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To cite this article: Syahril *et al* 2019 *J. Phys.: Conf. Ser.* **1364** 012077

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The Effect of EPS Addition to Soil Stabilized with Fly Ash as Lightweight Fill Materials for Embankment Construction

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Abstract. Design and construction of road embankment presents several challenges, including the possibility of bearing capacity failure, large total settlement, differential settlement, and slope instability, which may result from the weight of the embankment construction itself, and/or weak foundation. A number of techniques have been developed and can be used to overcome these problems, one of them is by modifying the weight of the embankment itself with the use of lightweight materials, such as soil-EPS mixture. The use of soil-EPS mixture as lightweight material provides several advantages, among which can achieve the same volume or elevation requirement with a significantly lighter weight compared to ordinary materials, improving slope stability, embankment over high compressibility soil, and to reduce soil pressure to soil retaining structures, abutment or bridge pillar. Fly ash also added to act as binder to increase shear strength of mixture. The result of the compaction test shows that the addition of a small amount of EPS to the mixture can significantly reduce the maximum dry density of the mixture. Triaxial UU and UCS test results show a reduction in mixture strength as EPS contents increase, but due to the presence of fly ash increases the strength of mixture as the number of day increases, so that the use of lightweight materials has the potential to be one of soil improvement solutions.

1. Introduction

The design and construction of the road embankment presents several challenges, including the possibility of bearing capacity failure, large total settlement, differential settlement, and slope instability, which may result from the weight of the embankment construction itself, and/or weak foundation [1]. A number of techniques have been developed and can be used to overcome these problems. These techniques include modifying the load of the embankment itself (the use of lightweight materials, changes in the embankment geometry), improving the ground (preloading, surcharging, gradual construction, excavation and replacement of soil, stone column), accelerating consolidation (vertical drainage, vacuum consolidation), retrofitting construction, and providing additional structural support for the construction of embankments [2].

One method of soil improvement is to reduce the weight of the embankment construction by the use of lightweight materials, especially when there is soft soil. The use of lightweight material as embankment material provides several advantages, among which can achieve the same volume or elevation requirement with a significantly lighter weight compared to ordinary materials, improving



slope stability, embankment over high compressibility soil, and to reduce ground pressure to soil retaining structure, abutment or bridge pillar [3].

Lightweight fill mixture consists of soil, binder, water and lightweight material. The soil may be selected from unused soil on construction site, sludge, clay or standard sand. Whereas, lightweight materials are usually selected, among others, expanded polystyrene (EPS) beads, foaming agents, waste foam or rubber tires [4] [5]. The use of a lightweight fill mixture has the following advantages:

- 1) Lightweight fill mixture has similar flexibility to ordinary soil, so it can occupy more adaptively on the ground [1].
- 2) The strength and stiffness of the mixture can be adjusted by changing the type and/or content of the binder, depending on the type of soil and the needs of the project [1].
- 3) The cost of using EPS beads is lower than geo-foam, not only because it can be mixed with soil to save the EPS volume and meet the same reduction requirements, as well as to recycle waste-categorized materials [1].
- 4) The use of soil mixtures with EPS as a lightweight material can reduce the weight of the soil by 6 kN/m³ to 15 kN/m³, so the total weight of the embankment construction can be reduced by 30% to 50% [6].
- 5) The use of EPS as soil modifier can reduce swell-shrink potential of expansive soil as well [3] [7].

Based on cost and the capacity to reduce the weight of the embankment, the use of EPS beads provides an advantage in controlling the settlement and avoids the possibility of bearing capacity failure, also can be an attractive solution for highway construction [1] [6]. Therefore, further research is needed on the effect of adding EPS on soil mixtures.

2. Methodology

2.1 Material

The materials used in this research consist of clay type of soil, fly ash as binder, and EPS beads as lightweight material as shown in Figure 1. Soft clay sample is originated from Gedebage region, Bandung city, West Java province, Indonesia. Table 1 shows the characteristic of clay sample.

Fly ash (FA) can be used to modify soil and increase soil strength. Fly ash is a waste material or by-product, derived from fine ash deposits from the burning coal on thermal power plant, so their use has a positive impact on the environment [8]. Based on coal sources used to generate power, fly ash is classified into Class C or class F. Fly ash class C has SiO₂ + Al₂O₃ + Fe₂O₃ content at least 50% and has self-cementing property due to the presence of Calcium Oxide (CaO) of 20% - 30%. Fly ash class F has SiO₂ + Al₂O₃ + Fe₂O₃ content at least 70%, with low lime content, it has non-self-cementing property [7] [8]. Fly ash sample used in research is originated from Suralaya Unit 8 thermal power plant, Banten province, Indonesia. Table 2 shows the characteristic of fly ash sample. According to Table 2, fly ash used in research can be classified as class F. Fly ash used in this research was determined as much as 25% of the weight of dry soil for all specimens. This is based on research that have been done by previous researchers that state the optimum content of fly ash is at 25% measured from dry soil weight [9] [10] [11].



Figure 1. Materials used in research

Table 1. Characteristics of Clay

| Parameters | Value | Units |
|------------------|-------|--------------------|
| ω | 62.16 | % |
| γ_m | 1.62 | gr/cm ³ |
| Gs | 2.49 | |
| Liquid limit | 72.80 | % |
| Plastic limit | 35.57 | % |
| Plasticity index | 37.23 | % |
| Gravel content | 0.00 | % |
| Sand content | 5.02 | % |
| Silt content | 19.26 | % |
| Clay content | 75.72 | % |
| q_u | 3.30 | N/cm ² |

Table 2. Characteristics of Suralaya Fly Ash

| Parameters | Content | Units |
|--------------------------------|---------|---------------|
| Al ₂ O ₃ | 22.78 | % |
| CaO | 3.19 | % |
| Fe ₂ O ₃ | 7.91 | % |
| K ₂ O | 1.08 | % |
| MgO | 3.71 | % |
| Na ₂ O | 3.51 | % |
| SiO ₂ | 51.55 | % |
| TiO ₂ | 0.90 | % |
| LOI | 2.44 | % |
| D ₅₀ | 34.31 | μm |

Expanded polystyrene (EPS) is a white polymeric (plastic) foam, widely known used as packaging materials. EPS has a very low thermal conductivity and almost 98% of its volume consists of air. EPS on the application can be used in the form of blocks (also known as geo-foam) or beads. The use of EPS is very broad, due to its favorable characteristics, such as very low density, good insulation properties, chemical and water resistance, low cost and ease during construction [7]. EPS beads used in research has mean D50 of 2.34 mm and density of 20.39 kg/m³. The amount EPS contents used in this research are 0%, 0.2%, 0.4%, 0.6%, and 0.8% measured from the weight of dry soil.

2.2 Laboratory Investigation

Laboratory investigation has been carried out to obtain mechanical properties of soil-fly ash-EPS mixtures and to determine the effect of EPS addition on mixtures. A series of test have been conducted to obtain these parameters, such as standard compaction test, unconfined compressive strength (UCS) test, and triaxial unconsolidated undrained (UU) test. Compaction test was carried out to determine the value of maximum dry density (MDD) and optimum moisture content (OMC) of each mixture. Test was carried out based on ASTM D698-12e2 [12]. The test results are used for manufacturing specimen for UCS and triaxial UU tests. UCS test was carried out to determine strength parameters, such as maximum stress (q_u) and stiffness of each mixture as shown in Figure 2. UCS test was carried out based on ASTM D2166 / D2166M-16[13]. Triaxial UU was carried out to determine shear strength parameters of each soil-fly ash-EPS mixture, such as cohesion (c) and friction angle (ϕ) as shown in Figure 3. The test was carried out based on ASTM D2850-15 [14].

**Figure 2.** UCS Test**Figure 3.** Triaxial UU Test

3. Test Result

3.1 Compaction Test

The result of compaction test can be seen in Figure 4 and the specimens can be seen in Figure 5. Based on the compaction test result, it shows that the addition of fly ash to ordinary soil can significantly increase MDD, and significantly decrease OMC as well. This is believed to be due to very small fly

ash particle size characteristics filling voids in the soil, thus increasing MDD as well as lowering OMC mixture. The magnitude of this change can be seen in the ordinary clay curve against clay+25%FA+0%EPS curve, showing an increase in MDD from 1.210 gr/cm³ to 1.317 gr/cm³, while the OMC decrease from 36.6% to 30.2%. A significant reduction of OMC provides an advantage, which can reduce water quantities during the construction of embankment.

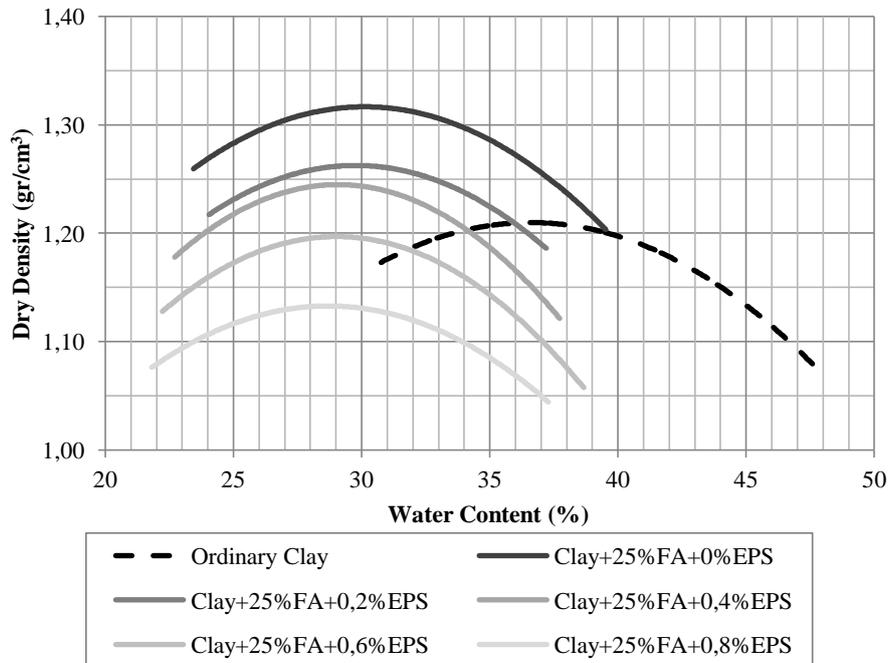


Figure 4. Compaction curve of soil, fly ash, and EPS mixtures [15]



Figure 5. Extruded specimen of soil, 25% fly ash and varies content of EPS mixture

The addition of EPS to stabilized soil with fly ash shows the opposite, a significant decrease in the MDD of the soil mixture occurred as expected, accompanied by a slight decrease in OMC. This is shown in Figure 4, a downward shifting curve shifts along with increasing EPS contents in the soil mixture. The soil-fly ash-EPS mixture curves are still parallel with the control compaction curve (clay+25%FA+0%EPS), indicating the addition of EPS can reduce the weight of the mixture. Each compaction curve shows the dry density increase as the water content increases, and after reaching the optimum moisture content, the dry density decreases with increasing moisture content. To facilitate the observation, the authors made the relationship curve between MDD to EPS content shown in Figure 6 and the relationship curve between OMC to EPS levels shown in Figure 7. MDD reduction provides advantages, which reduce the embankment weight, improving slope stability, and to reduce ground pressure to structures. A slight reduction of OMC provides an advantage also, which can reduce water quantities during the construction of embankment. The use of EPS content over 1% of soil weight is not recommended due to the result of MDD being lower than 1 gr/cm^3 .

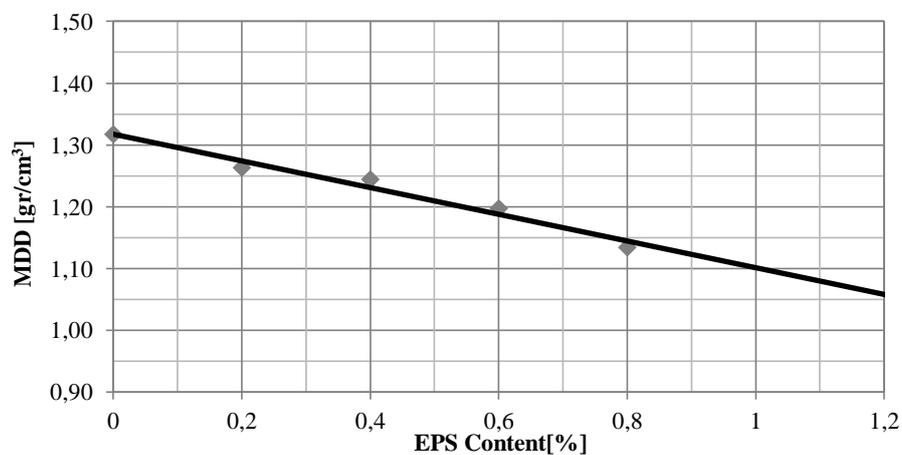


Figure 6. Relationship curve between MDD and EPS content of soil-fly ash-EPS mixtures

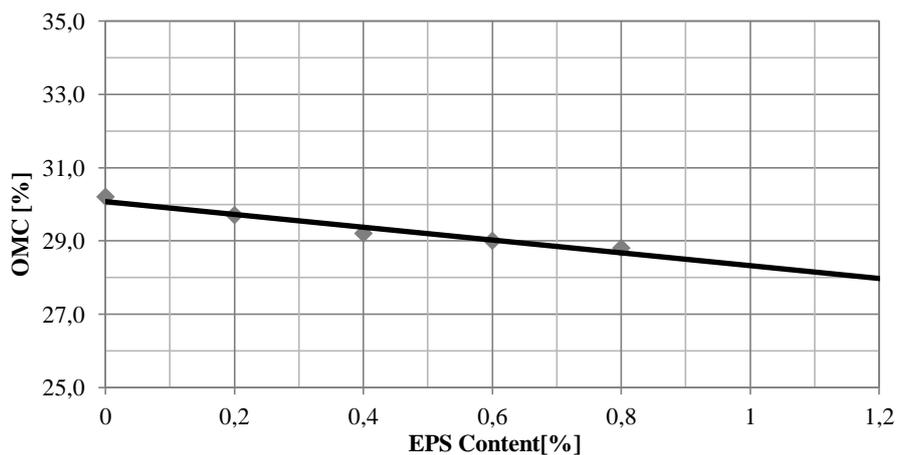


Figure 7. Relationship curve between OMC and EPS content of soil-fly ash-EPS mixtures

The reduction of MDD mixture as shown in Figure 6 may be affected by the characteristics of the EPS beads itself, as follows:

- Very small density, the reducing of dry density mixtures is largely influenced by very small density of EPS beads. The addition of a few percent EPS to the mixture can decrease the weight of the soil mixture, since part of the volume of the soil is replaced by EPS.

- Resistant to pressure, the ease of mixture to be compacted can be reduced by the addition of EPS at higher content. This is due to the nature properties of EPS itself at the time of compaction, which is energy absorption and elastic rebound [8].
- Resistant to shifting, at a certain degree, the presence of EPS may be able to inhibit the movement of the soil to a denser configuration during the compaction process, especially at higher EPS contents [8].

3.2 UCS and Triaxial UU Test

The result of UCS test of soil-fly ash-EPS mixtures can be seen in Figure 8. The test result shows that the maximum stress (q_u) of soil-fly ash-EPS mixtures decreases as the EPS content increases. But due to the presence of fly ash that act as binder, it increases the maximum stress of mixture as the number of day increases, as shown in Figure 8.

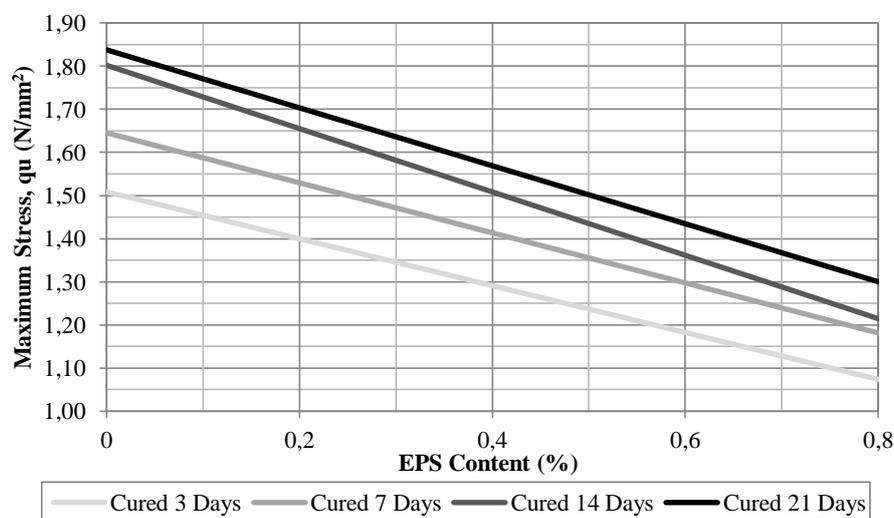


Figure 8. Relationship curve between maximum stress (q_u) and EPS content of soil-fly ash-EPS mixtures

The result of triaxial UU test of soil-fly ash-EPS mixtures can be seen in Figure 9 and Figure 10. The test result shows that the cohesion (c) mixtures decrease as the EPS content increases. But due to the presence of fly ash that act as binder, the cohesion of mixtures increase as the number of day increases, as shown in Figure 9. The opposite behavior occurred at the friction angle, as shown in Figure 10, as the numbers of day increase, the friction angle decreases. The presence of EPS beads increases the friction angle at early curing time, but then decreases as the number of day increases. This happens when the cohesion increases. The reduction of mixture strength as shown in Figure 9 to Figure 10 may be affected by several factors, as follows:

- The EPS beads characteristic that resistant to shifting, so at a certain degree, the presence of EPS may inhibit movement of the soil mixtures to a denser configuration during the compaction process resulting in decreased mixture strength.
- The presence of fly ash can increase the mixture shear strength, but the rate of increasing was not significant. This happens because the characteristic of fly ash class F as the binder used in the soil mixture itself has nonself-cementing properties, so it takes longer time for soil mixture strength to increase. This problem can be solved by replacing or adding another binder that has high CaO content to the mixture, such as cement to activate fly ash, thereby increasing the shear strength of the mixture.

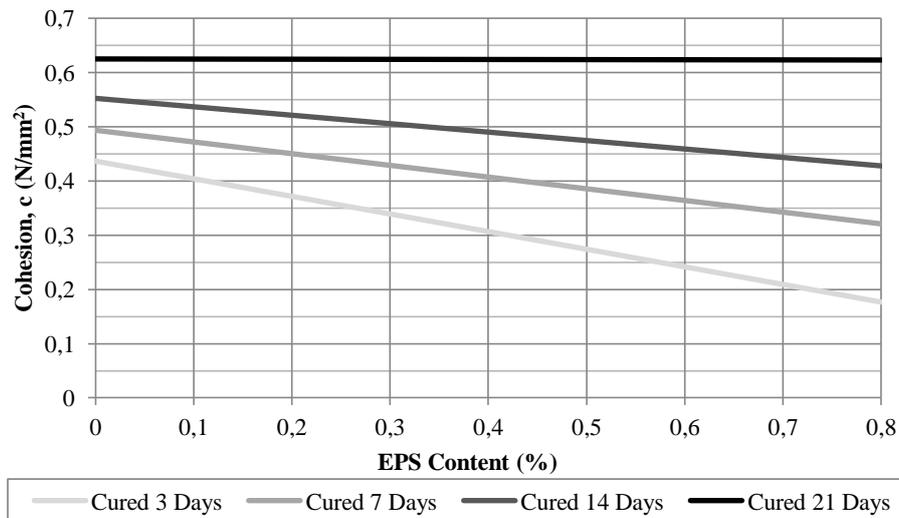


Figure 9. Relationship curve between cohesion (c) and EPS content of soil-fly ash-EPS mixtures

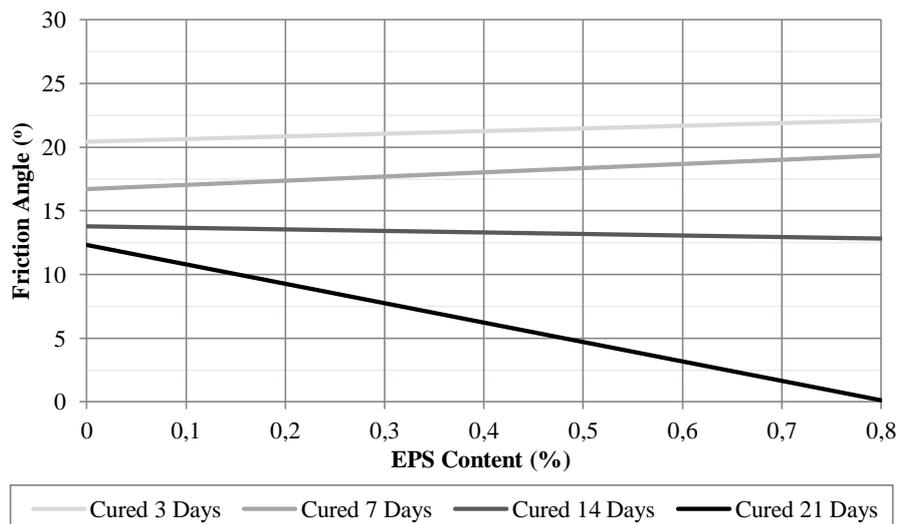


Figure 10. Relationship curve between friction angle (ϕ) and EPS content of soil-fly ash-EPS mixtures

4. Conclusion

Based on the research results, it can be concluded several things, as follows:

- The addition of fly ash to ordinary soil can significantly increase MDD, and significantly decrease OMC as well. A significant reduction of OMC provides an advantage, which can reduce water quantities during the construction of embankment.
- The addition of EPS to stabilized soil with fly ash shows the opposite, a significant decrease in the MDD of the soil mixture occurred, accompanied by a slight decrease in OMC. MDD reduction provides advantages, which reduce the embankment weight, improving slope stability, and to reduce ground pressure to structures. A slight reduction of OMC provides an advantage also, which can reduce water quantities during the construction of embankment. But the use of EPS content over 1% of soil weight is not recommended due to the result of MDD being lower than 1 gr/cm^3 .
- The shear strength of soil-fly ash-mixture decrease as the content of EPS increases. This be affected by the EPS beads characteristic that resistant to shifting, so at a certain degree, the presence of EPS may inhibit movement of the soil mixtures to a denser configuration during the

compaction process resulting in decreased mixture shear strength. The presence of fly ash can increase the mixture shear strength, but the rate of increasing was not significant. This happens because the characteristic of fly ash class F as the binder used in the soil mixture itself has nonself-cementing properties. This problem can be solved by replacing or adding another binder to the mixture, such as cement, thereby increasing the shear strength of the mixture.

- The use of lightweight fill materials (soil mixtures modification using EPS beads) has the potential to be one of the soil improvement solutions for cases of embankment construction on soft soil. It is believed can reduce the deformation of soft soil compared to ordinary fill materials. The soil-fly ash-EPS mixture has been proven can decrease the weight of soil. Another advantages are lightweight fill mixture has similar flexibility to ordinary soil, so it can occupy more adaptively on the ground, and the strength and stiffness of the mixture can be adjusted by changing the type and/or the amount of content of the binder.

Acknowledgment

The authors acknowledged to UPPM POLBAN that support the funding of the research, PT. Indonesia Power that provide the material used in research, and the support from Department of Civil Engineering Politeknik Negeri Bandung that provided and allowed authors to use the soil mechanics laboratory facility for the research to be conducted.

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