in the Trans Sumatra Toll Road Simpang Indralaya – Prabumulih Zone 6 STA 59 + 425 project also helps solve problems that are often caused by groundwater because geofoam is not affected by moisture. Prabumulih City has alluvial, clay, and sandy soil in a young layer containing a lot of petroleum, known as the Prabumulih-Jambi – Jambi valley. The land is relatively flat and low, and the places are rather high in the northern part of the city. Some of the cities of Prabumulih are flooded, especially if it rains continuously. Figure 2 shows geofoam technology on the Trans Sumatra Toll Road Simpang Indralaya – Prabumulih Zone 6 STA 59 + 425.

Fig.2 Geofoam technology on the Simpang Indralaya – Prabumulih Zone 6 STA 59 + 425 Toll Road.

In certain nations, design guidelines are available to make geofoam use easier. Nonetheless, research serves as the main foundation for these current design guidelines. In this project, the embankment design adopts the design implemented by [32]. Figure 3 shows the cross-section of the abutment design in the project studied in this study.

PLAXIS, a finite element software, is used to analyze the stability of the structure. The first step, the transverse cut of the soil and geofoam embankment, is analyzed in the landslide field, followed by the longitudinal cut of the soil and geofoam embankment. The results of the analysis are shown in Fig. 4 until 9, respectively.

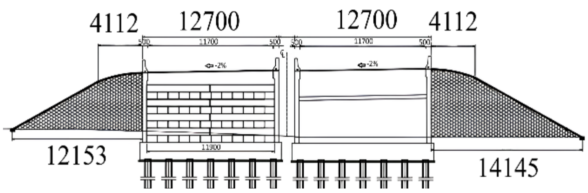

Fig.3 Cross section of the EPS Embankment and Instrumentation at Abutment of the Trans Sumatra Toll Road Project Simpang Indralaya – Prabumulih Zone 6 STA 59 + 425

5.2 Plaxis Results

The analysis of Plaxis was divided into two criteria: cross-section and long-section modeling. All the calculations are aimed at obtaining SF value and displacement analysis. The first model is cross-section analysis; the output of SF is presented in Fig. 4 and 5, while the displacement is described in Fig. 6. The SF values in these models are 2.062 and 2.059, respectively. Meanwhile, the vertical displacement reaches 0.38 m. According to the Fig. 6, the maximum displacement is located around the middle body of the embankment and will be reduced until the subgrade of the embankment model. As a result, the monitoring for displacement in the middle of the structure should be considered to minimize the risk of collapse during the construction period.

Regarding long section assessment, the SF value presents 2.955 and 3.306, respectively, and the vertical displacement output is 0.95m. All the detailed results are provided in Fig.7 and 8. Analysis using Plaxis shows that the embankment has a safety factor greater than the requirements safety number. Due to the lightweight property of EPS geofoam, it can be used as an embankment fill to reduce the intensity of loads on underlying soils. Subsequently, it also minimizes the total settlement of the embankment.

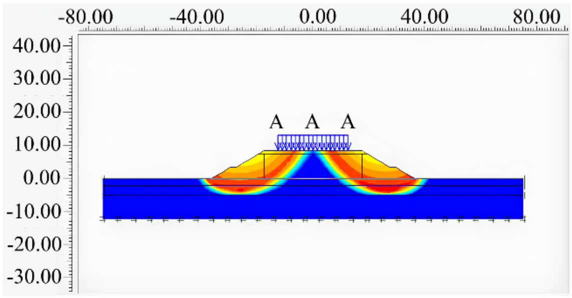

Fig. 4 Plaxis output for cross-section embankment stability, Landslide field pattern in transverse cut out (SF = 2.062)

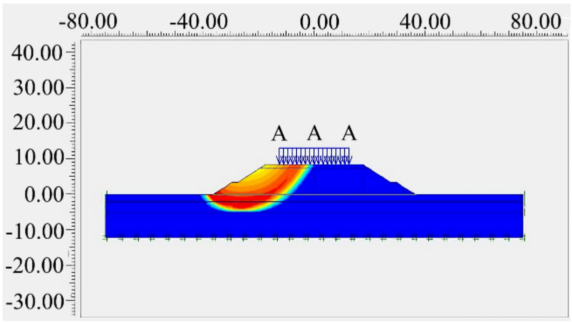

Fig. 5 Plaxis output for cross-section embankment stability, Geofoam landfill landslide field pattern (SF = 2,059)

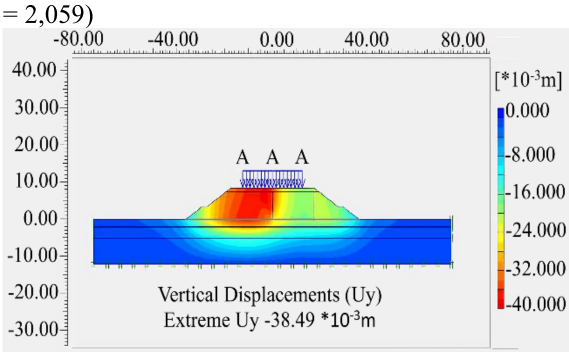

Fig. 6 Vertical displacement output for cross-section

embankment

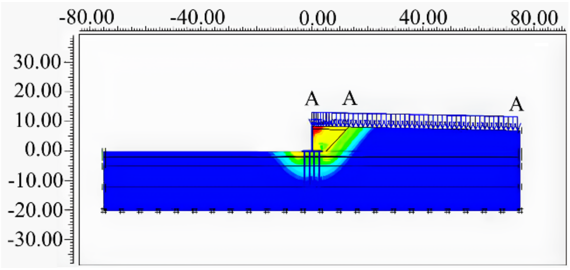

Fig. 7 Plaxis output for long section embankment stability Landslide field pattern in elongated cut (SF= 2.955)

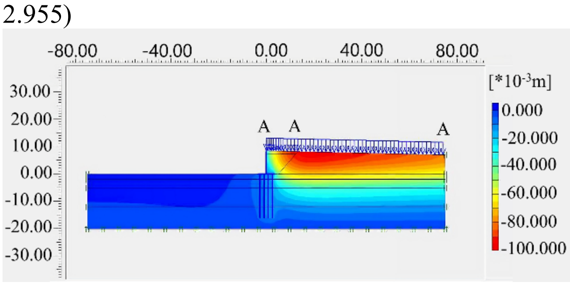

Fig. 8 Plaxis output for long section embankment stability, Geofoam landfill landslide field pattern, Elongated cut (SF = 3,306)

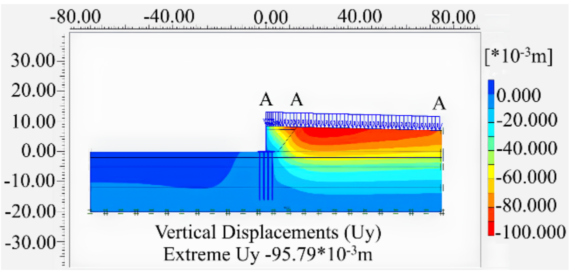

Fig. 9 Vertical displacement output for long section embankment

The analysis results show that the safe number owned by the soil embankment or geofoam embankment produces a value above 2, both for longitudinal and transverse cuts. Referring to the SF value determined by [33], this safe number value meets the safe criteria. In Indonesia's geotechnical standard [34], if the level of uncertainty of the analysis conditions is high and the cost of repairs is greater than the additional cost of designing a more conservative slope, then the SF > 2.0 or more. If a non-conservative safety factor is desired, it is recommended to optimize the design of the solid pile at the planning stage, for example with comprehensive numerical simulation.

These results from Plaxis as FEM analysis in both SF and displacement can be reliable outputs because, at the end of the construction, the whole embankment is in a safe condition. In addition, the embankment stability based on another previous research [35]. conducted with Plaxis also showed a correlation between LEM and FEM output. Consequently, the Plaxis utilization for this study can be accountable for the output as the design standardization.

As the result of cross-section analysis based on Plaxis, which means the FEM examination of the construction, the SF value from FEM is influenced by the Elastic modulus and shear strength of the input parameters; further analysis needs to be conducted to emphasize the SF value such as LEM analysis or another suitable method [35]. The threshold of the composite material also had to be tested in the experimental result for the comprehensive analysis of the geofoam utilization. Furthermore, based on the analysis of the graphical results, the highest displacement is at the bottom of the load. The displacement in the Y axes and negative values means that the displacement number is in the bottom direction. Although the geofoam material is lighter than the soil as fill material, the displacement also occurs as a consequence of the external load.

5.3 Construction Period Obstacles and Solutions

During the implementation period of the geofoam installation, several obstacles were encountered. Table 3 summarizes the obstacles, causes, and solutions taken.

Table 3. Construction period obstacles and solutions

No	Obstacles	Cause	Solution	Information
1	Geofoam material cracks after cutting	The production process is not perfect; shock during mobilization or impact during lifting	If there is still a fault, it is pasted with EPS glue	-
2	There is an empty space	Inconsistency between the cutting list image and the size of the field	a. If it is still possible to increase the volume of Geofoam by producing materials of the required size b. If it is not possible because it is too small or the time and delivery are too long, the empty space can be filled with compacted Soil/Aggregate	Fig. 10
3	Geofoam Bounces and vibrates when the pavement is carried out	Geofoam soil has the characteristic of full elasticity at the deformation of about 1.5% first	Keeping the soil at a still high moisture content	Fig. 11

In light of the relatively new use of geofoam materials in Indonesia, the parties need to evaluate the environmental impact and socio-economic benefits of the use of geofoam in this project, i.e., a thorough evaluation of the benefits and risks of using geofoam in the context of the project, including an assessment of the cost, construction speed, durability, and conducting effective communication and providing research on the use of geofoam. According to [36, [37], Several studies have examined the detrimental effects of recycling on land usage of geofoam such as air pollution, and greenhouse gas emissions from the standpoint of environmental economics. Consequently, the result of study showed that incorporating recycling into different embankment building techniques might lower life cycle costs and environmental impacts. This can help address concerns and build support for using these new technologies in civil infrastructure projects, Fig. 12.

Fig. 10 Empty space

Fig. 11 Soil bale

Fig. 12 Construction process of geofoam

6. CONCLUSION

The whole performance of Geofoam in this research through the Finite Element Method yields sufficient results; the SF value offers 2.602 and 2.059 for cross-section analysis, while 2.955 and 3.306 for long section analysis. The safe condition for the construction process until the end of fabrication. In addition, case studies show that geofoam can be used as a backfill with satisfactory results, shown by adequate SF, i.e., greater than 2. This showcases the potential contribution of geofoam to sustainability. Before construction work, at the planning stage, it is necessary to optimize the design of the geofoam as a backfill so that a safe and efficient solution is obtained. However, because of the simplification of FEM materials input and the problems that occurred in the stage construction, such as cracks after the cutting and offering empty space between the cutting, the engineer should be able to cover the unexpected matters during the construction process.

7. ACKNOWLEDGMENTS

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