A New Light-weight Geomaterial – EPS Composite Soil

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ABSTRACT
This paper introduces a new light-weight geomaterial - expanded polystyrene (EPS) composite soil. EPS composite soil (EPSCS) is a new kind of light-weight geomaterial, which is made of soil, EPS beads or shreds, a binder (normally cement), and water. This material is an environment-friendly material which makes use of recycled materials as its aggregates. Geotechnical properties of EPSCS are significantly affected by its constituents. A wide range of engineering properties including the density and the compressive strength has been reported based on the variation in its ingredient proportions. The unit weight of EPSCS, which ranges from 5 kN/m^3 to 18 kN/m^3, is lighter than that of natural soils because of adding super-light EPS into the mixture. The reported values of unconfined compressive strength are in the range of 50~550 kPa, which meets almost all the requirements for filling materials. Both the density and the compressive strength of this geomaterial can be easily adjusted by changing the mixture ratios. This material has been successfully used in practice in Asia for many engineering applications.

RÉSUMÉ
Ce document présente un nouveau geomaterial léger - sol composé augmenté du polystyrène (ENV). ENV le sol composé (EPSCS) est un nouveau genre de geomaterial léger, qui est faite en sol, qu'ENV perle ou des lambeaux, une reliure (normalement ciment), et l'eau. Ce matériel est un matériel favorable à l'environnement qui se sert des matériaux réutilisés en tant que ses agrégats. Des propriétés géotechniques d'EPSCS sont sensiblement affectées par ses constituants. Un éventail de propriétés de technologie comprenant la densité et la résistance à la pression a été rapporté basé sur la variation de ses proportions d'ingrédient. Le poids spécifique d'EPSCS, qui s'étend de 5 kN/m^3 à 18 kN/m^3, est plus léger que celui des sols normaux en raison d'ajouter l'ENV hyperlégère dans le mélange. Les valeurs rapportées de la résistance à la pression illimitée sont dans la gamme du kPa 50~550, qui répondent à presque toutes les exigences pour des matières d'agrégation. La densité et la résistance à la pression de ce geomaterial peuvent être facilement ajustées en changeant les rapports de mélange. Ce matériel a été avec succès employé dans la pratique en Asie pour beaucoup d'applications de technologie.

1 INTRODUCTION

Expanded polystyrene (EPS) composite soil (EPSCS) is a new kind of light-weight geomaterial which was first introduced in Japan in the 1980s. This material is normally made of soil, a binder (usually cement), water, and EPS. It has been used for building roadway embankments, backfilling behind retaining walls and bridge abutments, backfilling pipeline trenches, and so on. The well-known super-light-weight EPS geofoam has played an important role in solving extra settlement problems over soft ground (Stark et al. 2004). However, the wide range of applications of EPS geofoam has been limited due to its high cost, poor buoyancy resistance, and incompatibility with petroleum products (Negussey and Jahanandish 1993). EPS composite soil can offer an attractive solution to effectively reduce or eliminate excess settlements while avoiding above issues.

EPSCS is an environment-friendly geomaterial, which recycles wastes such as EPS foam waste and dredged mud. An abundance of non-biodegradable EPS wastes occupy a large amount of landfill and cause incineration toxins problems. The European Union has restricted the disposal of EPS foam into landfills and has made it a recycling target (UNEP 2000). EPSCS provides a superior solution to a growing global EPS waste with an ecologically friendly strategy. Recycling industrial wastes to produce a new kind of high-quality geomaterial is attractive for geotechnical engineering.

Since its inception, EPSCS has attracted the interests of many researchers. However, there is no literature available to provide engineers in practice a comprehensive review of its physical and geotechnical properties. This paper presents a comprehensive review of its engineering properties. A few names have been used to describe this material, including but not limited to, light-weight treated soil, EPS beads-mixed light-weight geomaterial, soil-EPS mixes, light-weight soil mixed with EPS beads and so forth. The EPSCS is used throughout this paper to avoid confusions.

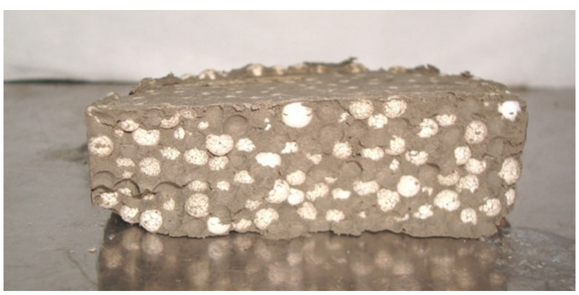
2 WHAT IS EPS COMPOSITE SOIL?

EPSCS consists of EPS, soil, a binder, and water. A few forms of EPS materials can be used in the composite soil including pre-puff EPS beads, EPS shreds, EPS strips. Cement, fly ash, quicklime, or plaster can be used as a binder material to increase the shear strength of EPSCS. Water is used to carry out the hydration reaction and facilitate the construction by increasing the fluidity of EPSCS.

The construction of EPSCS can be divided into two types: pumping and compaction. The first one is to pump the composite soil to the construction field after mixing it into a liquid form. It can expedite the construction due to its excellent fluidity. The other is to compact the material layer by layer onsite when a low water content is used to make EPSCS.

Cement has been successfully used for a long time to improve the strength of soil (Mitchell 1981). Instead of only cement, EPS is added to the mixture to create this new light-weight geomaterial. Similar to cemented soil, EPSCS has an improved strength over natural soil due to the existence of cement while a low density due to the addition of superlight EPS. Furthermore, the density and strength of this material can be controlled easily with different mixture ratios. Figure 1 shows the dry mixture before adding water and an EPSCS sample after curing.

a.) Making the dry mixture



b.) EPS composite soil after test

Fig. 1 EPS composite soil

3 TYPICAL PHYSICAL AND GEOTECHNICAL PROPERTIES OF EPSCS

3.1 Unit Weight

The unit weight of EPSCS has been investigated by many researchers (Yamada et al. 1989 and Liu et al. 2006). Its dry unit weight, reported to vary from 5 to 18 kN/m^3, is mainly controlled by the EPS content regardless of what type of soil is used.

Liu et al. (2006) studied the influences of different weight ratios including EPS and soil (EPS/S), cement and soil (C/S), and water and soil (W/S) on the unit weight of EPSCS. Compared to the unit weight of native clay, which ranged from 17 to 19 kN/m^3, the unit weight of EPSCS varied from 7 to 11 kN/m^3. As expected, the most important influence factor on the dry unit weight is from super light EPS. No significant effect was found from cement and water contents. The unit weight decreases linearly with the increasing EPS/S ratio from 2 to 6%. Within the tested EPS/S range, a 1% increase in the EPS/S ratio results in an approximate drop of 1 kN/m^3 in the dry unit weight of the sample.

3.2 Compressive Strength

Several testing methods have been applied to study the compressive strength of EPSCS, such as the direct shear test, triaxial compression test, and unconfined compression test (Nagasaka et al. 1994, Tsuchida et al. 2001). As expected, the cement content is the fundamental factor in controlling the compressive strength of this material. According to the literature, the compressive strength of EPSCS ranges from 50 kPa to 550 kPa depending on its ingredients and mixture ratios.

Liu et al. (2006) studied the unconfined compressive strength (UCS), q_u, of EPSCS. A range from 110 kPa to 520 kPa of UCS was measured from samples cured for 28 days at different C/S and EPS/S ratios, as shown in Fig. 2. An increase in the C/S ratio within the study range of 10 - 25 % leads to an almost linear increase in the UCS.

The initial modulus, E_o, of EPSCS ranges from 79 to 555 MPa depending on the curing periods and the mixture ratios of specimens. These E_o values are much higher compared with that of EPS geofoam, which are in the range of 1.4-15 MPa depending on the density of the EPS blocks (Horvath 1994). Therefore, EPSCS is less compressible than EPS geofoam.

3.3 Permeability

The coefficient of permeability of this material has been reported to vary from 10^{-6} to 10^{-7} cm/s depending on the native soil and the amount of EPS used in the sample. The permeability of the mixture from coarse-grained soil tends to be larger than that from fine-grained soil.

A series of constant head permeability tests was performed by Yasufuku et al. (2002) to study the effect of the EPS ratio and compaction degree on the permeability values. The coefficient of permeability increases with the increase of the EPS ratio and decreases with the increase of the compaction degree. More influences from compaction can be found in the samples with a lower EPS ratio. Based on constant head permeability tests, the coefficient of permeability, k, was found to be on the order of 10^{-6} to 10^{-7} cm/s (Liu et al. 2007). The permeability decreases with the increase of the C/S ratio and curing period. However, it increases with the increase of EPS/S ratio.

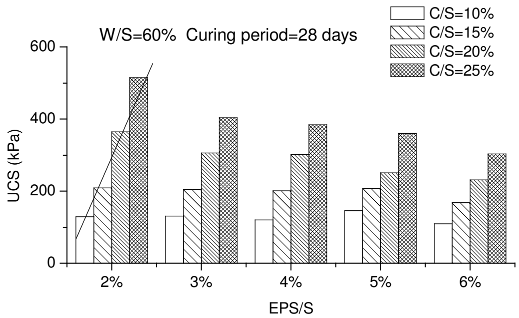


Fig. 2 Influences of C/S and EPS/S ratios on UCS (after Liu et al. 2006)

3.4 Creep Properties

Gao et al. (2008) used an oedometer to investigate the creep behaviour of EPSCS. This material was made of EPS beads (4% to clay by dry weight), cement (10%), clay, and water (80%). The samples with a height of 2 cm and a cross-sectional area of 30 cm^2 had been cured for 14 days under curing conditions (a temperature of 20±2^{o}C and a relative humidity of 100%) before the creep test. Two types of loading methods, separate loading and step loading, were used in the tests with five loading stages at 25kPa, 50kPa, 100kPa, 200kPa, and 400kPa. A typical deformation vs. time curve from a step loading test is shown in Fig. 3. The creep deformation increases with the increase of the stress level. The creep deformation becomes more appreciable under a higher stress level than a lower stress level, especially for 200 kPa loading stage. The higher the stress level, the longer time the samples take for the creep to become stable. No failure was noticed under the tested loading conditions.

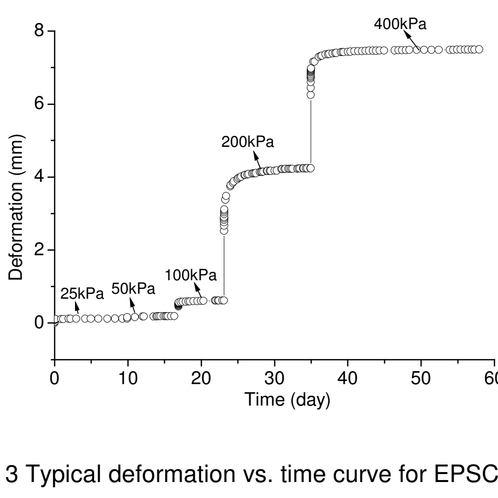


Fig. 3 Typical deformation vs. time curve for EPSCS

3.5 Dynamic Properties

Minegishi et al. (2002) used cyclic triaxial tests to study the dynamic deformation behaviour of EPSCS under various loading conditions, including different stress levels and confining pressures. The material with a unit weight of 11 kN/m^3 was made of EPS beads (1.7% to clay by weight), cement (7%), and clay. The relationship between dynamic shear strain and the number of cycles is shown in Fig.4, where the stress level, *s*, is the ratio between the magnitude of dynamic stress and the static compressive strength. The dynamic shear strain increases with the increase of the stress level. Yielding is observed after the number of cycles exceeds 1,000. The dynamic strain of EPSCS increases sharply as the number of cycles exceeds 10,000 at the stress level of 0.8. The failure stress of EPSCS under cyclic loadings was found to be the same as that of a cemented sample without EPS. It was believed that EPS has no significant contribution to induce failures compared to soil aggregate itself under cyclic loadings.

Wang and Gao (2007) studied the dynamic secant shear modulus, G_{sec}, of EPSCS. Like natural sand, EPSCS had a similar reduction in dynamic secant modulus with dynamic shear strain. Due to the cementation, the dynamic shear modulus became independent on the confining pressure once the C/S ratio exceeded 10%.

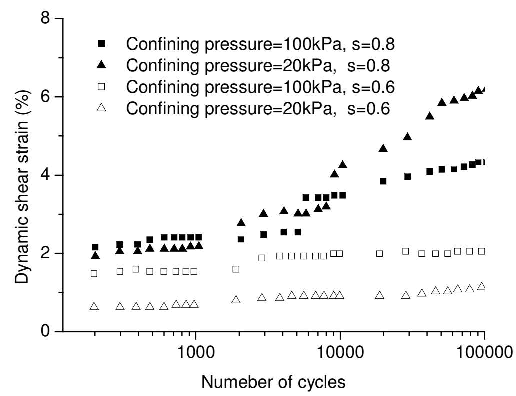


Fig. 4 Dynamic strain-number of cycles curve (after Minegishi et al. 2002)

3.6 Water Absorbability

Water absorbability, *R*, is defined as the weight ratio of water absorbed after immersion to the dry sample before immersion. Gu et al. (2005) discussed the water absorbability of EPSCS, which consisted of EPS beads, sand, cement, and water. The water absorbability increased quickly after the sample was immersed in water; however, no remarkable change was measured following the 28th day.

4 GEOTECHNICAL APPLICATIONS

EPSCS has been successfully applied in many geotechnical constructions. The first successful application, in 1988 in Japan, with a total volume of 100 m^3, was the backfilling of an underground pipeline with a length of 359.3 m (Yamada et al.1989). The unit weight of EPSCS used in this case was 11 kN/m^3 and the UCS of the sample cured for 1 week was 160 kPa. The accumulated deformation after construction was only 4 mm, 0.5% of the thickness of EPSCS backfills, which met the design needs. From 1988 to 1994, this material had been used to backfill underground pipeline, trench walls, retaining walls, highway embankments, river embankments, and bridge abutments in 17 engineering cases in Japan with a total construction volume of 19,490 m^3 (Nagasaka et al. 1994). By the year of 2000, a total volume of 195,000 m^3 of EPSCS had been used in ports and airports, and approximately 6,000 m^3 for river embankments in Japan (Illuri 2007).

In China, the first application of this material was in 2001 to stabilize an embankment for the Zhangzhou-Shaoan Expressway Project in Fujian (Ma 2001). Based on this experimental study, EPSCS significantly improved the stability of the embankment and largely reduced the lateral displacement when compared to other conventional fill materials. In 2004, a total volume of 200 m^3 of this material was used as a fill material to stabilize a slope in the Xinanjiang Power Plant in Zhejiang, China (Zhu 2004). In 2005, EPSCS was used for embankment construction on very soft ground in the Yangxi Segment of the Yong-Yu Express Project in Zhejiang, China (Yang 2007). Based on field performance, EPSCS improved the stabilities of the embankment, reduced the post-construction settlements, and minimized the bump issues at the end of the bridge. In addition, EPSCS reduced the construction schedule and resulted in a cost saving of 37% over the original design.

5 CONCLUSIONS

EPS composite soil is an environment-friendly material which can make use of recycled industrial wastes such as dredged mud and EPS waste. This material provides an alternative for long-term storage of EPS. Nowadays, a large proportion of EPS waste is disposed of in landfill and claims lots of land.

Geotechnical properties of EPS composite soil are significantly affected by its constituents and mixture ratios. A wide range of engineering properties has been reported based on the variation in its ingredient proportions.

The EPS content is the controlling factor for its unit weight. The unit weight of this material can vary from 5 to 18 kN/m^3 depending on its ingredients. The cement ratio is the controlling factor for its strength. The compressive strength of EPSCS covers a wide range; for example, UCS was reported to vary from 50 to over 500 kPa. Such a wide range of UCS values makes EPSCS very attractive in many geotechnical engineering applications. The good durability under dynamic loading and long-term monotonic loading makes this material very attractive for pavement construction.

EPS composite soil has been successfully used in practice in Asia for many engineering applications, mainly as a fill material for bridge abutments, embankments, and underground cavities. There are still many engineering applications where this material can be a very attractive alternative.

Although EPS composite soil can be applicable for many engineering projects, a rational and systematic design approach needs to be developed to address for a specific application, including performance criteria, optimum mixture ratio design, and cost-efficiency analysis. It is known that EPS composite soil can reduce lateral earth pressure significantly. The exact reduction of lateral earth pressure needs to be investigated in the field. As a new light-weight geomaterial, EPS composite soil is expected to play a more and more important role in geotechnical engineering practice.

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