International Journal of GEOMATE, Oct., 2022, Vol.23, Issue 98, pp.39-46
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2022.98.3415
Geotechnique, Construction Materials and Environment

EXPERIMENTAL STUDY OF AN EMBANKMENT OVER A SOFT SOIL LAYER USING CLAY-FLY ASH-EPS MIXTURES AS A LIGHTWEIGHT FILL MATERIAL

*Aditia Febriansya[1], Andri Krisnandi Somantri[2], Iskandar[3], Lindung Zalbuin Mase[4] and Reni Raafidiani[5]

[1,2,3]Department of Civil Engineering, Politeknik Negeri Bandung, Indonesia; [4]Department of Civil Engineering, University of Bengkulu, Indonesia; [5]Department of Civil Engineering, Politeknik TEDC Bandung, Indonesia

*Corresponding Author, Received: 19 April 2022, Revised: 19 Sept. 2022, Accepted: 09 October. 2022

ABSTRACT: The use of lightweight fill materials as highway embankment can reduce the total settlement of soft subsoil is one method of design improvement by reducing the weight of the embankment itself. The lightweight fill material used in this research is a mixture of clay, fly ash, and expanded polystyrene or EPS. The objective of this experimental test was to see how lightweight fill material affected the displacement that occurred in the soft subsoil layer. Three models with a scale of 1/10 were constructed using a mixture of clay, 25% fly ash, and variations of EPS content in each model, which were 0% (TR-00), 0.2% (TR-02), and 0.4% (TR-04) respectively. The TR-00 model shows higher stiffness than the TR-02 and TR-04 models according to experimental test results. At a displacement of 2.54 mm, the stiffness of the TR-02 and TR-04 models is reduced by 9.8% and 21.8%, respectively, compared to the TR-00 model. The overall displacement experienced by the TR-02 and TR-04 models, on the other hand, is less than that of the TR-00 model. The TR-04 specimen has the highest performance among other specimens with the lowest displacement while still having satisfactory stiffness.

Keywords: Geotechnical modeling, Soft soil, Soil-EPS mixtures, Lightweight fill material, Soil improvement

1. INTRODUCTION

The design and construction of highway embankments face several challenges, including bearing capacity failure, significant total settlement, differential settlement, and slope instability, which can be caused by the embankment's weight and/or a weak foundation [1-3]. To overcome these problems, several techniques have been developed and can be applied. Modifying a load of embankment construction (using lighter materials, adjusting the geometry of the embankment), improving the subgrade (preloading, surcharging, phased construction, excavation and soil replacement, stone column), accelerating consolidation (vertical drainage, vacuum consolidation), strengthening embankment construction, and providing additional structural support for embankment construction are some of these techniques [3-5].

By using lightweight fill materials to modify the load of the embankment, the weight of the embankment can be reduced so that the total settlement of subsoil also will be reduced. When compared to ordinary embankment materials, using lightweight fill material as an embankment construction material has several advantages, including the ability to achieve the same volume or elevation requirement with significantly less weight, improving slope stability, and reducing lateral earth pressure to retaining structures, abutments, or piers [6]. Geo-foam, air-foam, waste tire utilization, and expanded polystyrene (EPS) particle soil mixtures are just a few examples of lightweight fill materials that have been developed and used in a variety of projects. EPS is a thermoplastic material that will not rot, dissolve, or corrode over time. EPS is commonly used in two different ways: (1) EPS block (commonly known as geo-foam), and (2) EPS particulates mixed with soil and binder, also known as lightweight fill mixtures [1].

Due to its beneficial qualities, such as lightweight, high strength, good chemical and water stability, good mechanical properties, and ease of application, geo-foam has been utilized worldwide for more than 30 years [6-7]. Geo-foam weighs about 1/100 of the weight of most soils [1]. In 1965, Norway completed the first successful project utilizing geo-foam blocks, and in 1972, the first project to construct a roadway using geo-foam was completed. Furthermore, utilizing geo-foam as a backfill behind retaining structures can reduce lateral earth pressure by up to 75% [1].

Soil, binder, water, and light material make up the lightweight fill combination. Unused construction soil, sludge, clay, or standard sand can be used as soil. Meanwhile, light materials such as particulate polystyrene, foaming agent, waste foam, or rubber tires are commonly used [8-9]. The use of a lightweight embankment mixture has advantages over the use of geo-foam, including the following:

1. Since lightweight fill mixtures have the same flexibility as regular soils, they can settle on subsoils more adaptable.
2. Depending on the soil type and project needs, the strength and stiffness of the lightweight fill mixture can be adjusted by modifying the type and/or grade of the stabilizer.
3. The cost of using EPS particulates is less than that of geo-foam, not only because it can be mixed with soil to minimize EPS volume while meeting the same design/construction needs, but also because it can utilize waste materials and soil that was not used in the project [1].
4. By using a soil mixture containing EPS as a lightweight fill material, the bulk density of the soil can be reduced by 6 kN/m^3 to 15 kN/m^3, reducing the total weight of the embankment construction by 30% to 50% [10].
5. EPS could also minimize the swell-shrink potential of expansive soil as soil modifiers [4].

However, there are some disadvantages or limitations that need to be addressed when considering using EPS beads or blocks as construction materials such as:

1. The use of EPS as an addition a to lightweight fill mixture can reduce the shear strength of soil [6,9,11].
2. Due to its very low density, groundwater fluctuations will influence geofoam causing it to easily float away if not properly secured [6].
3. Geofoams have the potential to shrink after construction because of defect in the manufacturing process due to insufficient curing time.
4. EPS is not environmentally friendly in production, primarily through carbon emissions released during the process.

Based on the consideration of cost and the ability to reduce the weight of embankment material, the use of EPS particulate with soil and binder provides advantages in controlling settlement and avoiding possible bearing capacity failure and can be an attractive solution for highway embankment construction [1,10]. Therefore, further research is needed on the effect of using a mixture of lightweight fill materials as an embankment on the behavior of the embankment construction itself, its effect on the soil layer below it, and the pavement structure above it.

2. RESEARCH SIGNIFICANCE

The addition of very low-density EPS into soil has a large effect on the mass and volumetric properties of the resulting modified soil mixtures and their influence on mechanical properties. The addition of EPS has the potential to produce a modified soil with improved performance and a wide range of practical and beneficial applications. EPS-modified soils could be used as lightweight fill-in slopes or embankments to reduce total settlement and improve slope stability. Soil-EPS mixture could also be used to reduce earth pressures against retaining structures.

3. LITERATURE REVIEW

3.1 Lightweight Fill Mixture Modifications

Illuri [6] investigated a mixture of expansive clay with EPS particulate. EPS in this study functioned as a swell-shrink modifier. Experimental investigations were carried out in the laboratory with EPS content of 0%, 0.3%, 0.6%, and 0.9% of the weight of the soil. The test results indicate that the higher the EPS content in the mixture, the smaller the dry density of the soil mixture, and can also reduce the swell-shrinkage potential of the expansive soil. There is a reduction in the shear strength of the mixture as the EPS content increases. The addition of limestone to the mixture is carried ou, so that the shear strength of the mixture increases due to the pozzolanic reaction. The decrease in strength caused by the addition of EPS content in the mixture can be overcome by adding additives, so suggestions are given for further research, namely by adding industrial-by products, such as fly ash or slag as a chemical stabilizer to increase the decreasing soil shear strength parameters [6].

Rocco [7] investigated a mixture of clay soil with the addition of EPS particulate with a content of 0%, 0.5%, 1%, and 1.5% of the weight of the soil. The test results indicate that the addition of EPS can have a large effect on the dry density of the mixture and affect the mechanical properties of the mixture. For every 0.5% increase in EPS content, there an 8%-12% reduction in dry density and an increase in the void ratio of 15%-21%. Evaluation of the mechanical properties of the soil mixture with EPS showed that the shear strength of the modified soil was not harmful until the addition of EPS > 1%. The swelling-shrink potential decreases as EPS levels increase. Overall, the results of the laboratory evaluation showed that the soil mixture with EPS was still in the usable range. A significant decrease in density, along with an increase in EPS content, can be an alternative solution for embankment construction on soft soil, because it can reduce the settlement that occurs on the subgrade and reduce the driving force that causes landslides [7].

Previous research by Syahril [11] and Somantri [12] investigated the effect of stabilized clay mixture with fly ash as a binder and EPS as a lightweight material. In this study, researchers were involved in testing the physical and mechanical properties of the lightweight fill mixture. The fly ash content in the entire mixture is 25% of the weight of the soil, while the EPS content used is 0%, 0.2%, 0.4%, 0.6%, and 0.8% of the weight of the soil. Based on the results of the compaction indicated that the addition of EPS to the mixture could significantly reduce the maximum dry weight of the mixture, but the addition of EPS did not significantly affect the optimum water content of the mixture as shown in Figure 1 [11].

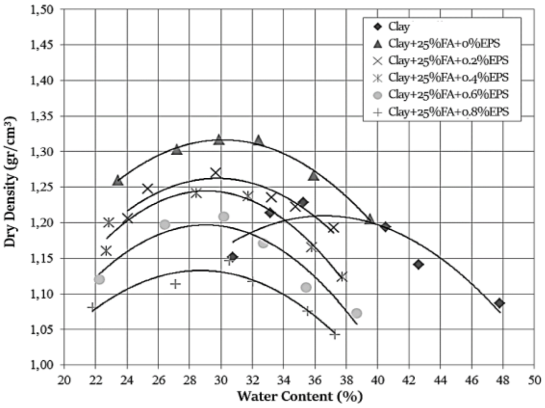

Fig. 1 Compaction curve lightweight fill mixtures [11]

The unconfined compressive strength test (UCS) was carried out to determine the effect of adding EPS to the lightweight fill mixture on the mechanical properties, namely the compressive strength (q_u) as shown in Figure 2. Figure 2 shows the higher the EPS content in the mixture, the compressive strength (q_u) of the mixture will decrease. However, the length of curing time affects the q_u value of the mixture, the longer the treatment time the mixture increases the q_u value which is quite significant.

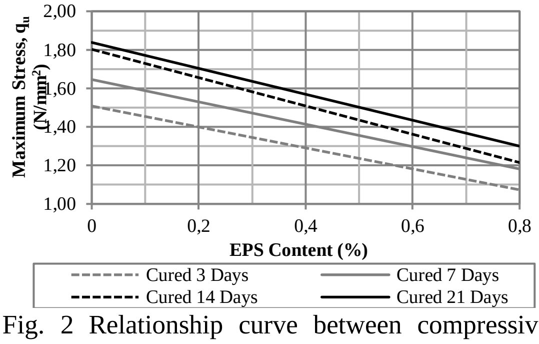

Fig. 2 Relationship curve between compressive strength and EPS content in mixtures [11]

3.2 Geotechnical Modeling

The embankment construction modeling is carried out to determine the effect on the subsoil settlement and the stability of the bearing capacity caused by the weight of the embankment itself and the load on it, as well as on the reinforcement or repairs carried out, namely the use of a mixture of lightweight fill materials.

Latha [13] investigated the geocell reinforcement mechanism in improving the bearing capacity of soft soil foundations and reducing settlement through model testing in the laboratory. Steel container measuring 1800 mm × 800 mm × 1200 mm was made for embankment model testing. On one side of the container, an acrylic sheet is used, so that the failure of the embankment model can be visualized, while on the other three sides, flat and rigid steel plates are used to create plane strain conditions in the container. In the test container, a 600 mm deep soft clay layer was constructed. The clay is mixed with a substantial amount of water and consolidated under a 10 kPa pressure. To achieve homogeneous characteristics, the soft clay layer was treated for one week. The value of CBR and shear strength of the soft clay layer was determined using undisturbed samples. By carefully managing the addition of water during mixing, density, moisture content, shear strength, and CBR of soft clay layers were maintained for all test models [13].

Pressure is applied to the embankment using a hydraulic jack, and the pressure intensity is increased gradually. The load addition is carried out when the displacement value reaches a stable condition. The additional load is measured using a proving ring. Two container-wide I-profile sheets of steel, rigid steel plates and a layer of expanded polypropylene placed on top of the embankment were used to distribute the load. To measure vertical and horizontal displacements, dial gauges are set at various positions along the embankment. Displacement behavior in the embankment, as well as strain in the geocell, are observed continuously until the model reaches failure [13].

Esmaeili [14] investigated the efficiency of micro piles to strengthen railroad embankments and determined the optimum arrangement of reinforcement elements through experimental testing of three embankment models with a geometric scale of 1/20, one specimen was an unreinforced embankment, while the other two were reinforced embankments. with micro piles. During laboratory testing, data, including embankment bearing capacity, embankment, subgrade displacement, and micropile axial strain were measured using instrumentation tools [14].

The behavior of the material is nonlinear, and the studied geotechnical structure consists of several materials interacting with each other. This problem results in a higher level of difficulty in investigating component behavior through theoretical models. One method to study the load-displacement behavior of geotechnical structures is to create a laboratory model, which must be able to represent the behavior of the prototype. In this case, the use of a suitable scale and the law of scale used is very important to describe the relationship between the model and the prototype [14].

The main criterion in selecting the dimensions of the container is a minimal disturbance between the slip surface of the embankment model and the side walls of the container. Therefore, the dimensions of the specified test container are 2.5 × 2.5 m^2 with a height of 2 m. Poorly graded sand with gravel (SP) and loamy sand (SC) were selected to model the subsoil and embankment layers, respectively. To carry out the embankment model at the best compaction, the embankment model is made per layer 10 cm thick with optimum moisture content. The compaction process is carried out using a 50 kg roller, rolled over the model until it reaches the maximum density [14].

4. RESEARCH METHOD

4.1 Materials

4.1.1 Expanded polystyrene (EPS)

Particle size analysis (PSA), particle weight measurements, and scanning electron microscopy (SEM) was carried out to determine the characteristics of the EPS particulate material used. PSA testing is carried out to determine the size distribution of the EPS particulates used so that when combined with the results of the particle weight test, the density of the EPS particulates used can be known. Figure 3 is a particulate size distribution curve from the PSA EPS test results used in this study. Based on the PSA test, the mean D_{50} of EPS particulates was 2.34 mm.

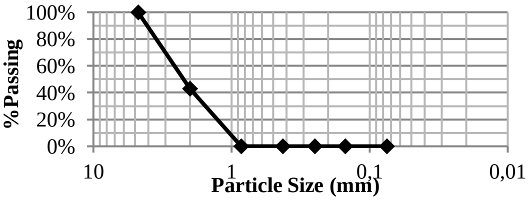

Fig. 3 Particle size distributions of EPS

The particle weight test was carried out using an electronic semi-micro-analytical balance Santorius BP 210 D with an accuracy of 0.01 mg. Based on the particle weight test, the mean weight of the EPS particulates is 0.00014 grams. SEM testing is used to inspect the topography and microstructure of the specimen at very high magnification using an electron microscope [15]. SEM testing in this study was carried out using the Hitachi SU3500 Scanning Electron Microscope. The results of the SEM test of the EPS particulate sample indicate that it can be seen in Figure 4. Based on both tests the weight content of the EPS particulates used is 20.39 kg/m^3.

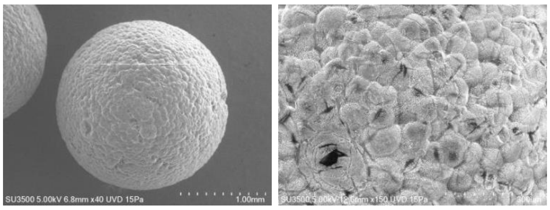

Fig. 4 SEM result of EPS; (left) 40x magnification; (right) 150x magnification

4.1.2 Fly ash

Fly ash can be used to improve the strength of unstable soils. Fly ash is a pozzolanic waste material or by-product formed from fine ash deposits arising from coal combustion in a steam power plant, and its utilization has a beneficial environmental impact [16].

To determine the characteristics of the fly ash material used, chemical analytical tests, PSA, and SEM were conducted. The results of the chemical analysis test can be seen in Table 1. Based on the results of the chemical analysis test, the fly ash produced from coal combustion at the Suralaya Power Plant is classified as class F because it has a SiO_2 + Al2O3 + Fe_2O_3 content of at least 70% and CaO content <10% [12]. Class F fly ash is a non-self-cementing pozzolan, so the binding process takes a long time [16]. The results of the SEM test of the fly ash sample of PLTU Suralaya Unit 8 can be seen in Figure 5, indicating the shape of the fly ash particles tends to be spherical with a mean D_{50} size of 34.31 µm.

Table 1. Fly ash chemical analysis

Compound	Content (%)	Compound	Content (%)
SiO_2	51.55	TiO_2	0.90
Al_2O_3	22.78	MnO	0.10
Fe_2O_3	7.91	P_2O_5	0.16
K_2O	1.08	LOI	2.44
Na_2O	3.51	H_2O-	0.22
CaO	5.58	SO_3	0.54
MgO	3.71		

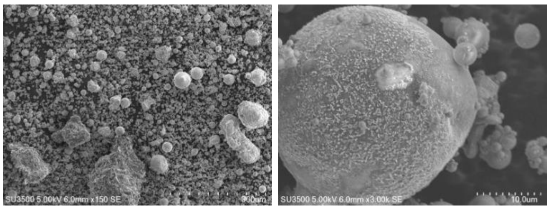

Fig. 5 SEM result of fly ash; (left) 150x magnification; (right) 3000x magnification

4.1.3 Soft clay

Soft clay samples taken from the Gedebage district of Bandung City, West Java Province, Indonesia, were tested in the laboratory to identify their characteristics, including physical and mechanical properties using Indonesian standards and ASTM standards. The results of laboratory tests can be seen in Table 2.

Table 2. Soil test results

Parameters	Unit	No. Samples	
		BH-1	BH-2
Density	gr/cm^3	1.62	1.60
Water content	%	62.16	61.76
Specific gravity	-	2.49	2.50
Liquid limit	%	72.80	77.50
Plastic limit	%	35.57	38.71
Plasticity index	%	37.23	38.79
Grain size analysis			
Gravel	%	0.00	0.00
Sand	%	5.02	4.46
Silt	%	19.26	28.06
Clay	%	75.72	67.48
UCS	N/cm^2	0.33	-

Based on the results of laboratory testing of the Gedebage clay sample, indicates that the sample is classified as CH (clay with high plasticity) with a very soft to a soft consistency. The results of the SEM test of clay samples that have been dried and mashed can be seen in Figure 6.

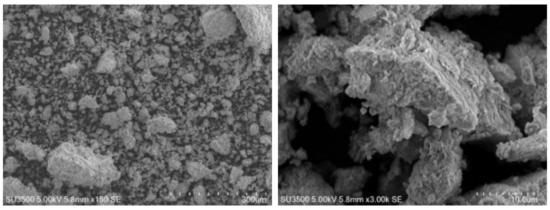

Fig.6 SEM result of soft clay; (left) 150x magnification; (right) 3000x magnification

4.1.4 Variables

The determination of the mixed content used in this study was based on the compaction curve of the lightweight fill mixture from previous studies done by researchers, namely in Figure 1 and Figure 2. The criteria for selecting the lightweight fill material are a mixture that has a maximum dry density (γ_{dmax}) that is still higher than the γ_{dmax} of the original clay, which is a soil mixture with EPS content of 0%, 0.2%, and 0.4% of the dry weight of the soil. Thus, three models of embankment construction with variations in EPS content in the embankment material were constructed, as shown in Table 3. Models with 0.6% and 0.8% EPS levels in this study were not investigated, this was due to low-density levels and low shear strength at higher EPS content. The fly ash content added to the mixture is 25% of the dry weight of the soil.

The physical and mechanical properties of soil mixtures (cohesion; c and angle of internal friction; φ) at 14 days of curing times are shown in Table 4. The addition of water is carried out carefully so that the optimum water content (ω_{opt}) and γ_{dmax} of each model can be achieved.

Table 3. Research variables

No	Variable	Symbol
1	CH+25%Fly Ash+0.0%EPS	TR-00
2	CH+25%Fly Ash+0.2%EPS	TR-02
3	CH+25%Fly Ash+0.4%EPS	TR-04

Table 4. Variable parameters at 14 days

Variable	γ_{dmax} (gr/cm^3)	ω_{opt} (%)	γ (gr/cm^3)	c (N/mm^2)	φ (°)
TR-00	1.210	36.6	1.715	0.55	13.77
TR-02	1.317	30.2	1.638	0.52	13.53
TR-04	1.263	29.7	1.607	0.49	13.30

4.2 Initial Modeling

Initial modeling of embankment construction, rigid pavement, and soft subsoil layer were carried out to obtain a prediction of the failure patter, so that the appropriate dimensions and slopes were obtained to anticipate the limited internal dimensions of the test container. The initial modeling was analyzed using a numerical method with a geometric scale model in accordance with what will be made in the laboratory, which is a scale of 1/10. The intended failure expectation is that the magnitude of the stress on the bottom and right side of the model has reached a value of 0, so that disturbances caused by the limited dimensions of the test container can be anticipated.

4.3 Experimental Setup and Instrumentations

Physical modeling is done to validate theoretical or empirical hypotheses [17]. Modeling of embankment construction, rigid pavement, and soft subsoil layer was carried out at a geometric scale of 1/10 of the actual construction. Many geotechnical researchers have proposed various variations of the law of scale. Wood [17] collected the laws of this scale and presented them in an integrated format, which can be seen in Table 5. The exponent value of several scale factors is 0.5 for sandy soil (granular), and 1.0 for clay soil (cohesive).

Table 5. Laboratory scale factors [17]

Quantity	Scale factors	Quantity	Scale factors
Length	1/n	Force	$1/n^3$
Mass density	1	Force/unit length	$1/n^2$
Acceleration	1	Strain	$1/n^{1-\alpha}$
Stiffness	$1/n^{\alpha}$	Displacement	$1/n^{2-\alpha}$
Stress	1/n	Time (creep)	1

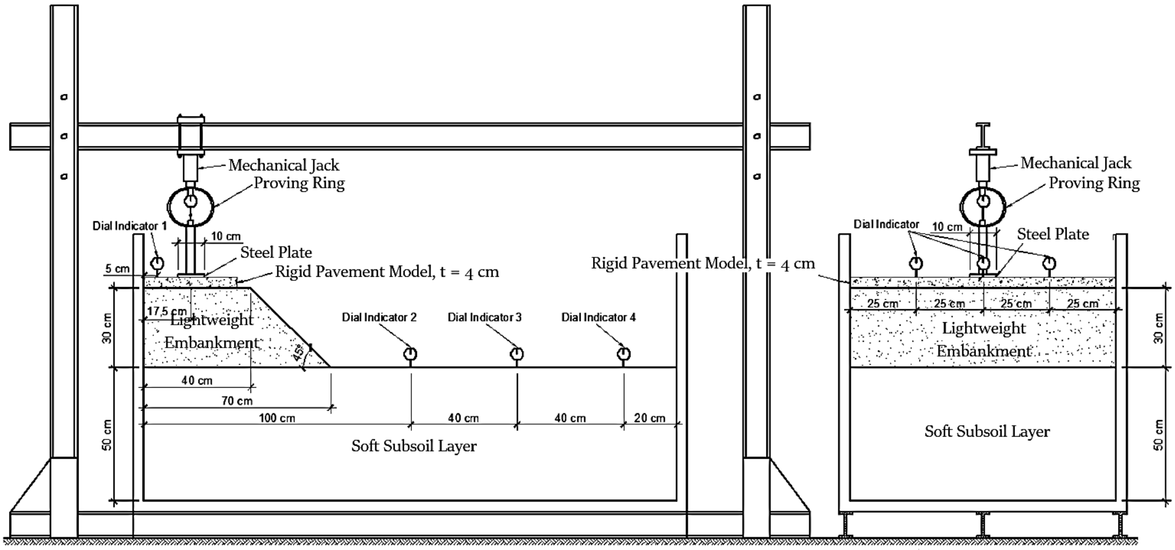

Fig. 7 Experimental setup and instrumentation of embankment construction over soft subsoil layer

Researchers prepared a steel container with dimensions of 2000 mm long × 1000 mm wide × 1000 mm high to model soft subsoil layers, embankment construction, and rigid pavement. On the front and sides of the container, acrylic sheets are installed so that the failure/collapse pattern of the embankment construction and soft subsoil when it is given a load can be visualized, while on the other two sides it is made of steel plates to create plane strain conditions. All parts where there is a connection (between the plate and the frame) are coated with silicone to prevent water from seeping out. Steel containers are made quite rigid so that there is no deformation of the container during the preparation of the model test object or when the test is carried out. Model testing was carried out with differences in the lightweight fill soil mixture on the embankment construction model, according to the research variables in Table 3.

The instrumentation used in the model loading test consists of the steel container itself, loading frame, mechanical jack, analog dial indicator, and load measuring ring (proving ring). Figure 7 shows is a schematic of a steel container and loading frame testing model on a 1/10 scale that will be used by researchers to model soft soil layers, embankment construction, and rigid pavement structure models with installed instrumentations.

After the treatment/curing process, each model of lightweight embankment construction and rigid pavement structure has reached the specified number of days, which are 14 and 7 days, respectively. The loading process starts using a mechanical jack that has been connected to a proving ring with the pressure intensity being increased gradually (monotonic static loading) until the model collapses or the load starts to decrease as the displacement of the model increase.

5. DISCUSSION

5.1 Load-Displacement Relationship

In this section, the comparison of the results of testing three embankment construction models in the laboratory, one model that does not use EPS in the embankment mixture (TR-00), and two models that use EPS in the embankment mixture (TR-02 and TR-04) will be described. Figure 8 is a load-displacement relationship curve from the test results of the TR-00, TR-02, and TR-04 models. The comparison is used to determine how much influence soft subsoil is produced by the use of lightweight fill material, namely a mixture of soil, 25% of fly ash, and variations in EPS content.

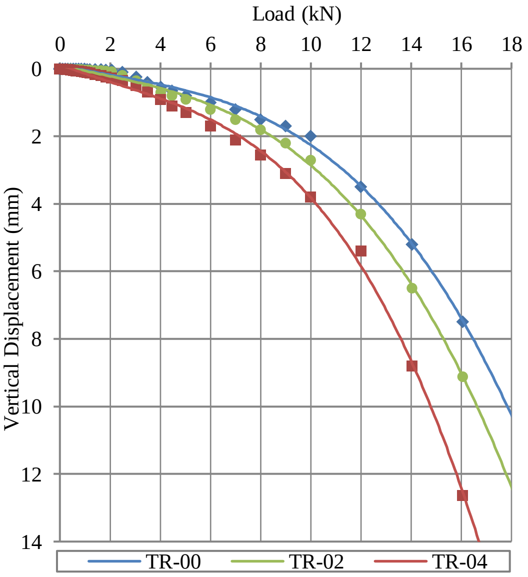

Fig. 8 Load-displacement relationship curve of TR-00, TR-02 and TR-04

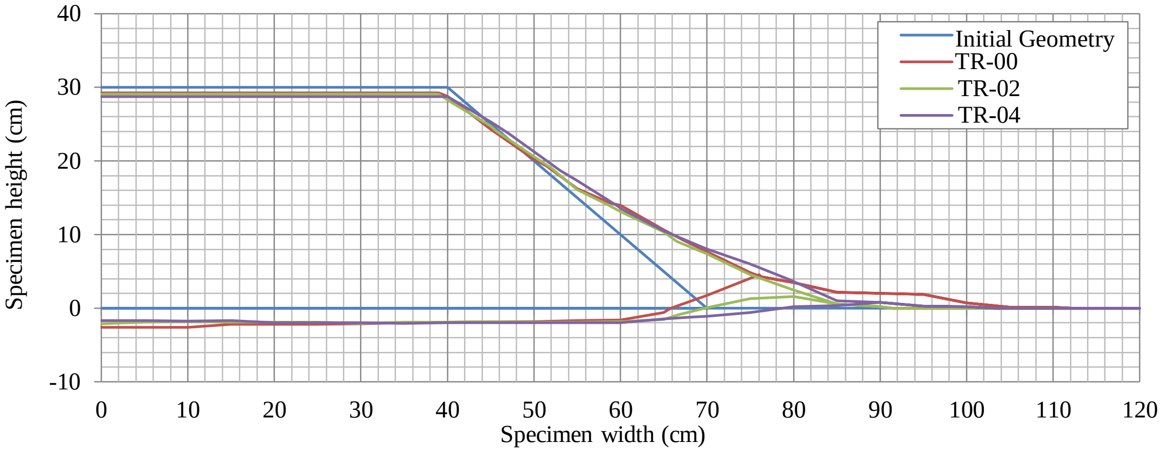

Fig. 9 Specimen failure visualization of TR-00, TR-02 and TR-04 specimens after load test

It can be observed that the TR-00 model has higher stiffness, higher maximum load capacity and smaller displacement compared to the TR-02 and TR-04 models. Models TR-02 and TR-04, which use a mixture of lightweight fill material (mixture of clay, fly ash and EPS), exhibit lower stiffness and strength compared to the model TR-00 test specimens, as shown in Figure 8. There is a reduction in stiffness, of approximately 9.8% (TR-02) and 21.8% (TR-04) of the specimen TR-00 at a displacement of 2.54 mm (0.1 inches), from about 10.48 kN (TR-00) to 9.45 kN (TR-02) and 8.20 kN (TR-04). Stiffness reduction of about 7.5% (TR-02) and 17.9% (TR-04) of the specimen TR-00 at a displacement of 7.5 mm (last displacement reading of model TR-00), from about 16.11 kN (TR-00) to 14.90 kN (TR-02) and 13.22 kN (TR-04). The amount of reduction that occurs is calculated by reducing the stiffness of TR-00 by TR-02 or TR-04 and then dividing it by the stiffness of TR-00.

It was expected that the reduction in stiffness of the model using EPS would occur, given the results of testing the strength of the soil mixture using EPS as an added material, resulting in lower shear strength and stiffness values compared to soil mixtures that did not add EPS. Several factors can contribute to the TR-02 and TR-04 model's decreased shear strength, including:

1. Because the particulate characteristics of EPS are resistant to shifting, the presence of EPS can restrict soil movement to a denser configuration during the compaction process, resulting in a reduction in model stiffness to a certain degree.
2. The characteristics of class F fly ash as a binder used in soil mixtures are non-self-cementing, so it takes a longer time for the strength of the mixture to increase. This problem can be overcome by replacing or adding another binder that has a high CaO content in the mixture such as cement to activate fly ash, to increase the shear strength of the mixture.

5.2 Failure Modes

Although the model that uses EPS as a soil modifier for the lightweight fill mixture has lower stiffness and larger displacement, the total displacement of models TR-02 and TR04 which is observed through visualization of the failure mechanism of the model in Figure 10 is lower than that of Model TR-00. The TR-02 and TR-04 models experience less total displacement than the TR-00 model, which is about 19% and 36% respectively at the bottom of the model compared to the TR-00 model. The total displacement is observed at 0 cm from the left side of the model (y = 0) in Figure 9.

At 80 – 100 cm from the left side of the model, there is an increase of displacement in the soft subsoil layer caused by horizontal and vertical stresses that occur in the model. The magnitude of the displacement decreases as the EPS content increases in the soil mixture used as the embankment material. Models TR-02 and TR-04 show a significant reduction in the displacement that occurs. Another thing that can be observed is the change in the overall embankment construction geometry, namely the change in the embankment slope from the original 45° to ±30° for the TR-00, TR-02, and TR-04 models. During the investigation and experimental setup, the displacement of the soft subsoil layer is quite difficult to observe. This is due to the subsoil beginning to displace during the construction of the embankment and pavement model. The magnitude of the displacement in soft subsoil can only be observed visually because of the limited instruments used, so obtaining the magnitude of the displacement caused by the weight of the embankment construction and external loads can be carried out numerically.

6. CONCLUSIONS

Based on experimental testing, obtained several things as follows:

1. The TR-00 model has higher stiffness and a smaller displacement than the TR-02 model, and there is a reduction in strength of about 9.8% (TR-02) and 21.8 % (TR-04) compared to the specimen TR-00 at a displacement of 2.54 mm, and about 7.5 % (TR-02) and 17 % (TR-04) compared to the specimen TR-00 at a displacement of 7.5 mm, according to the experimental test results. The reduction in strength is due to the model using EPS having a lower shear strength value than the soil mixture that does not add EPS.
2. The total displacement of models TR-02 and TR04, as shown through visualization of the model's collapse mechanism, is lower than that of model TR-00. The TR-02 and TR-04 models have less total displacement than the TR-00 model, which is around 19% and 36%, respectively, at the bottom of the model.

7. REFERENCES

[1] Miao L., Wang F., Han J., Lv W. and & Li J., "Properties and Applications of Cement-Treated Sand-Expanded Polystyrene Bead Lightweight Fill", J. Mater. Civ. Eng., ©ASCE, Vol 25, No. 1, 2013, pp. 86-93.

[2] Arsyad M., Mochtar I. B., Mochtar N. E., and Arifin Y. F., “Road Embankment Full-Scale Investigation on Soft Soil with Geotextile Stabilization”, International Journal of Geomate, Vol. 19, No. 71, 2020, pp. 145-152.

[3] Thaothip A. and Kongkitkul W., “Strength and Deformation Characteristics of Eps Bead-Mixed Sand”, International Journal of Geomate, Vol. 13, No. 35, 2016, pp. 8-15.

[4] Liu H. L., Ng C. W. W., and Fei K., "Performance of a Geogrid-Reinforced and Pile-Supported Highway Embankment over Soft Clay: Case Study", J. Geotech. Geoenviron. Eng., ©ASCE, Vol. 133, No. 12, 2007, pp. 1483-1493.

[5] Somantri A. K., Febriansya A., Rizkiya D. P., and Azhari R. N. F., “Subgrade Improvement with Potential for Liquefaction with Stone Column Method at Tebing Tinggi Junction”, Potensi, Vol. 23, No. 1, 2021, pp. 67-76. (in the Indonesian Language)

[6] Illuri H. K., “Development of Soil-EPS Mixes for Geotechnical Applications”, Doctor of Philosophy, School of Urban Development, Center for Built Environment and Engineering Research, Queensland University of Technology, Australia, 2007, pp. 9-63.

[7] Rocco N. T., “Characterization of Expanded Polystyrene (EPS) and Cohesive Soil Mixtures”, Doctor of Philosophy, Faculty University of the Graduate, Missouri University of Science and Technology, 2012, pp. 90-113.

[8] Fard M. K., Chenari R. J., and Soheili F., "Shear Strength Characteristics of Sand Mixed with EPS Beads Using Large Direct Shear Apparatus", EJGE, Vol. 20, No. 8, 2015, pp. 2205-2220.

[9] Guocai W., Ling S., and Feili J., "Study on the Strength Properties and Failure Mode of Recycled Sludge Lightweight Soil". Applied Mechanics and Materials, Vol. 275-277, 2013, pp. 1281-1284.

[10] Rekha S., and Kumar P. R., "Properties and Application of EPS beads as a Lightweight Fill Material for Embankment Construction", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, No. 5, 2014, pp. 428-438.

[11] Syahril, Somantri A. K., and Febriansya A., “The Effect of EPS Addition to Soil Stabilized with Fly Ash as Lightweight Fill Materials for Embankment Construction“, J. Phys.: Conf. Ser., Vol. 1364, 2019, pp. 1-9.

[12] Somantri A. K., Syahril, Hendry, Iskandar, and Febriansya A., “Effect of Addition of Particulate Expanded Polystyrene on Fly Ash Stabilized Soil on Optimum Moisture Content and Maximum Dry Fill Weight as Light Fill Material”. Proceeding of Industrial Research Workshop and National Seminar, Vol. 9, 2018, pp. 463-471. (in the Indonesian Language)

[13] Latha G. M., Rajagopal K., and Krishnaswamy N. R., "Experimental and Theoretical Investigations on Geocell-Supported Embankments", International Journal of Geomechanics, ©ASCE, Vol. 6, No. 1, 2006, pp. 30-35.

[14] Esmaeili M., Nik M. G., and Khayyer F., "Experimental and Numerical Study of Micropiles to Reinforce High Railway Embankments", International Journal of Geomechanics, ©ASCE, Vol. 13, No. 6, 2013, pp. 729–744.

[15] JEOL, "SEM Scanning Electron Microscope A to Z - Basic Knowledge for Using The SEM", JEOL Ltd., Japan, 2009, pp. 3-6.

[16] Hardiyatmo H. C., " Soil Stabilization for Road Works ", Yogyakarta: Gadjah Mada University Press, 2010, pp. 171-175. (in Indonesian Language)

[17] Wood D. M., "Geotechnical Modelling". New York: Taylor and Francis Group, 2004, pp. 246-258.