SUSTAINABLE BACKFILL MATERIALS MADE OF CLAY AND RECYCLED EPS

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Abstract

As conventional backfill materials are becoming more scarce and costly, there are mounting pressures to use recycled/secondary materials to produce commercially viable fill materials. In this case, despite their abundance, expansive soils are generally avoided as they can cause significant structural damage to structures such as domestic retaining walls.

This paper describes how expansive clays with plasticity indices (PI) ranging from 22% to 53% were artificially made and mixed with granulated waste expanded polystyrene (EPS) in the laboratory. A series of free swell and swell pressure tests were performed on these soils. Test results show that the inclusion of EPS granules significantly reduces the potential volume change of the soils when subjected to one-dimensional free swell conditions. In addition, three-dimensional volumetric shrinkage test results also show that the recycled EPS granules can reduce the volumetric shrinkage potential of the expansive soils.

The innovative application of the granulated waste EPS mixed with expansive soil at optimum moisture content, so as to make a beneficial use of the waste EPS products and the swelling clay, is a new concept which will offer a sustainable solution for both the housing and EPS industries.

1. Introduction

Expansive soils are clays or very fine silts that have a tendency for volume changes, to swell and soften or shrink and dry-crack, depending on the increase or decrease in moisture content respectively. Movement is usually in an uneven pattern and of such a magnitude as to cause extensive damage to various structures, including retaining walls (Figure 1).

Expansive clay soils are widespread throughout Australia. It has been found that the most troublesome soils are the black earths, red-brown earths, and the grey and brown soils of heavy texture. In this case, a number of treatment options for treating expansive soils before and after construction are available, which include the application of chemical additives, prewetting, soil replacement, moisture control, surcharge loading, etc.

Replacing expansive soils with non-expansive ones may offer a simple solution to eradicate expansive soil problems. However, this method is clearly unsustainable today as it produces waste soils and consumes significant amount of resources. As conventional backfill materials are becoming more scarce and costly, there are mounting pressures to reconsider the use of recycled/waste materials to produce commercially viable fill materials.

This paper describes how expansive clays were mixed with granulated recycled expanded polystyrene (EPS) in the laboratory. The innovative application of the waste EPS mixed with expansive soil at optimum moisture content, to utilize the otherwise unusable clay as construction materials, is a win-win concept. Use of waste EPS products in granulated form will promote recycling and reduce the quantity of waste EPS products destined for disposal in landfills considerably. The proposed technique is thus showing great promise in sustainable construction, particularly for the construction of domestic retaining walls.

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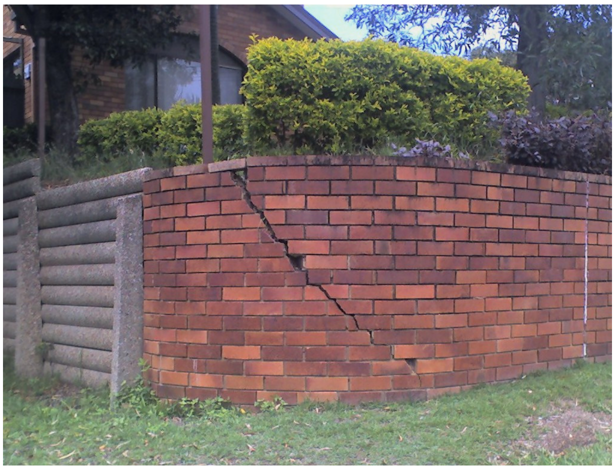

Figure 1 Failure of a domestic retaining wall due to earth pressure.

2. Backfill behind Retaining Wall

Expansive soils often create numerous problems when used as backfill materials behind retaining walls. Due to their lumpy and cohesive nature, it is often difficult to recompact these soils to states of uniform moisture content and unit weight that will ensure minimal future settlements, minimum swelling potential or minimum lateral earth pressures. Beyond the obvious problems of large and protracted surface settlements, expansive soil backfills require significantly stronger retaining structures to withstand the larger horizontal earth pressures than are exerted by non-expansive soil backfills (Hamilton, 1977). Moreover, expansive soils are relatively impermeable, which makes adequate drainage in back of the wall impossible. The wall, therefore, must be designed to resist water pressure in addition to the pressure of the earth backfill. This is uneconomical and may be needlessly wasteful.

To avoid failure of retaining walls located in expansive soil regions, Petry and Armstrong (1989) suggested that the expansive clay behind the retaining wall should be cut back to at least 45 degrees from the horizontal and should be filled with non-active, free draining material such as clean granular sand or gravel so that as the clay swells, it will not impose loads on the wall. Further, a system of weep holes and filter protected drains are to be installed at the base of the wall in the back fill as shown in Figure 2.

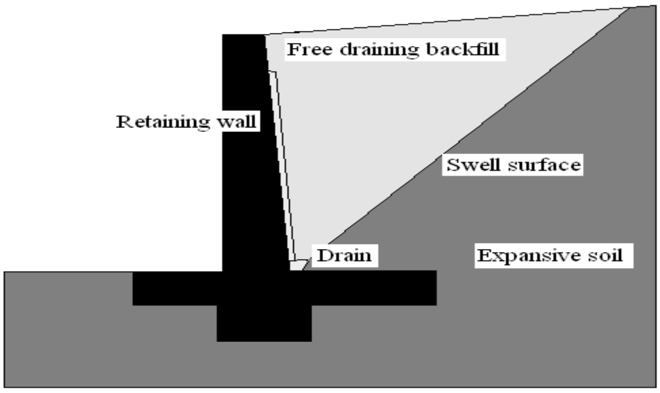

Figure 2 Retaining wall backfill treatments (Petry and Armstrong, 1989).

Recently, there has been a considerable interest on the potential benefit of placing geoinclusions (i.e. expanded polystyrene geofoam) behind retaining walls. EPS geofoam is a lightweight, rigid foam plastic that has been used around the world as a fill for more than 30 years. EPS geofoam is approximately 100 times lighter than most soil and at least 20 to 30 times lighter than other lightweight fill alternatives. This extreme difference in unit weight compared to other materials makes EPS geofoam an attractive fill material. Ikizler et al. (2007), for example, found that the swelling pressure caused by expansive soil behind a retaining wall may be decreased considerably by the application of EPS geofoam, which can accommodate soil expansion and reduce swelling pressures. Furthermore, Hatami and Witthoeft (2007) found that that placing geofoam behind the reinforced zone of reinforced soil retaining walls (RSRW) can reduce the maximum lateral earth pressure behind this zone by as much as 75%, depending on the backfill type and the geofoam thickness and stiffness values.

The above successful application of EPS Geofoam was the motivation behind the current study. Considering the large volume of EPS produce boxes and expansive soils that have to be disposed of in many places around the world, it was thought that reusing these materials would be a great advantage to the environment. Granulated EPS boxes would be added to the local expansive soils to produce a light-weight backfill material that could reduce the swelling pressure behind a retaining wall.

3. Soil-EPS Mix

The use of expanded polystyrene (EPS) beads in soil to produce lightweight fill materials is a relatively new concept. As the availability of land for suitable disposal sites has become scarce, the need to recycle the soil has evolved. In Japan, a research consortium consisting of Port and Harbor Research Institute, Coastal Development Institute of Technology and 23 other research institutes affiliated with construction companies was formed in 1992 to develop a new fill material by mixing EPS beads with surplus soils (Tsuchida et al, 2001).

Miki (1996) explained that because of the addition of EPS beads, this composite is lighter than the ordinary soil and thus can reduce the load applied to the ground. Furthermore, it is nearly as flexible as ordinary soil and can cope with ground subsidence. In addition, the strength can be adjusted to the requirements by the addition of a stabilizer appropriate to the soil type. Moreover, EPS spreading, on-site mixing and compaction can be done as with ordinary soil (Figure 3). This technique is suitable to all but gravelly soils.

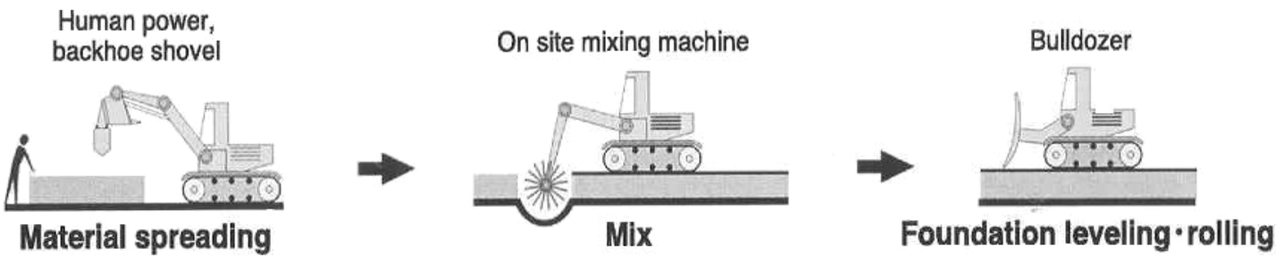

Figure 3 Onsite mixing of EPS beads and stabilized soil (Miki, 1996).

While research elsewhere shows that EPS blocks can be used as a compressible inclusion and EPS beads can be mixed with soils to produce a soil-EPS composite with new characteristics, a novel idea of mixing waste EPS granules with expansive soils is explored in the present study. It has been hypothesized that by mixing EPS granules (obtained from crushing EPS boxes) with expansive soils, the shrink-swell potential of the soil will be reduced through partial soil replacement and by providing a cushioning effect. If this idea works, there will be an opportunity to use unwanted expansive soils and waste EPS in various applications such as backfill for domestic retaining walls and general land cover materials.

It should be noted that EPS granules are often used to improve the drainage characteristics of clay soils. This happens in the vegetable and fruit growing industry, as well as in landscape gardening. Terrains that require greater interchange of air with the environment and evacuation of water can be acquired by mixing them with EPS granules. Hence, the potential benefit of EPS-soil mix will also include the improvement of soil characteristics for horticultural use.

4. Soil-Bentonite (SB) Mixes

To investigate the effect of mixing EPS granules with expansive clays, three expansive soils were manufactured in the laboratory by mixing fine sand with sodium bentonite of various proportions. A commercially available natural sodium-rich bentonite was mixed in various proportions with sand so as to replicate the shrinkage and swelling characteristics of expansive soils.

The sand was sub-angular silica sand and classified as a poorly-graded clean medium to fine sand (SP). More than 95 percent of the sand particles passed through #30 sieve (0.420 mm) and less than 5 per-cent passed #200 sieve (0.074 mm). Figure 4 shows the particle size distribution of the sand used in the present study.

The waste EPS produce-boxes were granulated into granular form in a blender to obtain 90 percent of the particles in the range of 1.2 mm to 9.5 mm (Figure 5).

With the bentonite contents selected (16, 24 and 32%), three different artificial clays (named SB16, SB24 and SB32) resulted, having an intermediate, high and very high plasticity value, respectively. With the % bentonite values used and the resulting PI values, the activity of each clay, defined as PI ÷ (% clay),can be calculated (see Table 1) and plotted on the Williams and Donaldson’s chart (Figure 6) to predict the expansion potential. The chart suggests that the clay’s expansion potential varies from medium to high.

5. Testing & Results

5.1 Mix Preparation

The waste EPS granules were added to the moist artificial soil at a certain percentage of the soil's dry mass. Mixing was done using a pug mill (Figure 7), which produced a uniform mix (Figure 8). Generally, segregation was not a problem up to an EPS content of 9% (although at 9%, slight segregation of granules was observed on the dry side of optimum). Hence, the maximum EPS content was kept at 0.9% by mass and mixing was done at the relevant optimum moisture content.

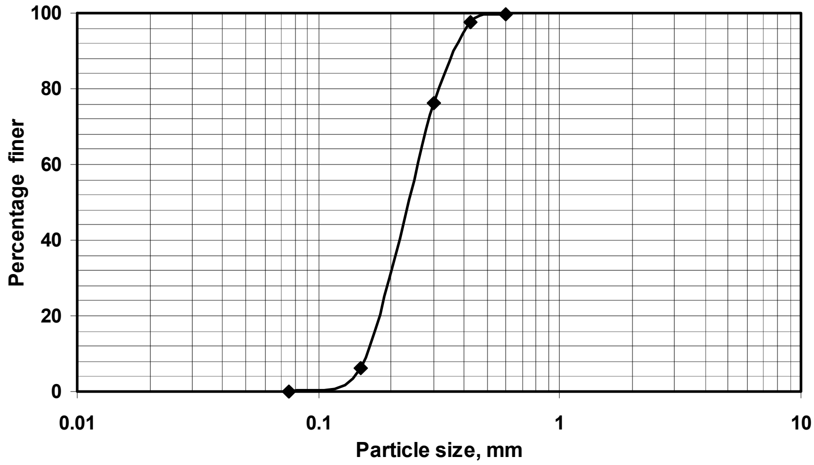

Figure 4 Particle distribution of sand.

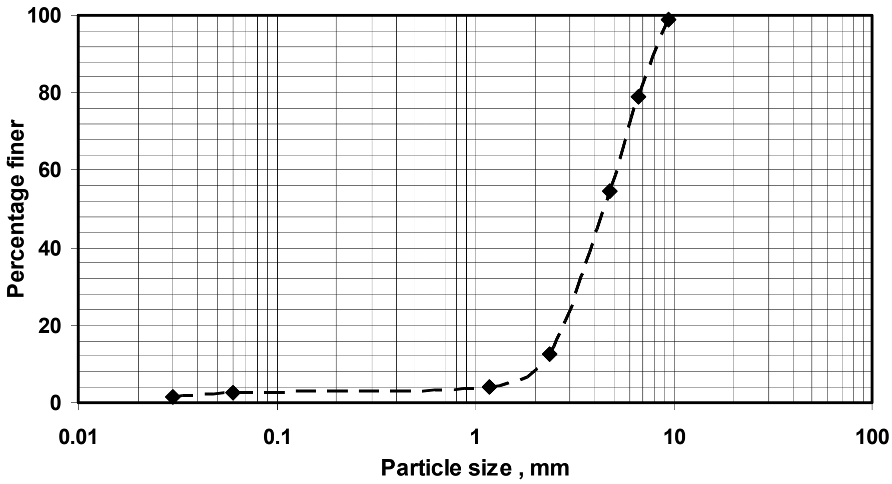

Figure 5 Particle size distribution of granulated EPS.

Standard Proctor compaction tests of the soil-EPS composite were subsequently carried out immediately after mixing the soil and EPS. To maintain consistency at all moisture contents, care was taken to minimize the effect of segregation while placing and compacting the soil-EPS composite.

5.2 Free swell

Using a fixed ring oedometer, the 'free swell' test was performed on the soil-EPS mixes to determine the swelling potential (ASTM D4546-96). The 70 mm diameter specimens were prepared using the static compaction method to the maximum dry density. To obtain free swell, a seating load of 6.9 kPa was firstly applied and the specimen was subsequently inundated with distilled water under this pressure. Axial displacements were measured using dial gauges of 0.002 mm precision. Each test was run for at least 2 weeks; thereafter relationships between swelling and elapsed time were plotted.

Figure 9 shows a typical free swell curve from this test indicating that even after 2 weeks, the specimens may still swell although at much lower rate. Therefore, to fit each experimental curve, the hyperbolic curve fitting techniques was used. The variation of maximum free swell with EPS content and maximum dry unit weight is shown in Figure 10 for each sand-bentonite (SB) mix.

Clearly, the effect of EPS inclusion is quite significant, generally reducing the maximum swelling by about 20-50% (higher value for higher EPS content). This is more than would be expected from soil replacement effect alone since the maximum EPS volumetric content was about 25%. This suggests that the EPS also works as a compressible inclusion within the soil.

Table 1 Sand-bentonite (SB) mixes and their properties.

Mix	% passing 2µm (by mass of dry sand)	*LL*, %	*PL*, %	*PI*, %	Activity, PI / (% clay)	Max. dry density, t/m³	Opt. Moisture content, %
SB16	12.8	43	21	22	1.72	1.73	14.0
SB24	19.2	60	22	38	1.98	1.74	13.0
SB32	25.6	77	24	53	2.07	1.71	12.5

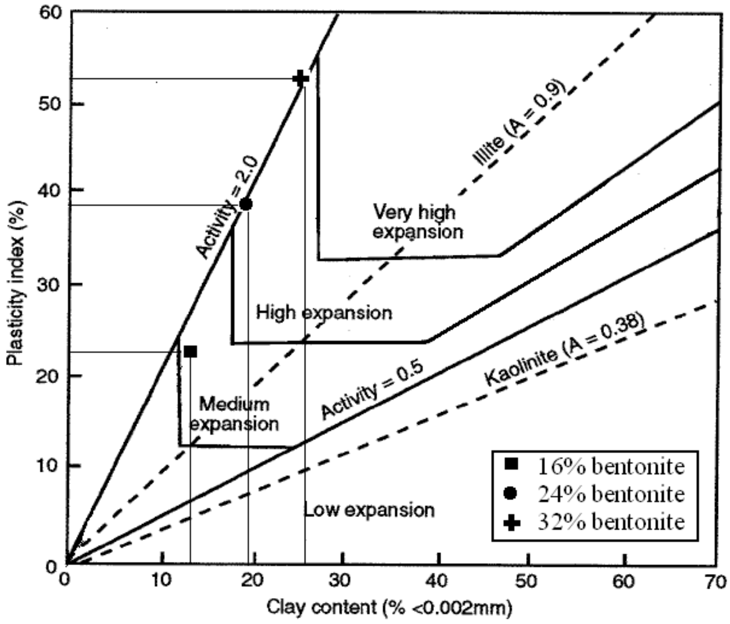

Figure 6 Expansion potential of the sand-bentonite mixes.

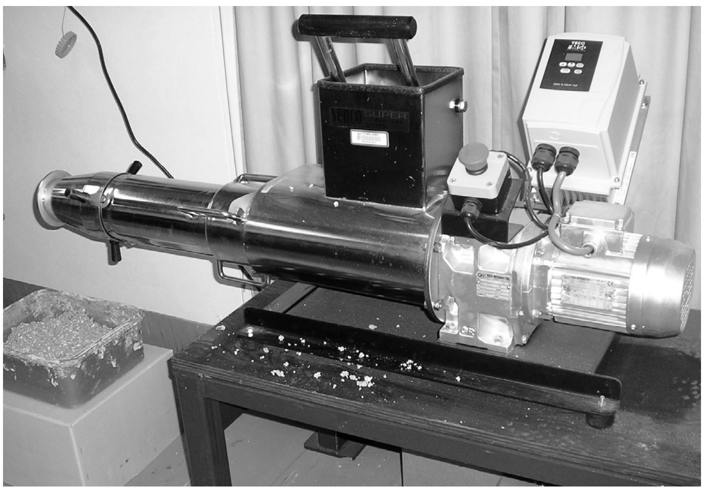

Figure 7 Pug mill for mixing EPS and clay.

5.3 Swell Pressure

Swell pressure is defined as the pressure to maintain the specimen's volume constant while undergoing saturation, in between two successive axial deformation readings. Variation of maximum swell pressure with

EPS content and maximum dry unit weight for the three SB mixes is shown in Figure 11. In general, it is seen that the maximum swell pressure of a clay can be halved by mixing with 0.9% granulated EPS by mass.

5.4 Volumetric Shrinkage

In this test, soil-EPS mixture was placed in a Proctor mould and lightly tamped to avoid the formation of any air voids. The specimen was kept inside the mould at room temperature for 4 hours for initial drying and subsequently oven dried at 70°C for 48 hours. During drying, the mould, containing the soil specimen, was weighed regularly, and turned upside down or rotated to let the soil specimen shrink uniformly. When the mass of the mould and specimen became constant, the volume change was determined by measuring the specimen's new dimensions. Figure 12 shows that the addition of EPS can reduce the volumetric shrinkage by as much as 50%.

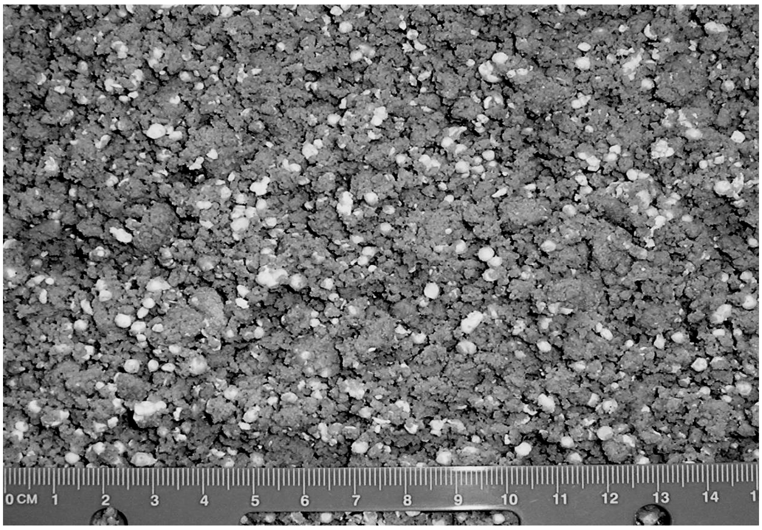

Figure 8 A well-mixed soil-EPS.

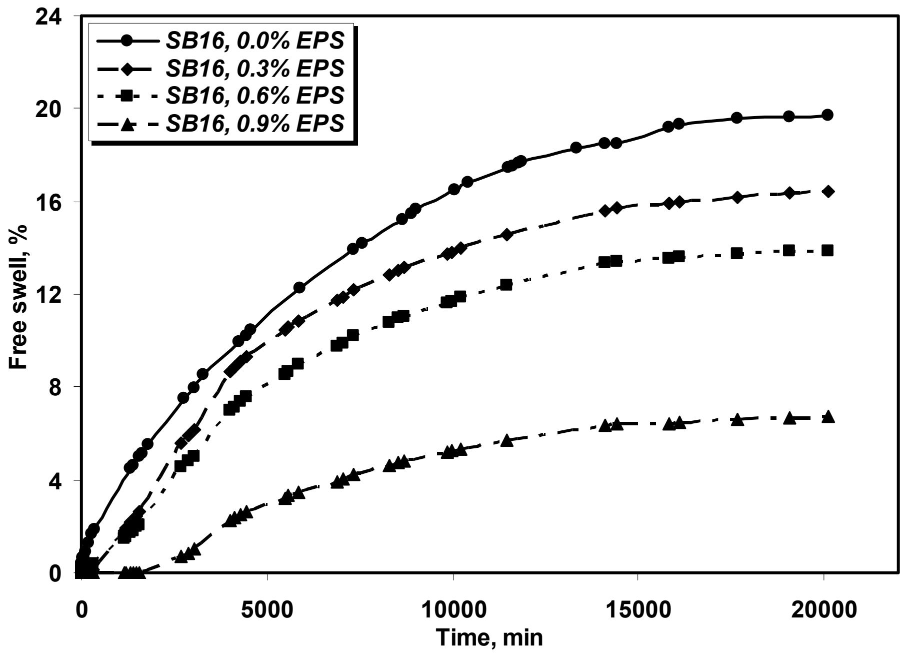

Figure 9 Free swell curves of a soil with PI of 38% and with different EPS contents.

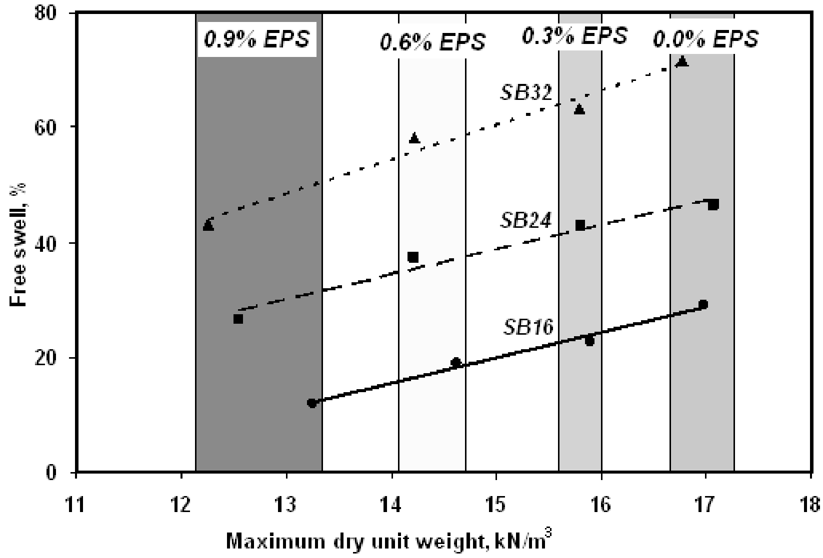

Figure 10 Variation of maximum free swell with EPS content for three sand-bentonite mixes.

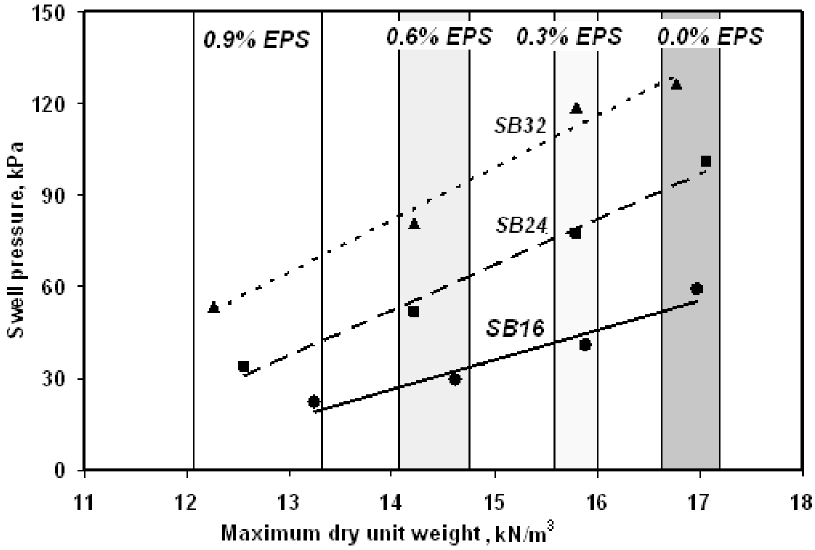

Figure 11 Variation of swell pressure of different soils at different percentages of EPS.

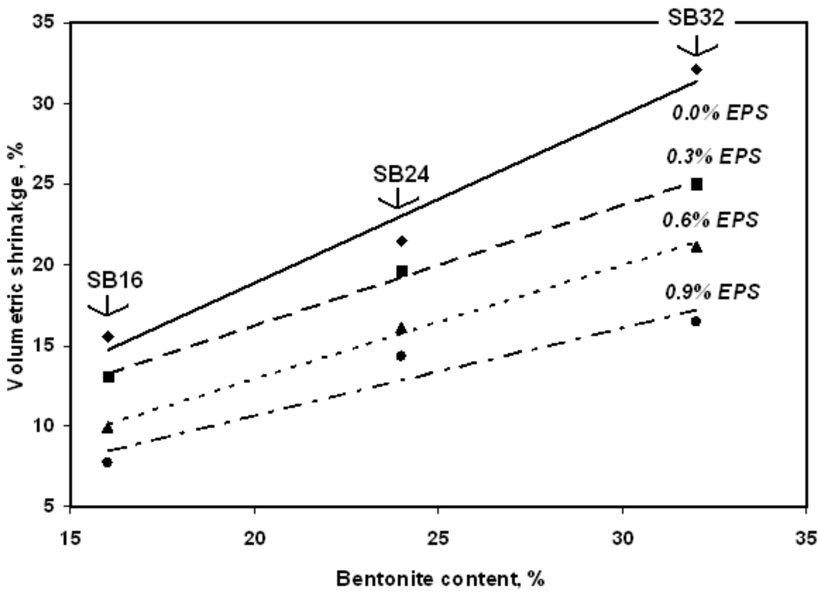

Figure 12 Effect of EPS on volumetric shrinkage.

5.5 Hydraulic Conductivity

As mentioned earlier, the ability of a backfill to drain water is an important factor that will affect the stability of a retaining wall. A permeable backfill will allow water to flow quickly so not to increase the magnitude of horizontal force that can destabilize the wall. The variation of hydraulic conductivity of SB24 with the addition of EPS is shown in Figure 13. It is seen that the hydraulic conductivity of the soil-EPS composite increases slightly with 0.3%EPS when compared with the control soil, but with higher EPS content a significant increase can be expected.

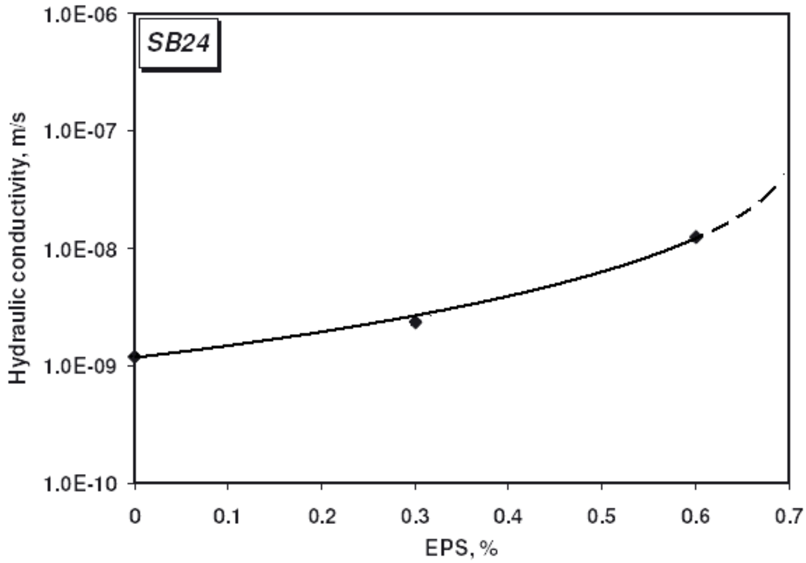

Figure 13 Variation of hydraulic conductivity with EPS content.

6. Conclusions

The results of a study on the potential use of granulated waste EPS to reduce the swelling and shrinkage potentials of expansive soils have been presented.

Artificially reconstituted soils of different plasticity values were prepared by mixing fine sand and sodium bentonite. It has been found that the addition of EPS granules into these soils results in light-weight backfill materials, suitable for use in domestic retaining walls.

The addition of EPS granules into a soil works well as a partial soil replacement. In swelling clays, this can reduce the magnitude of free swell and swelling pressure. It was also found that the higher the quantity of EPS granules in the soil, the less is the shrinkage potential. A reduction of about 50% in volumetric shrinkage can be expected for a soil with a PI of 53 mixed with 0.9% EPS granules by mass.

The innovative application of the granulated waste EPS mixed with expansive soil at optimum moisture content, so as to make a beneficial use of the waste EPS products and the unusable clay, will offer a sustainable solution for both the housing and EPS industries.

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