Lightweight mixture using sand, EPS-beads and cement

Un Mélange Léger en Utilisant le Sable, les Billes d'EPS et le Ciment

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ABSTRACT
A laboratory study is presented in this paper on the formation of a lightweight material for embankment on weak soils. The proposed material is made by blending sandy soil with (Expanded Poly-Styrene) EPS-beads and a stabilizing material such as cement. The effect of different compositions and different ratios between EPS-beads, and cement with sand on the maximum dry density, optimum moisture content, ultimate shear stress and angle of internal friction of the lightweight mixture are studied. It is observed that the density of the lightweight mixture can be effectively controlled by the amount and density of EPS-beads used. With the inclusion of 0.3 - 3 % of EPS-beads (to sand by weight), the bulk density of the lightweight mixture formed can be reduced to 8.5-18 kN/m^3. The shear strength and stiffness of the lightweight mixture can be controlled by adjusting the amount of cement used. The angle of shearing resistance of the lightweight mixture increases considerably if cement to soil ratio of 3-10% is used. With adding cement to EPS-beads and sand mixture, higher dry density and less optimum moisture content are obtained.

RÉSUMÉ
Dans cet article, une étude expérimentale est présentée au sujet de la composition d'un matériau allégé pour les remblais sur sols molles. Le matériau proposé est constitué par mélanger un sol sableux avec des billes de polystyrène expansé « billes d'EPS » et un matériau de cimentation comme le ciment Portland. Les effets de différentes compositions et différentes proportions des billes d'EPS et du ciment avec le sable sur la densité sèche maximale, la teneur en eau optimale, la résistance au cisaillement et l'angle de frottement interne du mélange léger sont étudiées. Il est observé que la densité du mélange léger peut être efficacement contrôlée par la quantité et la densité de billes d'EPS utilisées. Avec l'inclusion de 0,3 à 3,0% de billes d'EPS (pourcentage en poids du sable), la masse volumique du mélange léger peut être réduite à 8,5-18,0 kN/m^3. La Résistance au cisaillement et la rigidité du mélange léger peut être contrôlé en ajustant la quantité de ciment. L'angle de frottement interne du mélange léger augmente considérablement si un rapport du ciment sol de 3-10% est utilisé. Avec l'ajout du ciment au mélange du sable et de billes d'EPS, une densité sèche supérieure et une teneur en eau optimale moins élevée sont obtenues.

Keywords: Polystyrene EPS-beads; lightweight mixture; maximum dry density; OMC; shear strength; stabilizing Cement

1 INTRODUCTION

A construction technique using lightweight geomaterials has many practical advantages because of their light self weight which make it possible to reduce large deformations and differential settlement of a soft ground or a foundation with poor bearing capacity. It also may be used to improve slope stability adjacent to an embankment and to minimize the lateral earth pressure acting against or facing embankment wall. In recent years, lightweight materials, using expanded polystyrene (EPS) block geofoams, have been more introduced in the infrastructure rehabilitation and in the construction of new facilities such as roads and embankments. The use of EPS geofoam block in geotechnical construction started in Norway in 1960's, and has been used worldwide (Frydenlund, 1996; Van Dorp, 1996; Hillmann, 1996; Abdelrahman et al., 2008a &b; and others). Some disadvantages however, are in the applications of ESP geofoam block. These include that it have to be made into regularly shaped blocks and thus cannot be readily used to fill an irregular volume, and that the stiffness and properties of EPS blocks cannot be changed easily to suit the properties of the soil on-site. When the use of EPS blocks becomes difficult, soil may be mixed with expanded polystyrene-EPS-beads. EPS beads are produced from expandable polystyrene resin beads that generally ranging from 2 to 10 mm in diameter and contain microscopic cells filled with a blowing agent It offers an effective alternative for banking on soft ground or on ground subject to landslides. Liu et al (2006) compared EPS-beads and EPS-blocks. The biggest advantage of the EPS-beads mixed lightweight fill is that it can be made on site into a slurry form and poured anywhere before it hardens. Thus it is particularly suitable to be used to fill cavities, underground openings of irregular shapes or for rehabilitation works. Also it can be used in situations where compressive stresses higher than what the EPS blocks can provide are required.

When a stabilizing material as cement is used, the strength of the EPS beads mixed lightweight fill will increase due to the cement hydration effect. Water is used in the mixing process to enhance the workability of mixing and to activate hydration when cement is used. The density and other properties of the EPS-beads mixed lightweight can be changed easily by adjusting the EPS-beads to soil ratio or the cement to sand ratio.

Recently, studies and applications of EPS beads mixed lightweight fill or embankment including the use of cement began in south Asia. Satoh (2001) used EPS beads mixed lightweight fill under deep water. Minegishi, et al. (2002) investigated the characteristics of EPS-beads mixed lightweight geomaterial subjected to cyclic loading. Ruiming (2006), studied the dynamic strength behavior of lightweight sand-EPS beads soil under different confining pressures and different mixing ratios. Ma (2003), used EPS beads mixed lightweight

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fill for embankment on a soft foundation. Minegishi and Makiuchi (2006), described mechanical behavior of EPS beads and volcanic cohesive soil in Japan. In this research, a laboratory study on the effects of different compositions and ratios between sandy soil, and different densities of EPS-beads with different ratios; and different ratios of normal Portland for the same beads ratio and density. The EPS beads, sand and water mixture were mixed into cement, on the maximum dry density, OMC, and shear strength.

2 EXPERIMENTAL PROGRAM

2.1. Materials

Four components, EPS beads, cement, water, and sandy soil, were used in this study to make the lightweight embankment mixture. EPS beads is a super-light weight artificial material which belongs to a geofoam in geosynthetics, and an EPS beads has a soft and elastic nature as shown in Figure 1. The EPS-beads used are round in shape with diameters ranging between 2 and 7 mm as shown in table 1. The beads are highly compressible, having only about 1% of the density of a typical soil. Four EPS beads ratios by volume were used, 66%, 50%, 33%, and 20% of the sand volume, i.e. 3, 1.4, 0.7 and 0.3 %. by weight.

Table 1. EPS-beads properties

EPS-beads (No)	500	600	700
Density ρ (kN/m^3)	0.16	0.20	0.25
Particle Size (mm)	< 3	3-5	5-7

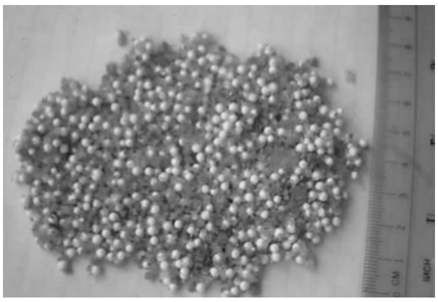

Figure 1 EPS-Geofoam beads particles and mixed with sand.

The used sand has been classified as poorly graded (SP). Results of different tests are shown in table 2. An ordinary Portland cement was used as a stabilizing material. The cement was used by dry weight to the sand, 3%, 5%, 7%, and 10%.

Table 2. Physical and Mechanical properties of sand

Sand Properties	C_u	C_c	G_s	$\varphi°$	$\gamma_{d\text{-}max}$ kN/m^3	OMC
SP	3.6	1.1	2.641	40.32°	17	12%

2.2 Standard Proctor Compaction Test

Standard proctor compaction test was used to measure EPS-beads effect with and with out stabilizing cement on maximum dry density, γ_d, and optimum moisture content, OMC, comparing to the pure sand. Maximum dry density and OMC were determined at different EPS-beads density and ratio. The Lightweight specimens mixed with beads are compacted using a rammer of 2.5 kg, in the 0.10 m diameter mold. Hong-Taek, et al (2002) measured the compaction strain of EPS beads, they found that it is 6.7-9 %, depending on the compaction energy, regardless of mixed beads to sand ratio.

2.3 Direct Shear Test

For direct shear test, the EPS-beads mixed sand was prepared as follows: the dried sand was first mixed with beads. Then water was added according to OMC which found in compaction test homogenous slurry. The mixing continued until the beads were evenly distributed within the specimens. If the tested specimens include cement, it would be added to the mixture as a powder before the water adding. The mixture was compacted in a standard proctor. Direct shear sampler of 0.06m square, was placed in the mold after compaction to get a specimen and immediately tested in shear box. If the test includes cement, no curing time was allowed for the specimens, the mixture was shearing in fresh paste. The direct shear test was conducted to measure the gain in shear strength and the stiffness of the mixture, with deformation rate 0.59 mm/min using conventional step loading method with normal stress 25, 50, and 100 kN/m^2.

3 RESULTS OF STANDARD COMPACTION TEST

3.1. Effect of EPS-Beads Density and Ratio

The maximum dry densities measured for the tested specimens prepared using different ratios are presented in Figure 2. It can be seen that by mixing 20–66% of EPS-beads (by sand volume), maximum dry density of the specimens can be controlled from 7.5 to 16 kN/m^3 especially if the sub-base strata consists of weak soil. This is a significant improvement in terms of density as the maximum dry density of pure sand was 17 kN/m^3. Figure 2 indicates that the increase of EPS-beads density increases the maximum dry density at the same beads ratio. OMC increases with the increase of the EPS-beads and sand.

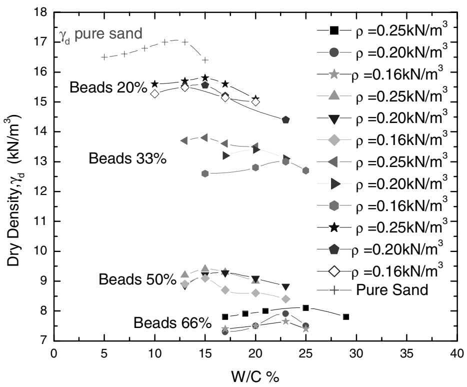

Figure 2. Effects of EPS beads on lightweight embankment dry density.

3.2. Effect of Cement ratios

Portland cement was used as a stabilizing material, to increase the shear strength even that the cement was added to the EPS-beads and sand mixture with water and tested immediately in standard compaction test with no curing time allowed.

The effect of cement with EPS-beads and sand mixture on maximum dry density was investigated using 0.20 kN/m^3 EPS-beads density (beads is 50% by volume of sand). In this research four different percentages of cement ratio were 3, 5, 7, and 10 % (by sand weight) were used to increase maximum dry density and shear strength. Under the test conditions shown in Figure 3, a slight decrease in the OMC due to the adding of cement to the EPS-beads and sand mixture. The increase of cement ratio from 3 to 10 % results in increase of maximum dry density from 9.2 kN/m^3 to 12 kN/m^3 with no curing time.

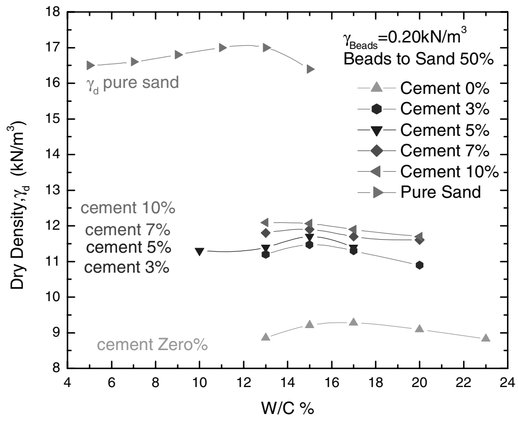

Figure 3. Effects of cement ratios on lightweight mixture dry density.

The difference in the effect of the EPS-beads and cement ratios to sand on dry density is attributed to the density difference between EPS-beads and sand. The EPS-beads densities used in this study were 0.16, 0.20, and 0.25 kN/m^3, which only about 1% of the sand density.

4 RESULTS AND DISCUSSION OF SHEAR TEST

4.1 Additive Effect on Shear Strength Parameters

The unconsolidated undrained shear test was measured for compacted specimens consist of sand and EPS-beads of different ratios and densities with and without cement ratios at OMC. As shown in Figures 4(a), it can be seen that, an increase in the EPS-beads ratio within a range of 20 to 66% (by sand volume) with no cement, leads to almost a linear decrease in the angle of shearing resistance, φ°. According to the fitting line for the effect of different beads ratio decreased the angle of shear resistance, φ° from 40.32°at pure sand to 25.5° at 66% beads ratio. While in Figure 4 (b) shows the angle shear resistance, φ°, measured for specimens of different cement ratio and constant EPS-beads ratio (50% by sand volume), with no curing time. It can be seen that with EPS-beads, an increase in the cement ratio within a range of 3–10% (to sand by weight) leads to almost a linear increase in the angle of shearing resistance, φ°. By adding cement to mixture with no hydration, it acts as a fine material; it increases the angle of shearing resistance φ'. According to the fitting line, the angle of shearing gains 6.5° increases due to cement ratio which depending upon EPS-beads ratio and curing ages. More gain is expected to take place in the cohesion, c, with time, depending on curing time. The cement ratio affects not only the angle of shear strength, φ°, but also the stiffness becomes higher. At a given cement ratio of, 5%, the friction angle φ°, decreases with increasing EPS-beads ratio, as illustrated in Figure 5(a). When cement ratio is equal to 5%, the angle of shearing resistance, φ°, increases from 27.92 to 32.5 with the increase of EPS-beads density from 0.16 to 0.25 kN/m^3 depending on the EPS-beads ratios. EPS- beads density has small effect on angle of shearing resistance with cement existence. In summary, for all the tested specimens, the friction angle, φ°, increases with increasing cement ratio and decreasing EPS-beads ratios.

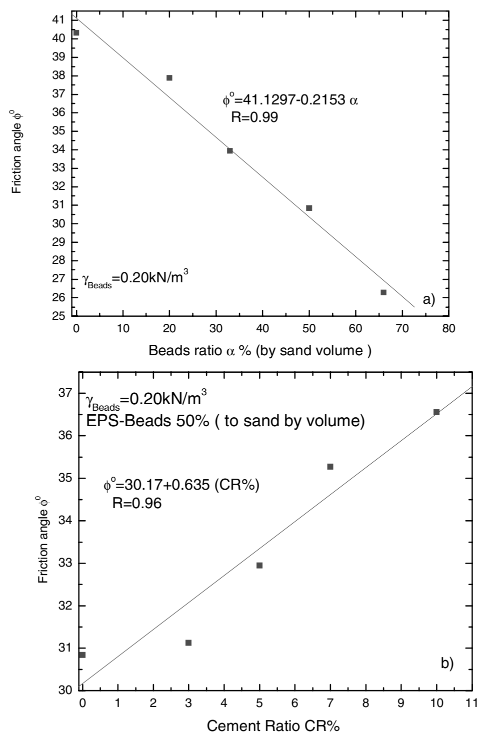

Figure4. Effect of a) Beads ratio and b) Cement ratio on friction angle

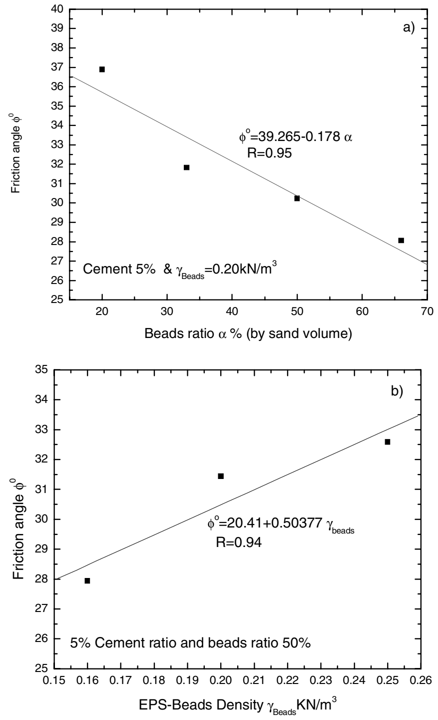

Figure 5. Effect of a) Beads ratio, b) EPS-beads density on angle friction.

4.2. Curing Effect on Shear Strength Parameters

To study the effect of curing effect on the strength of stabilized beads mixtures, the stabilized samples in this investigation were subjected to different curing conditions. The moisture condition was controlled by keeping the samples sealing in nylon wrap to make sure that no moisture loss takes place. After 24 hours the samples were unwrapped (i.e. exposed to laboratory conditions). Theoretically, the hydration of cement will continue indefinitely, this process is responsible for the strength gain with time. Usually, the 7-days unconfined compressive strength is used as criteria for design purpose, while 3-days strength is used for quality control purpose during field construction. Strength after

28-days of curing can also be used to assess the bearing capacity f a pavement for example. However, to speed-up construction, the 24-hour strength is some time used.

Three different curing periods, 1, 7, and 28 days, were used at temperature of 23˚C and compared with zero curing time. The compared samples have same beads, and cement ratios (0.20 kN/m^3, and 50% by sand volume for the beads, and 5% cement by sand weight). By allowing curing time as shown in figure 6 the existing of cement, gain the mixture shear strength parameter, c, it is increased from zero to 36kN/m^2 after 28 days although that no hydration during curing time. More gain in shear strength parameter, c, with time, if the tested samples were allowed to hydrate.

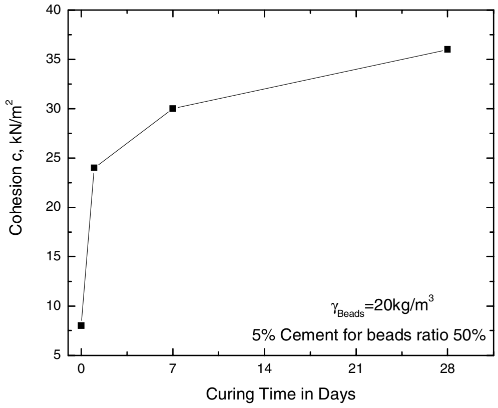

Figure 6 Effects of cement curing on polystyrene lightweight mixture shear strength.

4.3. Beads Effect on Stress–Strain Behavior

Direct shear test was used to evaluate the stress–strain behavior and the stiffness properties of the EPS beads mixed lightweight embankment. The stress–strain curves obtained from tests with the EPS beads ratios varying from 20 to 66% (by sand volume). It is found that with the increase of EPS-beads ratio, the ultimate shear strength decreases.

5 CONCLUSIONS

The following conclusions can be made from this study:
A lightweight embankment material can be produced by mixing EPS-beads with, sand and water which give bulk density in the range from 8.5 to17.5 kN/m^3. This is much lighter than the density of conventional materials. The density of the mixture is controlled mainly by the EPS beads ratio and density in the range of 0.3–3% (by sand weight). The increase of EPS beads ratio, decrease bulk density, maximum dry density, and angle of shearing resistance, and increases OMC. While the increase EPS beads density, slightly increase the maximum dry density and angle of shearing resistance.

Using stabilizing material as cement is effective factor to improve the shear strength parameters, and shearing behavior of the lightweight mixture. The increase in cement ratio from 3 to10% (by sand weight), increases the maximum dry density, angle of shearing resistance, and slight decrease in OMC.

The increase in shear strength with no curing time (fresh paste) is probably due to the viscosity of the cement, water, sand and EPS-beads mixture compared to the loose state of the EPS-beads, sand and water mix. If curing time is allowed, gain of shear strength parameter c, and, more increase in shear strength if cement hydration process is completed.

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