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NUMERICAL MODELING OF EMBANKMENT ON THIN CLAY SOIL WITH GEOFOAM

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Soft soils cause problems in road subgrades because they have low bearing capacity. Embankments on soft ground need to be identified and reviewed before construction starts. Various soil reinforcement techniques can be used to improve soft soil conditions. This research focuses on using geofoam material as an embankment on soft soil. The aim is to analyze the modeling of soft soil embankment with geofoam. The research method is a numerical method using the Plaxis 2D version 2023 application. There are two models in this study, namely the embankment model without geofoam, 100 cm thick subgrade, and the embankment model with 30 cm thick and 40 cm thick geofoam. The embankment geometry model is assumed to be symmetrical, hardening soil parameters are used to model soft soil for analyzing consolidation settlement, and elastic linear parameters to model geofoam. The type of FEM analysis in this research is plain strain. Numerical results at a maximum load of 100 kN showed a settlement of 0.1587 mm at 30 cm geofoam thickness and 0.1507 mm at 40 cm geofoam thickness. Deformation of 16 mm in 30 cm thick geofoam and 15.22 mm in 40 cm thick geofoam. Soil stress of 201 kN/m² in 30 cm thick geofoam and 192 kN/m² in 40 cm thick geofoamm. In conclusion, the model of embankment on soft soil with geofoam is that the thicker the geofoam used, the smaller the settlement and the stress on the soil that occurs.

Keywords: EPS22, soil reinforcement, 2D finite element, subgrade, clay

1 INTRODUCTION

Construction on soft soils is currently a significant challenge in geotechnical science. The main problem in pavement construction on soft soil is the limited bearing capacity of the soil which can cause construction failure [1, 2]. Clay is a type of soft soil that has high shrinkage expansion properties, and high to medium plasticity index values, and from a geotechnical point of view, clay is classified as a problematic soil [3, 4].

Low soil bearing capacity causes subsidence and needs soil improvement to overcome the settlement [5]. Soil improvement can help increase soil strength and reduce soil permeability [6]. Various methods to overcome it, one of which is by using lightweight embankment materials with geofoam in road embankments [7, 8].

Construction development at this time such as road construction is required to use environmentally friendly construction methods, by looking for various innovations to meet changing demands [9]. The use of Expanded Polystyrene (EPS) geofoam material is a breakthrough that could promise revolutionary changes for various modern infrastructure engineering application [10]. Contemporary infrastructure is indispensable for today's infrastructure development, as traditional methods may not be sufficient to meet the complex infrastructure needs [11].

It is essential to adopt innovative development to find contemporary infrastructure solutions, so the introduction of EPS geofoam is one of the methods to realize the concept of lightweight construction, time efficiency, material efficiency, and sustainability to be researched [12, 13]. EPS geofoam has been widely applied in the field of efficient construction, as it has low density and high durability [14, 15, 16, 17, 18].

EPS geofoam has been used since the 1970s around the world to solve subsidence problems [10, 19, 20]. EPS geofoam is a substitute for conventional embankment and is environmentally friendly so it has great potential for the infrastructure sector because it is categorized as a lightweight embankment [21, 22, 23]. EPS geofoam is a cellularized polystyrene that has a low density of 11.2 – 45.7 kg/m³ [24, 25]. EPS geofoam juga berfungsi untuk mengurangi penurunan pada tanah karena bersifat sebagai timbuan ringan[16,12]. EPS geofoam also serves to reduce soil settlement because it is a lightweight fill [16],[12]. Settlement criteria based on the South Carolina Department of Transportation (2008) for class I roads at a maximum 100-year design life of 2.54 mm. For the safety factor due to the load given, the criteria are> 1.2 [26].

Numerical modeling using the Plaxis 2D application was carried out to make it easier to analyze the calculation of land subsidence. Modeling helps to quickly view the subsidence model with the help of the Plaxis 2D application. This study aims to analyze the numerical model of settlement and safety factors that occur in embankments without EPS geofoam with EPS geofoam embankments using Plaxis 2D version 2023. This research conducted several road embankment models with variations in the applied concentrated load to analyze the ground settlement and safety factors. Two types of road embankment models were analyzed, namely the model without using EPS geofoam and the model with EPS geofoam embankment. The novelty of this research is the variation in the thickness of EPS Geofoam used as a substitute for embankment on soft soil. The thickness of the EPS geofoam model is varied to analyze the efficient settlement that occurs from the applied load. All models were assumed to receive loads of 0 kN, 10 kN, 20 kN, 40 kN, 60 kN, 80 kN, and 100 kN. The model variation of EPS geofoam thickness is 30 cm and 40 cm thick.

The purpose of this research is to analyze the modeling of soft soil embankment with geofoam. This research simulates the embankment model with EPS Geofoam with thickness variations of 30 cm and 40 cm. The subgrade geometry model with a height of 60 cm and a width of 200 cm, this geometry adapts to the test basin in experimental research. Plaxis 2D software version 2023 was used to run the finite element simulation of the road embankment.

Two types of models were analyzed: the embankment model without EPS Geofoam and the embankment model with EPS Geofoam of 30 cm and 40 cm thickness. All models were assumed to receive a centralized load with variations of 0 kN, 10 kN, 20 kN, 40 kN, 60 kN, 80 kN, and 100 kN.

2 METHODOLGY

This research method is a numerical method using the Plaxis 2D version 2023 application by modeling the subgrade and EPS geofoam embankment. The subgrade model without EPS geofoam embankment with a subgrade thickness of 100 cm and the subgrade model using EPS geofoam embankment with thickness variations of 30 cm and 40 cm are simulated in this study using Plaxis 2D application. The subgrade was modeled as a hardening soil model which was adopted as the soft soil parameter of the subgrade. Hardening soil was used in the subgrade modeling because the soil data parameter included is the soil consolidation value. The EPS geofoam is modeled as linear elastic because it is categorized as a rigid structure, for the load support a K250 concrete slab with a thickness of 10 cm is modeled as linear elastic because it is categorized as a rigid structure. The subgrade properties were obtained from laboratory testing, namely content weight testing, UU triaxial testing, and consolidation testing. Three different models were used to determine the ground settlement and safety factor of the embankment. The load given is a centralized load given in stages starting from 0 kN, 10 kN, 20 kN, 40 kN, 60 kN, 80 kN, and 100 kN. Load values refer to the RSNI T - 02 - 2005 Bridge Loading Standards regarding traffic loads for bridge planning with the most critical modeling, namely the centralized load model using the largest axle load of 112.5 kN with a wheel width of 200 mm.

2.1 Material properties of model used

For subgrade properties, laboratory testing was conducted. Before testing in the laboratory, soil samples were taken in the field using hand auger boring to take undisturbed samples. The parameters of the subgrade properties test are:

Properties of EPS 22 geofoam refer to ASTM D6817, for the properties parameters are presented in the following Table:

Table 1. Parameter properties of EPS 22 geofoam based on ASTM D6817

Type	EPS 22
Density (min), kg/m^3	21.6
Young modulus (E), kN/m^2	5000

For the poisson ration (v) value of EPS 22 geofoam, 0.12 was used [27]. The Poisson ratio value of the subgrade was used as 0.4 based on Terzaghi 1987. The Poisson ratio value of concrete according to Huang 2004, was used as 0.20.

2.2 Embankment model

There are 3 numerical models made, namely the first model of the subgrade without geofoam embankment with dimensions of 100 cm high and 200 cm wide, and above the subgrade is given a concrete slab with dimensions of 40 cm wide and 10 cm thick. The geometry model is assumed to be symmetrical according to field testing. In this study, the soft soil thickness is assumed to be 100 cm, referring to the Ministry of Public Works and Housing, Directorate General of Highways 2017, where the minimum subgrade height for the highway class is 600 mm. The geometry model for the subgrade refers to the dimensions of the test bed for experimental testing which is 200 cm x 50 cm x 110 cm, so the geometry model in 2D plaxis assumes the boundaries of the finite element model used in the study, namely the horizontal direction is set as far as 2 times the width of the subgrade dimension and for a fixed height, to see the sliding plane. The second model was a subgrade with a 30 cm thick EPS 22 geofoam embankment, and the third model was a subgrade with a 40 cm thick EPS 22 geofoam embankment. The embankment models are presented in Figure 1, Figure 2, and Figure 3. The models were evaluated using Plaxis 2D software version 2023. The subgrade model without EPS 22 geofoam backfill and the subgrade model with EPS 22 geofoam backfill were compared for settlement analysis due to a given centralized load of 0 kN. 10 kN. 20 kN. 40 kN, 60 kN, 80 kN, and 100 kN.

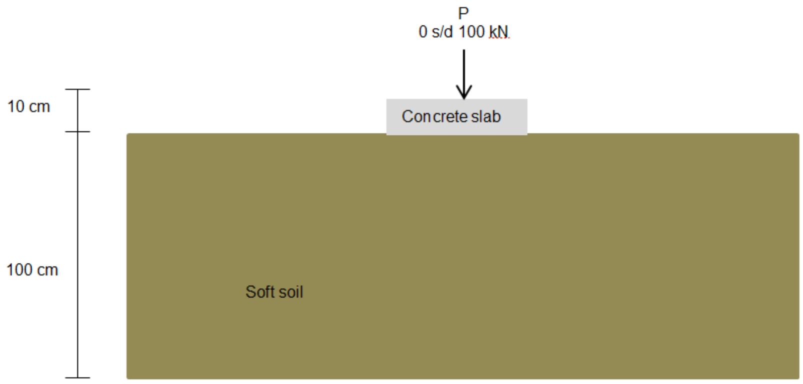

Fig. 1. Subgrade without geofoam embankment EPS 22

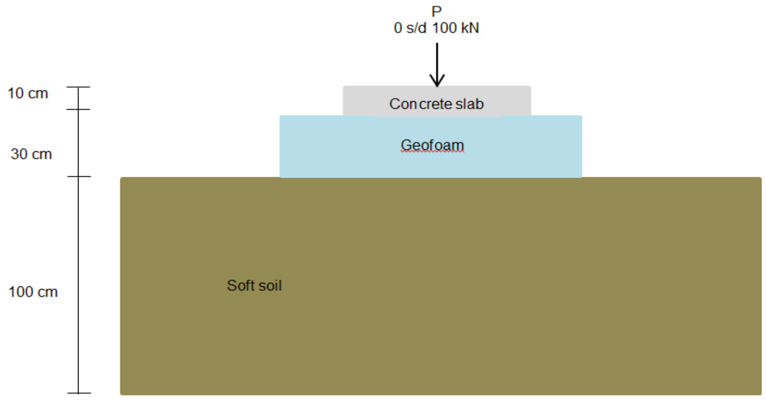

Fig. 2. Subgrade with 30 cm thick EPS 22 geofoam embankment

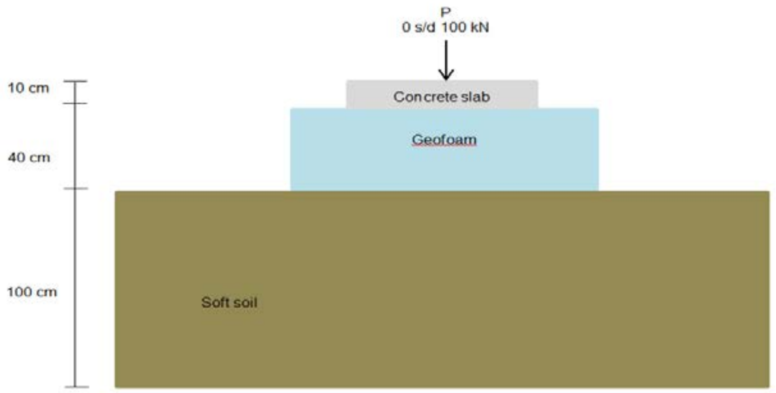

Fig. 3. Subgrade with 40 cm thick EPS 22 geofoam embankment

2.3 Model procedure

The construction of road embankment is made in 3 models, namely a model without embankment and a model with EPS 22 geofoam embankment with a thickness variation of 30 cm and 40 cm. The applied load is a centralized load of 0 kN. 10 kN. 20 kN. 40 kN, 60 kN, 80 kN, and 100 kN. The consolidation time is calculated for 100 years. Table 2, and Table 4 show the construction stages of subgrade with EPS 22 geofoam backfill.

Table 2. The construction phase for subgrade with 30 cm thick EPS 22 geofoam

Stuged construction	Time interval (day)
Initial phase	0
Subgrade	1
Geofoam	1
Concrete slab K250	1
Load 0 kN	36500
Load 10 kN	36500
Load 20 kN	36500

Stuged construction	Time interval (day)
Load 40 kN	36500
Load 60 kN	36500
Load 80 kN	36500
Load 100 kN	36500

Table 3. The construction phase for subgrade with 40 cm thick EPS 22 geofoam

Stuged construction	Time interval (day)
Initial phase	0
Subgrade	1
Geofoam	1
Concrete slab K250	1
Load 0 kN	36500
Load 10 kN	36500
Load 20 kN	36500
Load 40 kN	36500
Load 60 kN	36500
Load 80 kN	36500
Load 100 kN	36500

3 RESULT AND DISCUSSION

The results of laboratory testing of subgrade properties are presented in Table 4, the values will be entered into the material in the Plaxis 2D application version 2023.

Table 4. Results of laboratory soil testing

Testing	Results	Units
$\gamma_{unsaturated}$	14.47	kN/m^3
$\gamma_{saturated}$	20.47	kN/m^3
Pore number (e)	0.80	-
Cohesi (c)	20.98	kN/m^2
Shear angle (φ)	4.551	º
Compression coefficient (Cc)	0.0231	-
Koefisien swelling (Cs)	0.0031	-

The cohesion value of the subgrade was found to be 20.98 kN/m^2, based on Bowles 1995 is classified as a soft consistency because it is between 20 – 50 kN/m^2. From the type of soil obtained classified as soft clay based on Bowles (1995), the value of young modulus (E) is obtained 2000 kN/m^2 – 4000 kN/m^2. In numerical modeling, the young's modulus value used is 2000 kN/m^2. The materials included in the numerical modeling of Plaxis 2D version 2023 are presented in Table 5.

Tabel 5. Material properties used in the model

Type of material	Model material	Tipe drainase	γunsat (kN/m3)	γsat (kN/m3)	e	E (kN/m2)	v	c (kN/m2)	Cc	Cs
Soft soil	Hardening soil	Undrained B	14.47	20.47	0.80	2000	0.2	20.98	0.0231	0.0031
Geofoam EPS 22	Linear elastic	Non-porous	-	0.216	-	5000	0.12	-	-	-
Concrete slab K250	Linear elastic	Non-porous	-	24	-	2128939 0	0.2	-	-	-

3.1 Subgrade settlement model results

The model of subgrade settlement without EPS 22 geofoam embankment is presented in Table 6. The model of subgrade settlement with 30 cm thick and 40 cm thick EPS 22 geofoam embankment is presented in Table 7 and Table 8.

Table 6. Results of Plaxis 2D numerical model version 2023 subgrade without EPS 22 geofoam embankment

Load (kN)	Safety factor (SF)	Displacement (mm)
0	46.14	0
10	5.764	-2.588
20	3.073	-4.925
40	1.589	-11.457
60	1.071	-28.550

The maximum load that the subgrade can receive is 60 kN, a settlement of 28.550 mm, and a safety factor of 1.071. The safety factor value obtained < 1.2 means that the load carried is not safe for the subgrade [26] so it needs to be reinforced using EPS 22 geofoam as a lightweight embankment.

Table 7. Results of Plaxis 2D numerical model version 2023 subgrade with 30 cm thick EPS 22 geofoam embankment

Load (kN)	Safety factor (SF)	Displacement (mm)
0	121.5	0
10	11.18	-0.0080
20	6.133	-0.0177
40	3.006	-0.0387
60	1.957	-0.0635
80	1.464	-0.0969
100	1.243	-0.1587

Table 8. Results of Plaxis 2D numerical model version 2023 subgrade with 40 cm thick EPS 22 geofoam embankment

Load (kN)	Safety factor (SF)	Displacement (mm)
0	130.00	0
10	14.66	-0.0096
20	7.015	-0.0202
40	3.230	-0.0453
60	2.111	-0.0723
80	1.659	-0.1049
100	1.371	-0.1507

The maximum load that can be received by the subgrade with 30 cm and 40 cm thick EPS 22 geofoam embankment is 100 kN, with a settlement of 0.1587 mm for 30 cm thick EPS 22 geofoam and 0.1507 mm for 40 cm thick EPS 22 geofoam. Based on the South Carolina Department of Transportation (2008) settlement criteria for class I roads at a maximum 100-year plan life of 2.54 mm, the numerical model obtained values < 2.54 mm. For the safety factor due to the load given, the criteria are> 1.2 at a maximum load of 100 kN embankment with geofoam EPS 22 30 cm thick safety factor value 1.243. For 40 cm thick EPS 22 geofoam at a maximum load of 100 kN, a safety factor value of 1.371 was obtained.

Figure 4 shows the comparison of the safety factor of subgrade without EPS 22 geofoam backfill and subgrade with EPS 22 geofoam 30 cm thick and 40 cm thick. Figure 5 displays the safety factor for the variation of EPS 22 geofoam thickness.

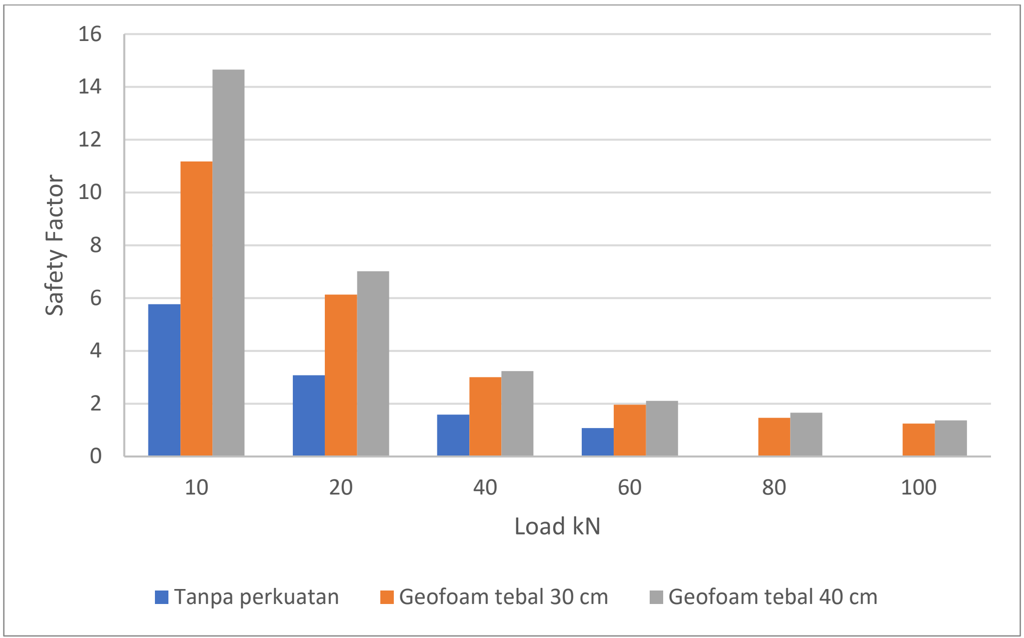

Fig. 4. A safety factor of subgrade without EPS 22 geofoam embankment and subgrade with EPS 22 geofoam embankment

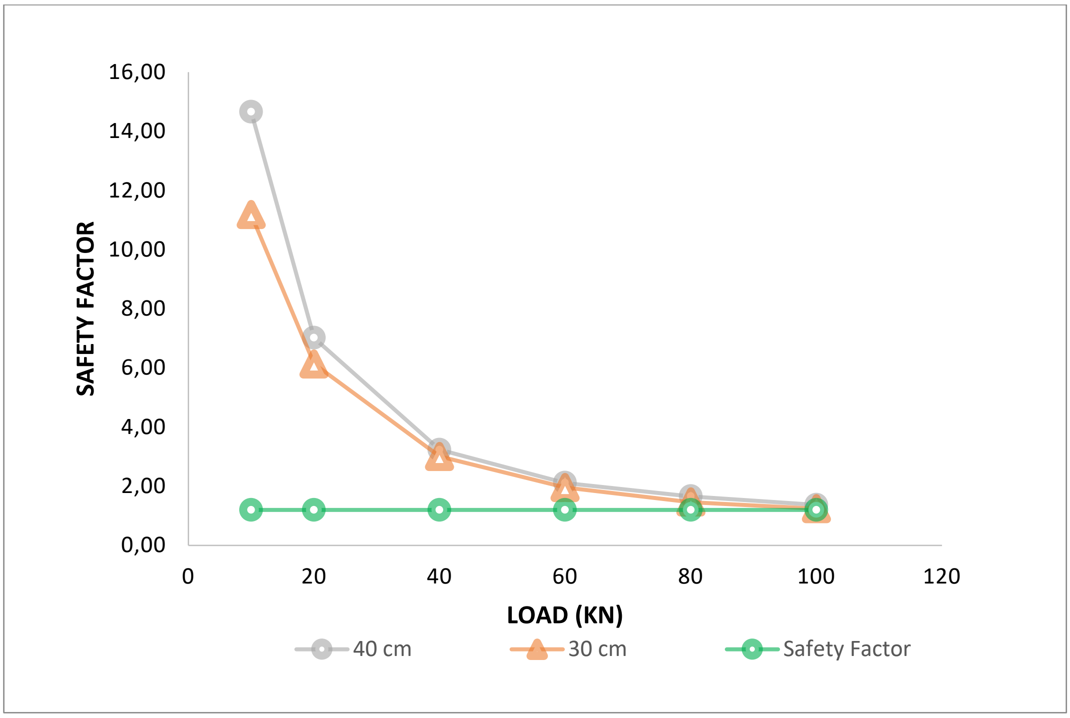

Fig. 5. Safety factor for thick variation of EPS 22 geofoam

Figure 4 shows the largest safety factor on the subgrade model with 40 cm thick EPS 22 backfill, the safety factor obtained is safe to carry a maximum load of 100 kN. The permissible safety factor value is > 1.2. Comparison of the safety factor of EPS 22 geofoam thickness, namely the safety factor value of subgrade with 40 cm thick EPS 22 embankment is greater than the subgrade with 30 cm thick EPS 22 embankment. The greater the load applied, the smaller the safety factor that occurs. The thicker the EPS 22 geofoam used, the greater the safety factor.

The model of the settlement caused by loading up to 100 kN on the subgrade with 30 cm thick and 40 cm thick EPS 22 geofoam backfill is presented in Figure 6. The greater the load applied, the greater the settlement that happens.

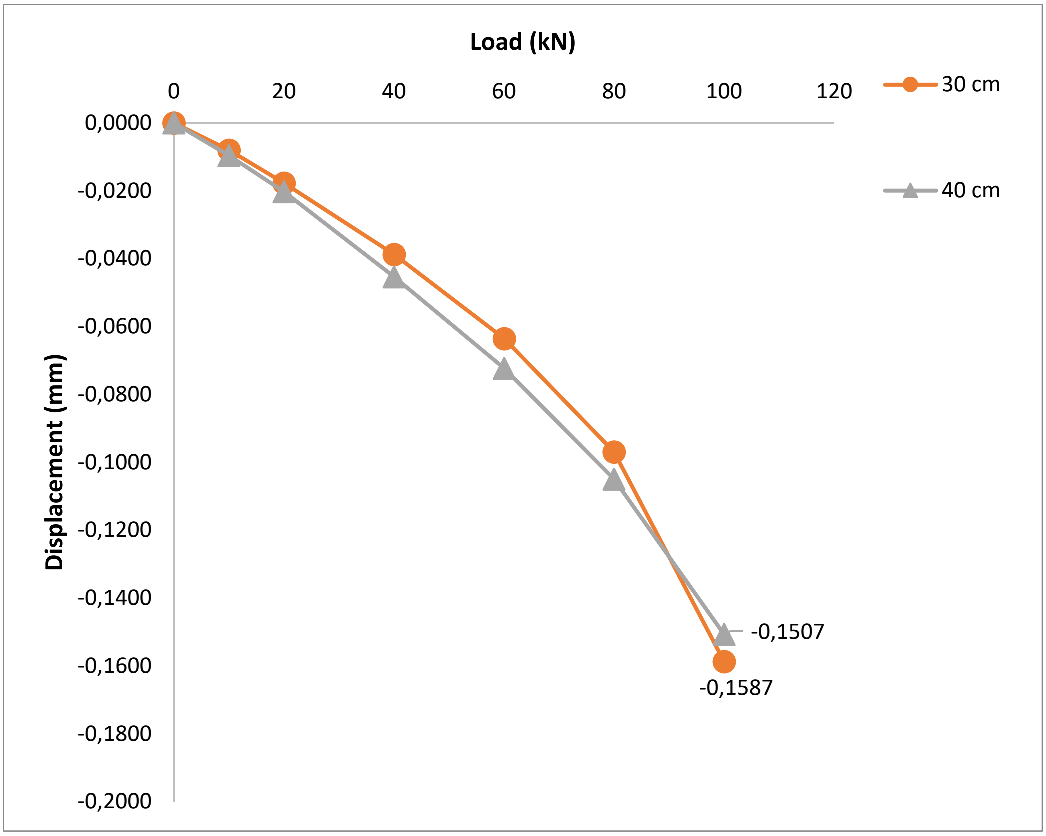

Fig. 6. Subgrade settlement with 30 cm thick and 40 cm thick EPS 22 geofoam embankment

In the model analysis made, the largest settlement value occurred on the subgrade with a 30 cm thick EPS 22 geofoam of 0.1587 mm. By using 40 cm thick EPS 22 geofoam as an embankment on top of the subgrade, a smaller settlement value of 0.1507 mm was obtained compared to 30 cm thick EPS 22 geofoam. The settlement that occurs meets the settlement criteria based on the South Carolina Department of Transportation (2008) settlement criteria for class I roads at a maximum 100-year plan life of 2.54 mm. This means that the settlement that occurs with EPS 22 geofoam is smaller than the subgrade without EPS 22 geofoam. Therefore, the use of EPS 22 geofoam as an embankment above the subgrade provides a safe safety factor value and makes the subsidence smaller than without using EPS 22 geofoam.

3.2 Deformation model results

Deformation of 30 cm thick EPS Geofoam and 40 cm thick with maximum load of 100 kN :

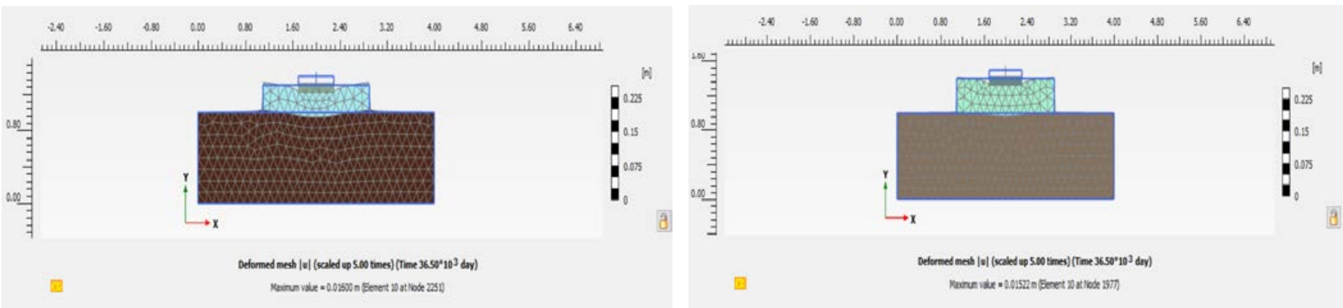

Fig. 7. Deformation due to maximum load of 30 cm thick and 40 cm thick EPS 22 geofoam embankment

The deformation that occurs is that the thicker the EPS 22 geofoam, the smaller the deformation that occurs. At a maximum load of 100 kN, the deformation of EPS 22 geofoam is 16 mm, and 40 cm thick is 15.22 mm.

3.3 Results of soil stress modeling

Table 9. Results of subgrade stress model with 30 cm and 40 cm thick EPS 22 geofoam embankment load (kN) soil stress (Δσz)

Load (kN)	Soil stress (Δσz)	
	Geofoam 30 cm thick (kN/m²)	Geofoam 40 cm thick (kN/m²)
0	0	0
10	35.65	19.37
20	60.20	38.67

Load (kN)	Soil stress (Δσz)	
	Geofoam 30 cm thick (kN/m²)	Geofoam 40 cm thick (kN/m²)
40	120.00	76.80
60	180.00	115.20
80	194.00	153.60
100	200.00	192.00

When a layer of soil is subjected to loading due to the load on it, the soil under the working load will experience an increase in stress, the impact of this increase in stress is a decrease in the elevation of the subgrade. The maximum soil stress at a load of 100 kN is 200.00 (kN/m²) on a 30 cm thick geofoam and 192.00 (kN/m²) on a 40 cm thick geofoam.

The greater the load received by the subgrade, the greater the stress that occurs in the subgrade. In this study, the thicker the Geofoam used for soft soil embankment, the smaller the stress received by the subgrade on its surface.

4 CONCLUSIONS

In conclusion, the subgrade model without EPS 22 geofoam backfill gives a large settlement value compared to the subgrade with EPS 22 geofoam. The backfill of the subgrade with EPS 22 geofoam minimizes the settlement. The thicker the EPS 22 geofoam embankment, the smaller the settlement, deformation, and soil stress values.

Future research is expected to conduct experimental testing in the laboratory to obtain valid analysis values and almost match the conditions in the field.

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