Short Communication

Swelling behaviour of expansive soils randomly mixed with recycled geobeads inclusion

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Abstract
Expansive soils exhibit greater volume change with variation in moisture content. In this study, an attempt has been made to reuse the waste expanded polystyrene (EPS) beads as an environmentally friendly additive to mitigate the swelling potential. The swelling behaviour of expansive soil was examined with and without EPS geobeads inclusions. Several swell-compression tests were carried out on one-dimensional large consolidation apparatus (LCA) which can accommodate the California bearing ratio (CBR) mould. The swelling characteristics of remoulded soil specimens were evaluated with the addition of 0%, 0.25%, 0.5%, 0.75% and 1% geobeads content (gc) by the dry weight of the soil. The test result shows that the increase in gc from 0.25 to 1%, there is a gradual decrease in the vertical swelling potential (i.e. percent swell and swelling pressure). A higher recycled gc inclusion up to 1% could be preferable to reduce maximum swelling potential, where compressional deformations are not of primary concern.

Keywords Expansive soil · Waste expanded polystyrene · Geobeads · Large consolidation apparatus · Swelling potential · Soil stabilization

1 Introduction

Expansive soils are often considered as problematic due to their inherent characteristics, which mainly include higher swelling and shrinkage [1, 2]. They swell upon absorption of water in the wet season, while they shrink when water gets evaporated in the dry season [3–5]. Due to seasonal variations, the soil experiences cyclic swell-shrink movement results in undesirable volume changes [6]. Thus, the overlying structure found on expansive soil poses great distress and severe damages [7]. Therefore, these soils require modifications, which necessitate engineering solutions to meet design criteria for prior application [8, 9].

Soil stabilization is one of the most widely followed techniques, to mitigate the swelling in the expansive soils through two methods, i.e. chemical and mechanical stabilization [10, 11]. Chemical stabilization is the oldest technique which mainly includes the addition of traditional binders such as cement and lime to improve the soil properties and restrict the swelling [12]. However, the effective utilization of cementing agents could be limited by leaching problems, low durability and adverse effect on local environment etc. [13]. The mechanical approach involves compaction of soil with the aid of reinforcing (e.g. geogrid and natural or synthetic fibres) or cushioning (e.g. cohesive non-swelling soil (CNS) layer and sand cushion method) or inclusion (e.g. geofoam, rubber and shredded tires) materials. As there is a global research need for turning into more sustainable practices, the researchers find a way to utilize alternative materials to replace or minimize the use of traditional cementitious agents [14].

In recent years, the reuse of solid waste materials and industrial by-products could be considered as alternative materials, to minimize landfills or reduce environmental

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pollution [15–17]. Various types of waste materials (e.g. shredded tyres and rubber powder) and industrial by-products (e.g. fly ash and bottom ash) were utilized to stabilize expansive soils. Also, geosynthetic inclusions (e.g. polypropylene/polyester fibres and expanded polystyrene (EPS)) were effective in reducing the swelling potential. Among other inclusion materials, EPS geofoam products are perform well in reducing the swelling potential due to its high compressibility characteristics [18, 19]. Recently, Selvakumar and Soundara [11] have reported the innovative technique to reduce the swelling potential with the introduction of recycled geofoam granules column (used waste EPS blocks/beads) inclusions. This study examines the beneficial use of recycled geobeads randomly mixed in expansive soils to mitigate swelling potential. Thus, this paper presents the efficacy of using recycled geobeads content (gc) with varying mix proportions (0%, 0.25%, 0.5% 0.75% and 1%) to arrive optimum content. For this study, a series of swell-compression tests were performed in a large one-dimensional consolidation apparatus (LCA), to assess the swelling reduction mechanism with the arrival of optimum gc content.

2 Materials and methods

A laboratory investigation programme was conducted for studying the performance of geobeads inclusions in arresting the swelling potential of expansive soils. Swelling behaviour of soil without geobeads was studied and compared with the soil specimens having geobeads inclusions. The experimental investigation was conducted on statically compacted soil specimen and tested on large one-dimensional consolidation equipment. Swell-compression tests were performed on soil specimens with and without geobeads inclusions. Further, the details of the laboratory tests are described in the subsequent sections.

2.1 Material characteristics

2.1.1 Expansive soil

Commercially obtained sodium bentonite was used as an expansive soil in this study which has a free swell index (FSI) value of 450%. Table 1 shows the physical properties of expansive soil. According to the USCS classification, the soil was classified as clay of high plasticity (i.e. CH) based on plasticity characteristics.

To study the mineralogical constituents, the X-ray diffraction (XRD) analysis has been done for the soil sample. Figure 1 shows the XRD plot of the soil sample, the diffraction data were collected from 10° to 45° (2θ degrees). The dotted vertical lines in the figure, spot the mineral names with d-spacing values in the parentheses (in the unit of Angstrom, Å). The intensity peaks (in the unit of Counts per second, Cps) indicates the presence of smectite group/expansible phyllosilicates minerals groups such as montmorillonite (M) and vermiculite (V), responsible for volume changes. Some other mineral groups such as oxides/hydroxides group like quartz (Q) and hematite (H), kaolins group like kaolinite (K), carbonate group like calcite

Table 1 Physical properties of the expansive soil

Property	Expansive soil
Specific gravity	2.80
Liquid limit (%)	276
Plastic limit (%)	33
Shrinkage limit (%)	8
Plasticity index (%)	243
FSI (%)	450
Clay (%)	96
Silt (%)	4
Sand (%)	–
Maximum dry density[a] (g/cm^3)	1.38
Optimum moisture content[a] (%)	38
USCS[b] classification	CH
Mineralogical composition[c] (%)	Montmorillonite: 42–44, Vermiculite: 24–26, quartz: 14–16, Calcite: 8–10, feldspar: 2–4

[a]Laboratory compaction test

[b]Unified soil classification system

[c]XRD spectrum

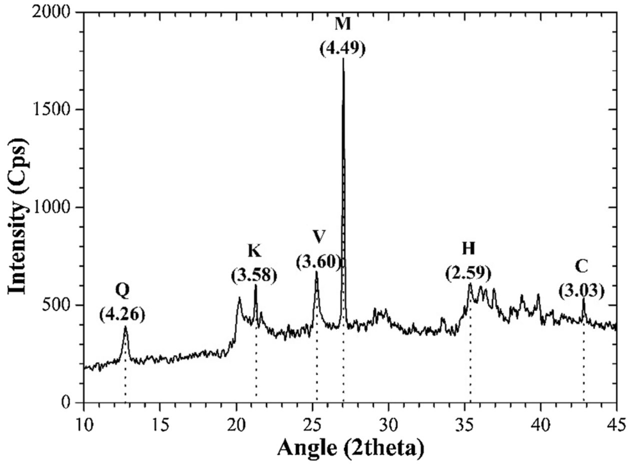

Fig. 1 X-ray diffraction pattern for soil sample

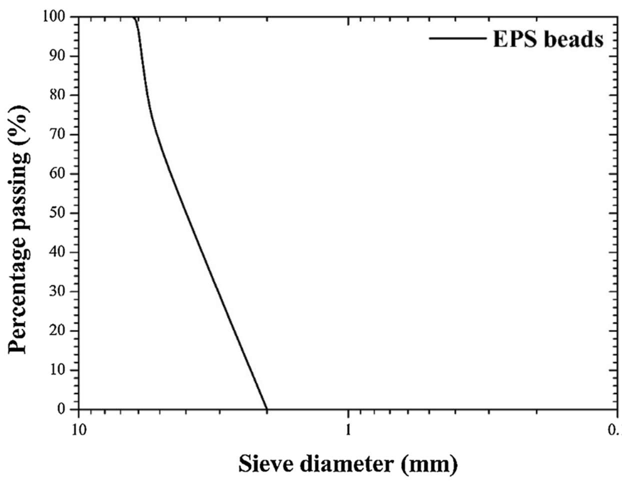

Fig. 2 Particle size distribution curve for EPS beads

(C) and some feldspar group are also present in the clay fraction [20].

2.1.2 Waste EPS beads

In this research, the investigation was carried out on the recyclability of waste EPS blocks in the geotechnical application by using EPS beads as an additive in expansive soils. The cut pieces of waste EPS blocks were collected from manufacturing units to reuse the wastes. The collected EPS blocks were converted into beads by hand crushing. EPS beads of size approximately in the range of 2–6 mm (D_{10} of 2.3 mm, D_{50} of 2.9 mm) were used in this study (Fig. 2). The specific gravity and the unit weight of EPS beads were determined using a modified procedure which is similar to that of the standard used for fine aggregates [11, 21, 22]. The unit weight of EPS beads was determined from the net weight of beads that occupy a volume of one-litre hydrometer jar without applying any compaction effort on the beads. The calculated unit weight of EPS beads based on the method was 0.15 kN/m^3. For the determination of specific gravity, the opening of hydrometer was covered with a piece of gauze fixed with O-ring. Then deaired water was added through the gauze until the total weight of hydrometer remains constant. The absolute volume occupied by the EPS beads in hydrometer has arrived and thus the specific gravity of EPS beads was calculated as 0.03. Table 2 summarizes the physical properties of the EPS beads.

2.2 Experimental programme

2.2.1 Large consolidation apparatus (LCA)

The large one-dimensional consolidation apparatus (LCA) was used to investigate the swelling behaviour of expansive soils with and without geobeads inclusions. The LCA accommodates the CBR mould (150 mm internal diameter and 175 mm height) covered with outer tank provision for bottom drainage purposes. The equipment provision has been described in detail by Selvakumar and Soundara [11]. Some of the information is concisely repeated here for completeness. The photographic view of LCA is shown in Fig. 3. The actual height of compacted specimen was maintained as 60 mm for all the tests to maintain the minimum diameter-to-height ratio of the specimen which is 2.5 (i.e. 150 mm diameter/60 mm height) by following ASTM D4546/ASTM D2435. The remaining height of the mould for adequate swelling as well as submerging the soil specimen. The top-loading plate and the base plate of CBR mould have uniform pores for the inundation of specimen with double way drainage. The vertical displacement of the specimen was measured using dial gauge with

Table 2 Physical properties of the EPS beads

Material	Properties					
	Specific gravity G_s	Dry unit weight (kN/m^3)	Effective particle size (D10: in mm)	Average particle size (D50: in mm)	Uniformity coefficient C_u	Coefficient of curvature C_c
EPS beads	0.03	0.15	2.3	2.9	1.4	0.9

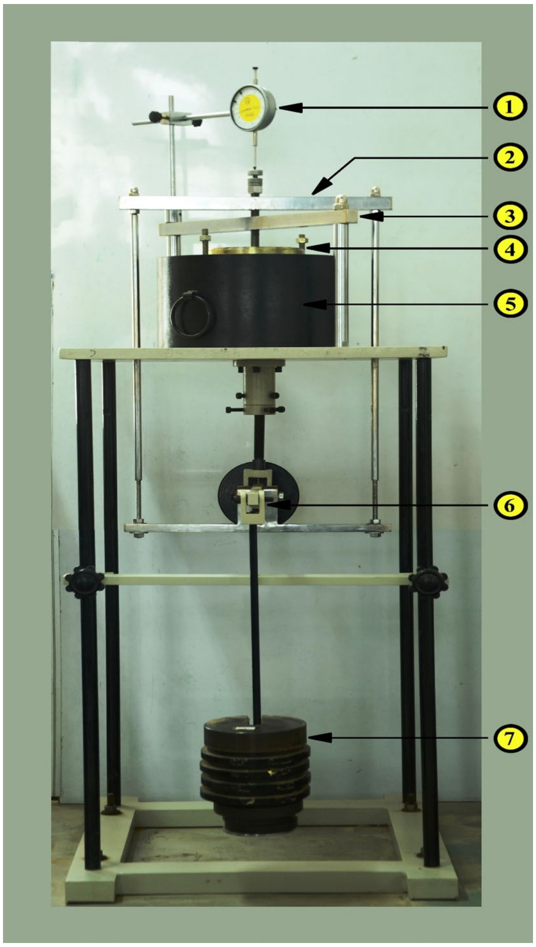

Fig. 3 Photographic view of large consolidation equipment. 1. Dial gauge indicator, 2. Reaction frame, 3. Fixed frame, 4. CBR mould, 5. Outer tank, 6. Lever arm (1:10), 7. Surcharge load

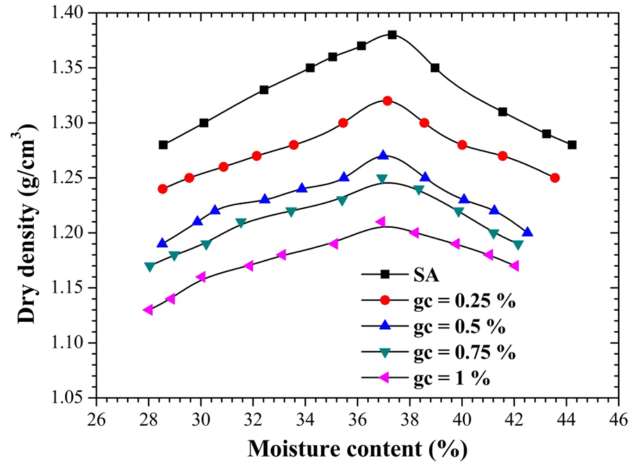

Fig. 4 Compaction characteristics of soil with and without gc

0.01 mm sensitivity attached to the reaction frame in the LCA.

2.2.2 Specimen preparation

Laboratory compaction tests were carried out on expansive soil with and without EPS beads to determine the optimum moisture content (OMC) and maximum dry density (MDD) by following the ASTM D698. The gc was taken as 0.25%, 0.5%, 0.75% and 1% by dry weight of the soil. The compaction test results are shown in Fig. 4. Minor variations were observed for OMC, while the MDD exhibited marginal decreasing trend with increasing EPS beads content. This could be attributed due to the lower specific gravity of EPS beads and maximum specific dried mass compared to soil particles [23, 24]. For swell-compression tests, all the samples were prepared by static compaction at their respective OMC and MDD of expansive soil (See Table 3). In the case of geobeads inclusion, the required amount of water corresponding to the desired OMC was added to each mixture and thoroughly mixed with geobeads content (gc = 0.25%, 0.5%, 0.75% and 1%) by hand. Care was taken while mixing the soil sample with beads mainly targeting the homogeneity of mixtures. Mixtures were then kept in desiccators for 24 h to maintain the moisture equilibrium. A specially fabricated metal spacer was used to achieve the static compaction of soil specimens. The inner surface of the CBR mould was smeared with silicone grease to avoid friction during compaction. Mixtures were gradually compressed in the mould by three layers to attain the maximum dry unit weight.

2.3 Test procedure

Upon completion of specimen preparation, the series of swell-compression tests were performed on LCA by following ASTM D4546. The test involved two stages: (1) swelling phase and (2) compression. In the first stage, the specimen was inundated with water to swell freely under nominal seating pressure of 6.25 kPa. The swelling strain was recorded at different time intervals to point out the equilibrium state. This resultant state is equivalent to the swelling potential of specimens (determined from Eq. 1). This could be attained after 18 days to 22 days of inundation. This is followed by the compression stage, where the swollen specimen was gradually loaded to counteract the build-up swelling strain. The pressure required to bring back the specimen's initial thickness is refereed as the swelling pressure.

$$Percent\ swell\ (PS) = \frac{\Delta H}{H} \times 100 \quad (1)$$

where ΔH = ultimate changes in the soil sample with respect to time intervals and H = actual thickness of the soil sample.

Table 3 Mechanical properties of the prepared samples

Test setup	Test identifier	Optimum moisture content, OMC (%)	Maximum dry density, MDD (g/cm^3)
Soil without geobeads content (Soil alone)	SA	37.33	1.38
Soil mixed with 0.25% geobeads content	gc = 0.25%	37.15	1.32
Soil mixed with 0.5% geobeads content	gc = 0.5%	36.98	1.27
Soil mixed with 0.75% geobeads content	gc = 0.75%	36.94	1.25
Soil mixed with 1% geobeads content	gc = 1%	36.92	1.21

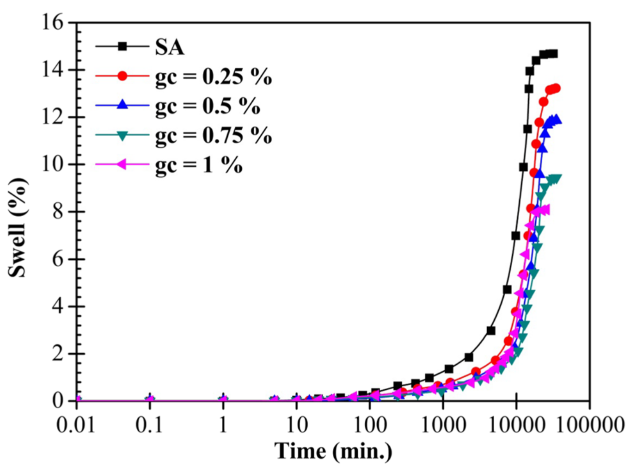

Fig. 5 Time versus percentage swell for varying gc

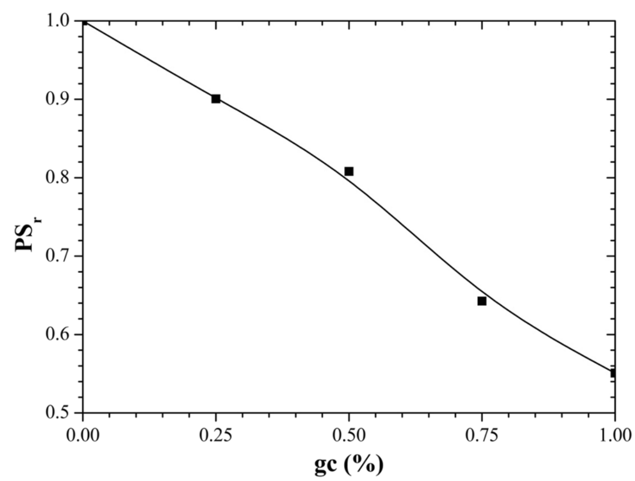

Fig. 6 Effect of gc on PS$_r$ values

3 Results and discussions

Time (logarithmic scale) versus swell strain plot for the soil alone (SA) and varying geobeads content of the soil samples are provided in Fig. 5. The vertical swell strain is expressed in percent swell which is the ratio of change in thickness at a given time to the original thickness of the sample, expressed in percentage. The percent swell of the sample is ranging from 14.7 to 8.1% upon increasing the gc from 0 to 1%. It indicates that there is a significant reduction in the magnitude of swelling strain for geobeads inclusion when compared to the swelling potential of SA. On increasing the gc, there is a gradual decrease in the swelling strain, indicates that gc was effective in arresting the swelling. This could be due to the replacement of swelling clay by compressible geobeads, which act as inclusion or rather act as obstruction of movement of water into the soil [25, 26].

Figure 6 shows the relationship between the percent swell reduction factor (PS$_r$) of the samples to the corresponding gc. From the plot, it is clear that percent swell (PS) is decreased with increasing the gc. For increasing gc from 0.25 to 1%, there is a substantial reduction in the PS of around 10% to 45%. PS$_r$ is defined as the ratio of maximum PS of soil with varying gc to the maximum PS of soil without gc (i.e. SA). The results of the measured PS and PS$_r$ values are given in Table 4. It clearly specifies the PS$_r$ for 0.25%, 0.5%, 0.75% and 1% of gc is about 0.90, 0.81, 0.64 and 0.55, indicating that reduction in PS by 0.10, 0.19, 0.36 and 0.45 times, respectively when compared to SA.

Figure 7 shows the graph of vertical stress (logarithmic scale) versus vertical strain for all the swell tests to evaluate the swelling pressure, which is corresponding to the zero vertical strain. The values of swelling pressure (SP) is noted from the plot and listed in Table 4. The vertical swelling pressure was the highest for the soil without gc inclusion. The data shown in both figure and table indicates that SP is reducing upon increasing the gc in the samples. As the maximum PS decreased with the inclusion of geobeads, obviously the swelling pressure of the sample is also decreased. For example, an increase in gc from 0.25 to 1%, there is a noticeable amount of reduction in the SP by 15% to 61% when compared to SA.

Figure 8 shows the relationship between swelling pressure reduction factor (SP$_r$) to the corresponding gc of the samples. SP$_r$ is defined as the ratio of SP for soil with

Table 4 Summary of measured percent swell and swelling pressure from the swell test program

Test identifier	Percent swell, PS (%)	Swelling pressure, SP (kPa)	Percent swell reduction factor, PS_r	Swelling pressure reduction factor, SP_r
SA	14.69	530	1.00	1.00
gc = 0.25%	13.23	452	0.90	0.85
gc = 0.5%	11.87	328	0.81	0.62
gc = 0.75%	9.44	273	0.64	0.52
gc = 1%	8.09	210	0.55	0.40

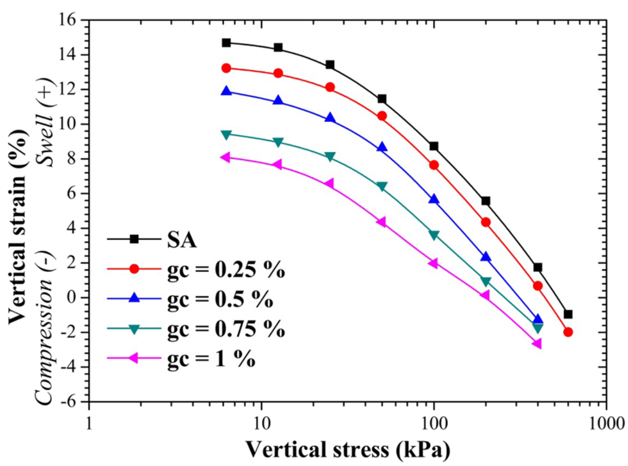

Fig. 7 Vertical stress versus vertical strain for varying gc

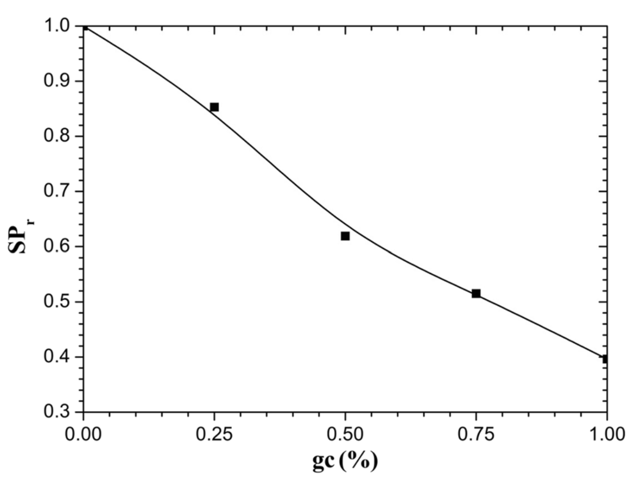

Fig. 8 Effect of gc on SP_r values

varying gc to the SP of soil without gc. From the graph, the SP_r values decreased with a gradual increase in gc of the samples. The results of the calculated SP_r values are given in Table 4. It indicates that SP_r for 0.25%, 0.5%, 0.75% and 1% of gc is about 0.85, 0.62, 0.52 and 0.40, specifying reduction in SP by 0.15, 0.38, 0.49 and 0.60 times, respectively when compared to SA. Based on the experimental results from the present study, when compressible EPS beads are mixed randomly, they tend to act as an inclusion or obstruction to the flow of water into the soil. This reflects in the reduction of the magnitude of swelling strain in the expansive soils as discussed earlier.

4 Conclusions

A series of swell-compression tests were carried out on large 1D consolidation equipment which can accommodate the CBR mould. An attempt has been made to ascertain the performance of EPS beads mixed expansive soil. The effect of geobeads inclusion on percent swell and swelling pressure was studied through the laboratory experimental program. Based on the observed results, the following conclusions can be drawn:

- The compressible recycled geobeads inclusion leads to a significant reduction in the swelling potential (i.e. percent swell and swelling pressure) was observed in the expansive soils.
- For increasing the geobeads content from 0.25 to 1%, there is a substantial reduction in the PS of around 10% to 45%, and there is a noticeable amount of reduction in the SP by 15% to 61% when compared to SA.
- Swelling potential was reduced at higher recycled geobeads content up to 1%, which could be considered as an acceptable choice.
- Reduction in swelling potential can be attributed to the replacement of swelling clay by compressible EPS beads which act as inclusion or obstruction to the flow of water into the soil.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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