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Numerical Modelling of Soft Soil Improvement Using Expanded Polystyrene Geofoam for Road Embankment

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Abstract: Soft soil brings abundant engineering issues due to low bearing capacity and shear strength. A comprehensive study of soft ground needs to be reviewed and identified before construction can start. Various techniques can be used to improve the soil. However, this study focuses on using material namely expanded polystyrene. The geotextile is embedded with expanded polystyrene to strengthen the soil condition. This study adopted the soil parameters from East Coast Expressway. There are two models in this study, which are earth embankment and EPS embankment. The settlement of the earth embankment is compared with the EPS embankment after construction. The Mohr-Coulomb parameters are used to model the soft soil and embankments, while the linear elastic parameters were adopted to model the EPS and geotextile. This study produced two embankment models, the conventional embankment models with and without surcharge. The second model is an EPS embankment with various densities (22 kg/m^3, 29 kg/m^3, and 39 kg/m^3). The settlement is recorded for ten years after the embankment construction was completed. The difference settlement value for the conventional model is 28mm. The settlement value for EPS 22 is 3.18mm, EPS 29 is 2.06mm, and EPS 39 is 1.51mm. For the geotextile embedded in EPS, the settlement for EPS 22 is 3.17mm, EPS 29 is 2.04mm, and EPS 39 is 1.49mm respectively. Since EPS uses three different densities, from the prediction of PLAXIS 2D, the higher density gives the lower value of the settlement. However, when the geotextile is embedded with EPS, there is no significant difference in settlement behaviour. In conclusion, the model with a surcharge gives a lower settlement than the model without a surcharge. But the expanded polystyrene block is the best model to reduce the settlement compared with the conventional model with a surcharge. Different densities of EPS resulted in different settlement value, and EPS 39 gives the lowest settlement value. In terms of the geotextile embedded with EPS, it does not give a significant change in settlement.

Keywords: Soft soil, PLAXIS 2D, EPS, soil improvement

1. Introduction

Recently, construction on soft ground layers has become a challenge in geotechnical engineering. Construction of road embankments on soft soils typically encounters problems related to excessive settlement issues. In Malaysia, many road embankments have built-in soft soil areas where the foundation is supported by low shear resistance and high compressible soils, as stated by Yusof *et al.* (2006). This weak soil area typically faces structural foundation problems. Since rapid urbanization recently, the engineering properties of soft soil need to be improved. Soil improvement is a system related to the ground structure to transfer or support loads. This soil improvement can help increase the strength and reduce the permeability of soft soil problems, as stated by Al-Taie in 2015.

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Heavy load from vehicles can cause weak soil structure and settlement to the road embankment as stated by Archeewa et al., (2011). Soft soil is generally compressible with a high void ratio, low undrained shear strength, and high compressibility as stated by Huat and Kazemian in 2012. Construction on soft ground deals with instability and continuous settlement problems in a long-term duration. Hence, this research suggested a method to solve the settlement issues by using embankment fill material, the expanded polystyrene (EPS) block in the road embankment as stated by Puppala *et al*., (2019).

The objective of this study is to determine the settlement behaviour of earth embankment and EPS embankment. Next, to compare the settlement of the Conventional Model embankment with EPS geofoam using PLAXIS 2D. This study simulated several models of road embankments to analyze the road settlement. The soil properties used in this study refer to the previous soil properties from Chik *et al*. (2013). The geometry model of the road embankment is four-meter height and ten meters wide. Besides, this paper uses PLAXIS 2D software to run a finite element simulation of a road embankment.

Two model types were analysed in the road embankment: conventional earth embankment and embankment replace with EPS block. The earth embankment model consists of two models: the model with surcharge and the model without surcharge. All models are assumed to receive a live load of 15 kN/m^2 from the vehicle. Also, the geotextile is used in this simulation to analyze whether it significantly affects the settlement when embedded within the EPS block. The EPS embankment with various densities and geotextile layers were investigate in term of their displacement performance. The settlement for ten years will be investigated immediately after the road open to the vehicle.

2. Soft Soil and Expanded Polystyrene

Soft soil is one of the most challenging due to its low permeability, low shear strength, and low bearing capacity. Soft soils are characterized by large voids between particles and lack organic substances to bind them together.

2.1 Embankment of Soft Soil

In road construction, the embankment increases the road height compared to the surrounding area. It is a large earth structure and is often used in infrastructure projects related to civil engineering applications. The current soil condition at LPT 2 could not support the high earth embankment. Many methods were used to improve this embankment using geotechnical techniques such as stone columns, chemical grouting, or fill material. The earth embankment can resist a 15 kN/m2 traffic load with a minimum safety factor of 1.4. Soft clay is the eight-meter depth from the ground soil. Settlement of embankment happens because the soil structure becomes tense when the load is applied.

2.2 Expanded Polystyrene (EPS)

EPS geofoam is a non-traditional building material that can reduce onsite construction time and project costs significantly. EPS geofoam is normally used to replace compressible soils or in place of heavy fill materials to prevent improper loading on underlying soil structures. EPS geofoam material has enabled roads to build faster, lighter, and with greater stability than other fill materials. Furthermore, construction with EPS geofoam saves time because it is easy to handle without special requirements. It is an engineered product since EPS geofoam already undergoes quality assurance checking before reaching the construction site.

Generally, expanded polystyrene (EPS) block is a polymeric geosynthetic material with a cellular closed-cell structure, as stated by Mohajerani *et al*. (2017). EPS is super lightweight blocks, closed cells, rigid and plastic foam with one percent soil density. Compared to other light fill types, expanded polystyrene (EPS) is an ultra-lightweight material with a material density of 12 to 35 kg/m^3. In this paper, three different densities of EPS are used. The density selected are 22 kg/m^3, 29 kg/m^3 and 39 kg/m^3. Besides, the geogrid used in this study is made from woven, and its axial stiffness is 5000 kN/m.

3. Methodology

The conventional embankment model and the enhanced embankment with EPS were simulated in this study using PLAXIS 2D software. The Mohr-Coulomb model is adopted for soft soil and embankments soil parameters. EPS is model using the linear elastic model, whereas the elastic material type is employed for the geotextile's characteristics.

The soil properties for the embankment is adopted from Chik *et al*. (2013). Three different models were used to determine the settlement of embankment. The first model is the conventional embankment model with a surcharge. The second model is a conventional embankment model without surcharge. The third model is the EPS embankment with and without surcharge.

3.1 Geometry and Material Properties of Proposed Model

The geometry model of the embankment is assumed to be symmetrical. Hence, the embankment was simulated for only half of the embankment. Figure 1 shows the embankment geometry of the conventional embankment model. This conventional model has two different designs which are embankment with surcharge and embankment without surcharge. Table 1 shows the soil parameters obtained from Chik et al. (2013) from the East Coast Expressway project, while Table 2 shows the parameters of reinforced material using geotextile material obtained from Mamat *et al.* (2021). In addition, table 3 shows the EPS parameter used in the FEM analysis obtained from Khan & Meguid (2021).

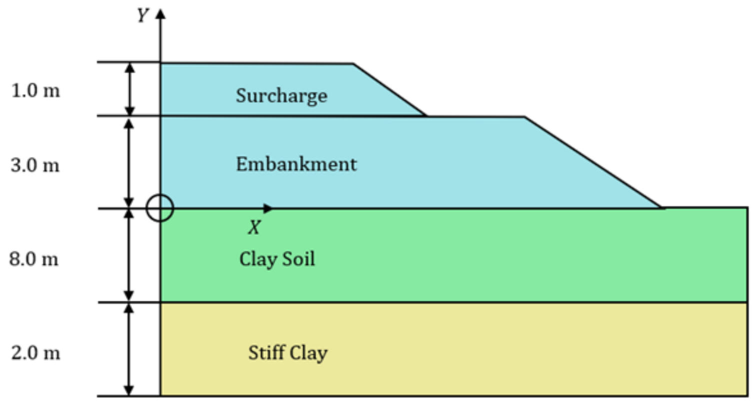

Fig.1 - Geometry of the proposed model

Table 1 - Soil parameters used proposed model (after Chik, *et al.*, 2013)

Material	Name	Embankment	Stiff Clay	Soft Soil	Unit
Material Model	Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	-
Material behaviour	-	Drained	Undrained	Undrained	-
Dry unit weight	γ_{dry}	19	16	15	kN/m^3
Bulk unit weight	γ_{bulk}	20	17	16	kN/m^3
Horizontal Permeability	k_h	0.0864	8.6 x 10^{-4}	8.6 x 10^{-6}	m/day
Vertical Permeability	k_v	0.0864	8.6 x 10^{-4}	8.6 x 10^{-6}	m/day
Young Modulus	E	20000	15000	1200	kN/m^2
Poisson's ratio	ν	0.3	0.4	0.4	-
Cohesion	c	5	23	10	kN/m^2
Friction angle	ϕ	30	28	23	°
Dilatancy angle	ψ	0	0	0	°

Table 2 - Parameters for reinforced material (Mamat *et al.*, 2021)

Material	Model type	Material type	EA (kN/m)
Geotextile	Geogrids	Elastic	5000

Table 3 - EPS parameters used in proposed model (Khan and Meguid, 2021)

Parameter	EPS 22	EPS 29	EPS 39
Unit weight, γ (kN/m^3)	0.22	0.29	0.39
Young Modulus, E (kN/m^2)	6910	10000	178000
Poisson Ratio, ν	0.12	0.13	0.15

3.2 Embankment Model

Conventional models have two different designs. The first design embankment model with surcharge and another model embankment without surcharge. Both embankments used a PVC drainpipe, and the EPS model was designed with a typical arrangement of EPS blocks to reduce the settlement value. The embankment model is shown in Figure 2, Figure 3, and Figure 4. The settlement of the three models was evaluated using the PLAXIS 2D software. The settlement will be compared from the conventional model (with surcharge and without surcharge) by choosing the less settlement value and compare with EPS model to determine the settlement effect when using embankment fill material.

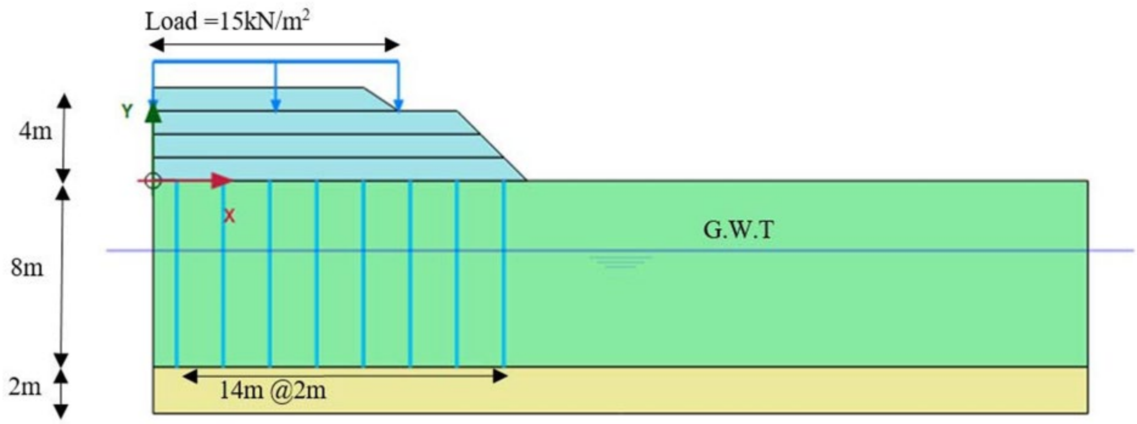

Fig. 2 - Conventional model with surcharge

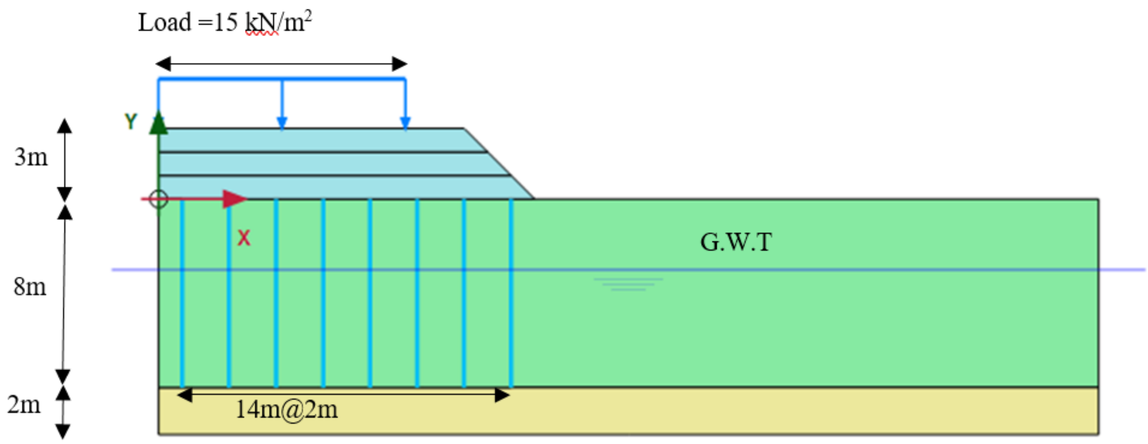

Fig. 3 - Conventional model without surcharge

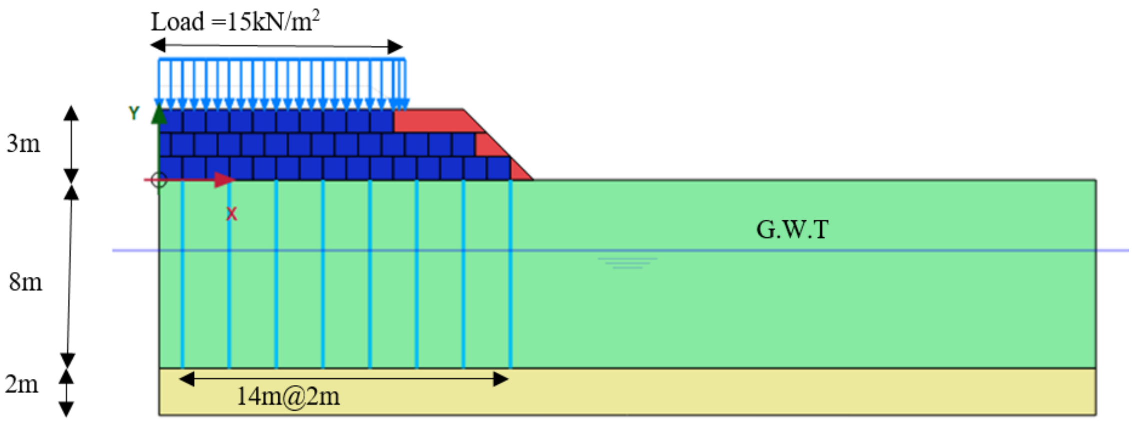

Fig. 4 - EPS embankment

3.3 Modeling Procedure

The construction of this road embankment was divided into four phases. The model with surcharge is constructed for a three-meter embankment and a one-meter for a surcharge. The surcharge is used to accelerate the consolidation time. After removing the surcharge, the road is open for the traffic used. The second model is a model without a surcharge. The embankment was constructed with a one- meter-thick soil layer up to a height of 4 meters. The traffic load for both models is set to 15 kN/m^2. Tables 4 and Table 5 show the stage of construction for the conventional embankment model. The construction time for an embankment with a surcharge is 310 days, and for an embankment without a surcharge is 222 days.

Table 4 - Construction phases for embankment with surcharge

Construction stage	Duration (day)	Fill thickness (m)
Initial Phase	0	0
First layer of embankment	14	1
Consolidation of first layer embankment	60	1
Second layer of embankment	14	2
Consolidation of second layer embankment	60	2
Third layer of embankment	14	3
Consolidation of third layer embankment	60	3
Surcharge layer	14	4
Consolidation of surcharge layer	60	4
Remove surcharge	14	3
Duration of construction stage	310	-
Duration of traffic load (10 years)	3650	-

Table 5 - Construction phases for embankment without surcharge

Construction stage	Duration (day)	Fill thickness (m)
Initial Phase	0	0
First layer of embankment	14	1
Consolidation of first layer embankment	60	1
Second layer of embankment	14	2
Consolidation of second layer embankment	60	2
Third layer of embankment	14	3
Consolidation of third layer embankment	60	3
Duration of construction stage	222	-
Duration of traffic load (10 years)	3650	-

The construction of the EPS embankment is continuing from the embankment with the surcharge model. This is because the model with a surcharge has a relatively lower settlement compared to the model without a surcharge. After removing the surcharge from the conventional embankment, the construction of EPS begins. The time interval for removing the surcharge is 14 days. The measurement of the EPS block used is one meter in height. Hence, the settlement of conventional and EPS embankments will be compared after the road opens to traffic within ten years.

The construction of the EPS embankment continues after removing the surcharge by layering the embankment with an EPS layer at a 3-meter height. After the construction is completed, the road will be open to traffic with an average live load of 15 kN/m^2. The duration of construction days for embankment improvements with EPS is 352 days. Table 6 shows the stage of construction for the EPS embankment. On the other hand, the influence of various densities of EPS and EPS embedded with geotextile has also been analysed to know the settlement difference for the embankment.

4. Results and Discussion

This section presents the study's data and analysis using the finite element method, which is PLAXIS 2D software. The analysis value is based on the selected node point (0,0). The coordinates of the embankment point (0,0) until (16,0) were chosen in the simulation of PLAXIS 2D to predict the total ground surface settlement.

Table 6 - Construction phases for EPS embankment

Construction stage	Duration (day)	Fill thickness (m)
Initial Phase	0	0
First layer of embankment	14	1
Consolidation of first layer embankment	60	1
Second layer of embankment	14	2
Consolidation of second layer embankment	60	2
Third layer of embankment	14	3
Consolidation of third layer embankment	60	3
Surcharge layer	14	4
Consolidation of surcharge layer	60	4
Remove surcharge	14	3
EPS installation - First layer	14	1
EPS installation - Second layer	14	2

EPS installation - Third layer	14	3
Duration of construction stage	352	-
Duration of traffic load (10 years)	3650	-

4.1 Surface Settlement without EPS

Figure 5 shows the settlement prediction of conventional embankment for full stage which include the stage construction from initial phase until the loading completion of the embankment - Embankment with surcharge and without surcharge. The difference settlement value for each graph is 80mm. Meanwhile, the settlement value when open for traffic load of 15 kN/m^2 within 10 years is 28mm as shown in Figure 6.

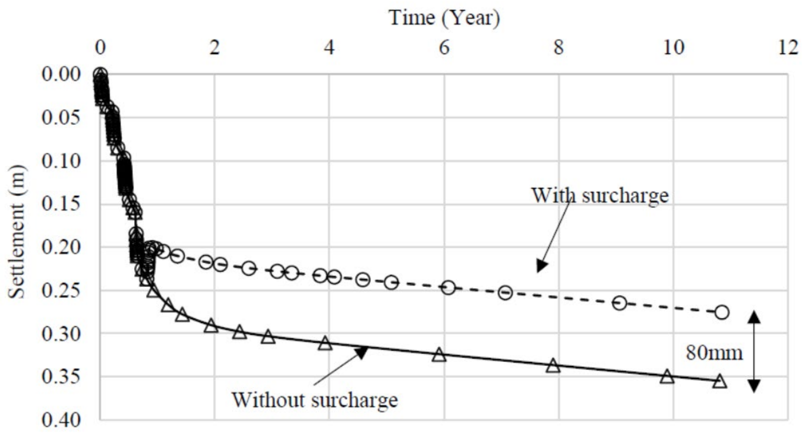

Fig. 5 - Settlement prediction of full stage construction of embankment with and without surcharge

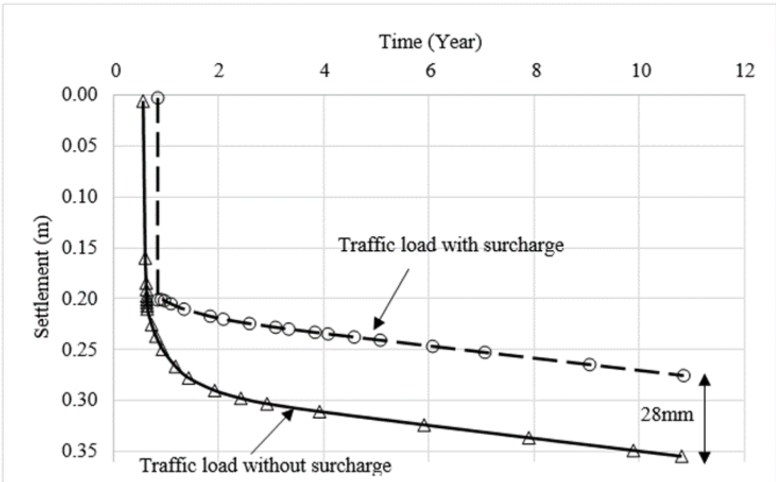

Fig. 6 - Settlement prediction considering the traffic load within 10 years

4.2 Surface Settlement with EPS

A total ground surface settlement graph from 0 m to 16 m embankments for conventional embankment model with surcharge and without surcharge were compared with EPS model in PLAXIS 2D analysis. From the PLAXIS 2D analysis, Figure 6 shows that the embankment settlement with surcharge is better than the settlement of embankment without surcharge. Therefore, in this study, the embankment model with surcharge were compared with embankment improved with EPS.

The construction of embankment with surcharge is 310 days, while the EPS embankment is 352 days. The settlement value for each model were evaluated after the construction of the embankment was complete. The prediction of settlement was analysed using PLAXIS 2D within ten years. Table 7 shows the summary of settlement. Figure 7, Figure 8 and Figure 9 shows the graph of settlement for conventional embankments and EPS embankments for different EPS densities.

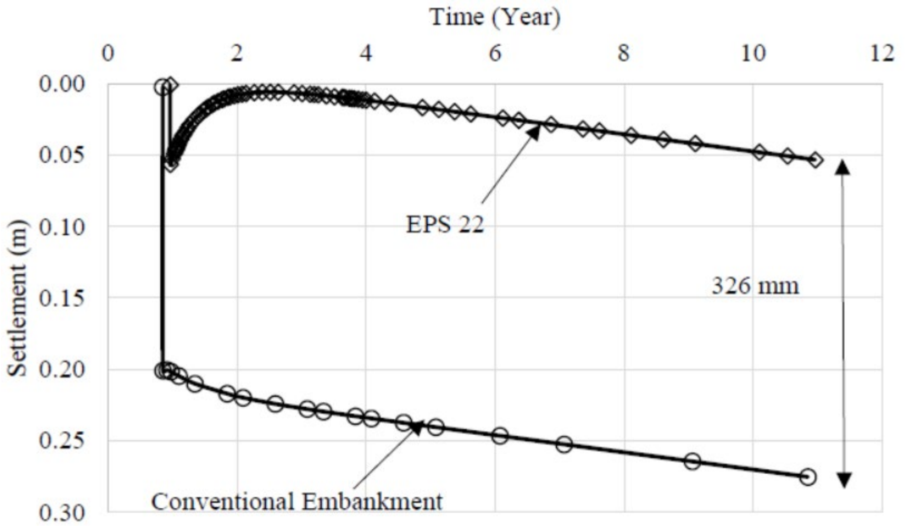

Fig. 7 - Settlement prediction for EPS 22 within 10 years

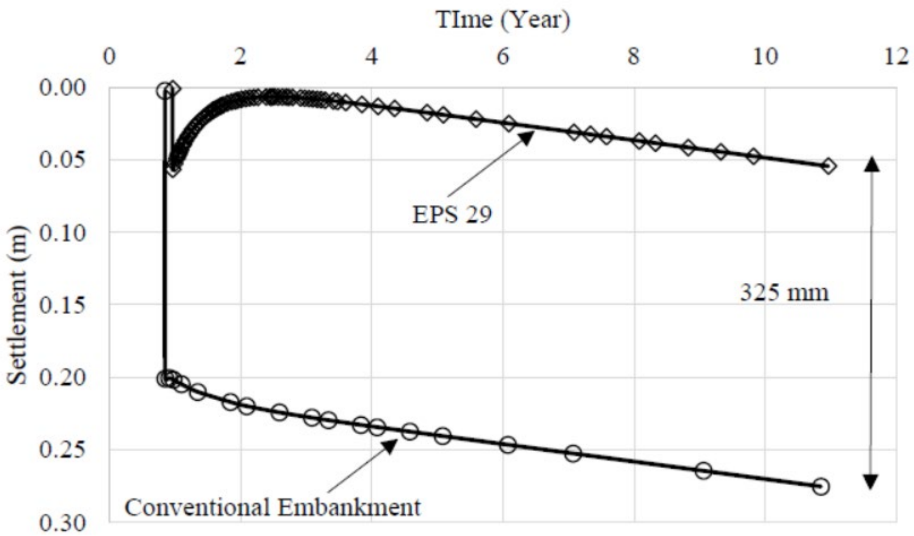

Fig. 8 - Settlement prediction for EPS 29 within 10 years

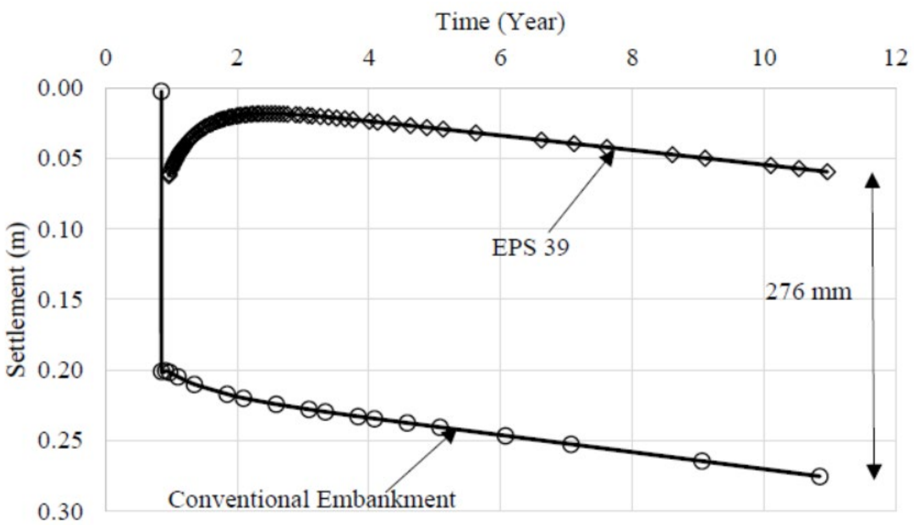

Fig. 9 - Settlement prediction for EPS 39 within 10 years

4.2.1 Effect of EPS Density on Settlement Behaviour

Three grades of EPS density were analysed to identify their effect on the settlement of soil. The EPS block has significant effects on the settlement of embankments. The settlement value for EPS after open for traffic within 10 years are 3.18 mm for EPS 22, 2.06 mm for EPS 29, and 1.51 mm for EPS 39 respectively. It is found that the settlement is directly proportional to the density of the EPS block, as shown in Figure 10. The result shows that the higher density of EPS-geofoam show better performance in terms of settlement reduction. Higher density of geofoams will have higher stiffness, requiring a higher load to deform them. The density also is an indicator of the quality, strength, and compressive resistance of EPS.

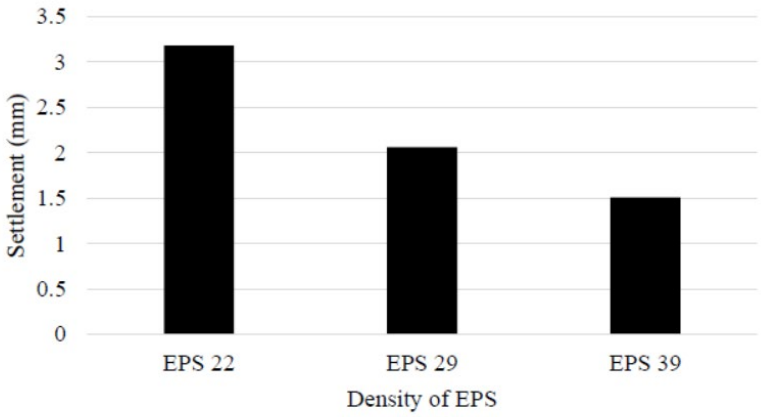

Fig. 10 - Settlement of various densities of EPS

4.2.1 Effect of Geotextile on Settlement Behaviour

In this analysis, the geotextile is used to strengthen the soil. However, there are not a significant difference when using geotextile. The value of settlement for geotextile embedded with EPS 22 is 3.17 mm, EPS 29 is 2.04, and EPS 39 is 1.49. Therefore, the settlement value does not have much difference because the EPS properties already strengthen the soil structure and reduce the settlement values. Figure 11 shows the graph of EPS with geotextile settlement values.

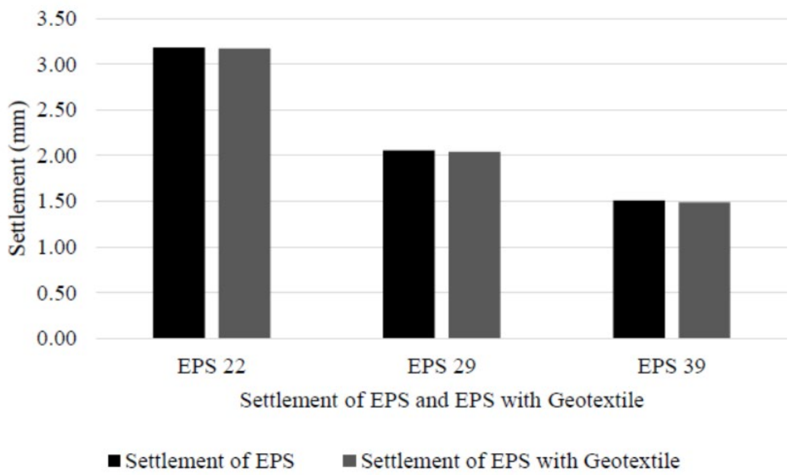

Fig. 11 - Settlement of EPS with and without geotextile

5. Conclusion

In conclusion, the model improved with surcharge gives a lower settlement than the model without surcharge due to it overconsolidation state after surcharge applied. But the expanded polystyrene block is the best model to reduce the settlement compared with the conventional model with a surcharge. Next, the different density of EPS gives different settlement value, and EPS 39 gives the lowest settlement value. Lastly, the geotextile embedded with EPS does not give a significant settlement value because the different settlement value is for EPS 22 with geotextile is 0.01mm, EPS 29 with geotextile and EPS 39 with geotextile is 0.02mm.

For the settlement percentage, embankment with surcharge is 39.77%, and embankment without surcharge is 50.11% for full-stage construction. The settlement percentage for open traffic until 10 years for embankment with surcharge is 13.92%, and for embankment without surcharge is 17.54%. Next, the settlement percentage for EPS is 17.17% (EPS 22), 17.12% (EPS 29), and 18.21% (EPS 39). The EPS settlement percentage for open traffic until 10 years is 17.33% (EPS 22), 17.38% (EPS 29), and 22.11% (EPS 39). Hence, all of the objectives of this study were achieved.

There are various areas for improvement and research for using EPS geofoam in pavement construction. Most of the improvements were related to the output parameters in PLAXIS 2D. This improvement helps to obtain more accurate and precise results from this modelling. Firstly, the properties of soft soil can be changed from the Mohr-Coulomb model to Hardening Soil Model to compare the two constitutive models. Second, EPS arrangement must be precise and close contact between each block during installation to minimise the incorrect EPS design. Next, the height of the surcharge load can be increased to two or three meters. This study uses only one-meter height for the surcharge load. Surcharge load is one method to accelerate the consolidation time of soil. Lastly, the consolidation time in every phase needs to increase to ensure that all the soil is in an over-consolidated state. The recommendation is increased to 90-days or 120-days since this study used 60-days of consolidation time.

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