Geotextiles and Geomembranes 47 (2019) 1–11

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Swelling behaviour of expansive soils with recycled geofoam granules column inclusion

S. Selvakumar, B. Soundara*

Department of Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, 638 401, India

ARTICLE INFO

Keywords:
Geosynthetics
Expanded polystyrene
Geofoam granules column
Expansive soil
Percentage of swell
Swelling pressure
Large scale consolidation apparatus

ABSTRACT

Structures founded on expansive soils experience large uplift pressure due to the high swelling nature of these soils. In this investigation, an effort is taken to reuse the waste expanded polystyrene (EPS) beads to form geofoam granules column (GGC) and quantify the swelling behaviour of expansive soil with and without GGC inclusion. Several swell tests were carried out in statically compacted soil specimen with uniform thickness of 100 mm placed in a large scale one dimensional consolidation apparatus which can accommodate the California bearing ratio (CBR) mould. Attempts were made to ascertain the performance of GGC inclusion in expansive soil by varying diameters of GGC (25 mm, 40 mm, 50 mm and 75 mm), density of formed GGC (15 kg/m^3 and 20 kg/m^3) and two placement conditions of soil samples (by varying moisture content). Tests results were analysed which showed that the percentage of swell, swelling pressure and the time rate of swell decreases upon inclusion of GGC and significant reduction is noticed for lesser GGC density. Further, the mechanism of GGCs influence in control swelling of expansive soil is explained with the help of soil-GGC interaction.

1. Introduction

Expansive soils endure adverse changes in volume and hydraulic conductivity due to the seasonal changes in moisture content. These variations cause detrimental effects on the structures over the expansive soils since they are prone to greater volume change characteristics (Jennings and Burland, 1962; Fredlund and Rahardjo, 1993; Sharma and Phanikumar, 2005; Puppala et al., 2006; Soundara and Robinson, 2009; Öncü and Bilsel, 2017). Expansive soils swell by absorbing water in wet season while they shrink when water gets evaporated in dry seasons (Chen, 1988; Nelson and Miller, 1992; Madhyannapu and Puppala, 2014). The effect of wetting and drying cycles in expansive soil is to cause swell-shrink actions resulting in undesirable volume changes depending upon the stress history and suction (Gens and Alonso, 1992; Singhal et al., 2015; Wang and Wei, 2015; Zhang et al., 2016). The cyclic swell-shrink behaviour causes great distress to rigid and flexible structures laid on expansive soils if it is not controlled (Rao et al., 2001; Yazdandoust and Yasrobi, 2010; Kayabali and Demir, 2011).

Soil stabilization is one of the most widely followed techniques to control the swelling behaviour of expansive soils in lightly loaded structures. The stabilization techniques to control the swelling characteristics in expansive soils can be grouped into mechanical, chemical and polymer as well as unconventional stabilizer methods (Petry and Little, 2002; Ikizler et al., 2009; Estabragh et al., 2014). Mechanical and chemical stabilization are the oldest and traditional methods followed to improve the engineering properties of the expansive soils. The mechanical stabilization does not alter the chemical properties of soil but have significant influence on changing the gradation and improvement in strength aspects (Katti, 1978; Chen, 1988; Sridharan and Gurtug, 2004), while, in chemical stabilization, some additives such as lime, cement, fly ash etc., are added, which physically interacts with the soil and change the index properties (Chen, 1988; Çokça, 2001; Jamsawang et al., 2017; Chittoori et al., 2018). In recent times, the use of polymer based product such as geosynthetics in expansive soil stabilization (Omari and Hamodi, 1991; Sharma and Phanikumar, 2005; Viswanadham et al., 2009; Buzzi et al., 2010) is widely practiced due to their desirable properties and durability (Jewell, 1991; Koerner, 1999).

Amongst the geosynthetic materials, EPS is light-weight polymeric foam made by fusing the pre-puff beads followed by manufacturing the foam blocks with desired densities. Intrinsically, EPS can be multifunctional, cost-effective and used for wide application which mainly includes goods packaging, construction appliance and domestic appliance. Recently, the EPS products are considered as a part of geosynthetics family and it has been named as geofoam since they have been increasingly used for geotechnical applications (Horvath, 1994, 1995).

---

* Corresponding author.
E-mail addresses: selva.geotech@gmail.com (S. Selvakumar), soundra_iit@yahoo.co.in (B. Soundara).

https://doi.org/10.1016/j.geotexmem.2018.08.007
Received 23 June 2018; Received in revised form 20 August 2018; Accepted 23 August 2018
0266-1144/

Likewise EPS blocks, beads and other EPS related material composites can be either called as geofoam or geomaterial (Deng and Xiao, 2010; Liu et al., 2006; Miao et al., 2013). These materials are inherently multi-functional, which make them effective to be used in wide variety of applications such as construction on soft ground, embankment widening, slope stabilization and retaining walls.

The use of geofoam as compressible inclusion in geotechnical application is not new. Typically, the inclusion is placed vertically and horizontally between the soil and structure which results in reduction of static earth pressure and also acts as a seismic buffer (Horvath, 1997; Ossa and Romo, 2011; Zarnani and Bathurst, 2008). The effectiveness of using geofoam blocks for the applications related to retaining walls, embankments and buildings has been reported by many researchers (Karpurapu and Bathurst, 1992; Horvath, 1994; Beinbrech, 1997; Duškov, 1998). The relevance of geofoam blocks and beads to control the swelling in expansive soil have been reported by few researchers (Aytekin, 1997; Horvath, 1997; Ikizler et al., 2008, 2009; Illuri, 2007; Abdelrahman and Ahmed, 2013). The swelling process can be accelerated by providing granular material to increase the rate of infiltration of water in to expansive soil (Sharma and Phanikumar, 2005; Nagaraj et al., 2009). In recent days, due to the inadequacy of granular materials in near vicinity, the geosynthetic related products are effectively used as an alternative for vertical drains such as prefabricated vertical drain, EPS beads, Sheet drain and geotextile etc. (Rajagopal, 2016).

The feasibility of utilizing geofoam blocks has been studied by many researchers (Ikizler et al., 2008, 2009; Wan et al., 2018) but only limited studies are available on the EPS beads, geocomposite and geomaterial related investigations. In the field application, the geofoam beads and geomaterial have numerous advantages than geofoam blocks (Liu et al., 2006; Padade and Mandal, 2014). However, the placing of blocks and mixing of beads shall be feasible only up to a shallow depth in the field condition which necessitates the development of a solution for stabilizing deep expansive soils.

It is evident from the above discussion that EPS geofoam beads can perform as compressible inclusion and vertical drain as well; however, there has been no prior studies reported on the effect of GGC in the expansive soil. These effects ought to be quantified in order to understand the swelling behaviour of expansive soil with GGC inclusion. In addition, EPS beads were obtained from waste EPS blocks and used to make GGC formation. Hence, in this research recycled material was considered to understand the vertical swelling behaviour of expansive soils with GGC inclusion by conducting swell tests on large one dimensional (1D) consolidation apparatus. The tests were carried out for two placement conditions of an expansive soil with and without the inclusion of four different diameters of GGC with two different geofoam granules density. From the experimental results, qualitative and quantitative reduction in swelling potential and swelling pressure was observed due to the inclusion of GGC in expansive soil.

2. Materials and methods

The expansive soil was obtained from Chennai, Tamilnadu, India at a depth of about 1.5 m from the ground level and used for the laboratory tests. The laboratory studies on the behaviour of expansive soils with and without GGCs inclusion were carried out on large scale 1D consolidation apparatus. The apparatus setup is provided with double way drainage, ceramic discs, porous loading plate and the required surcharge load is applied in the ratio of 1:10 through lever arm arrangement which is similar to that in the conventional 1D consolidation oedometer apparatus (ASTM D2435, 1996).

All the tests were conducted on remoulded dry samples at two different placement conditions i.e., Optimum moisture content (OMC) and hygroscopic moisture content (HMC) at maximum dry density (MDD) obtained from dry density vs. water content curve through standard proctor compaction test in laboratory. Firstly, the swelling behaviour of the compacted expansive soil specimen alone is studied for both OMC and HMC at MDD. Secondly, the influence of GGCs in the swelling behaviour of soil specimen was studied with four different diameters of GGC inclusion corresponding to the two different densities of geofoam granules in compacted soil specimens for two different moisture contents. The subsequent sections provide the details of laboratory tests.

Table 1
Index properties of the expansive soil.

Property	Expansive soil
Specific gravity	2.65
Liquid limit (%)	76
Plastic limit (%)	41
Plasticity index (%)	35
Shrinkage limit (%)	9
Clay (%)	72.5
Silt (%)	23.5
Sand (%)	4.0
Free swell index (%)	108
USCS classification[a]	CH
Optimum Moisture Content (%)	17
Maximum dry unit weight (kN/m^3)	17.65
Mineralogical composition (%)	Vermiculite: 46–48, montmorillonite: 33–34, quartz: 10–12, feldspar: 4-6

[a] Unified soil classification system.

2.1. Material properties

2.1.1. Soil characteristics

The natural soil received from the field was completely air-dried at room temperature and then ground to break up the aggregation thoroughly with the help of pestle. The physical index properties of the soil sample were determined and the results are summarized in Table 1. Based on the free swell index tests conducted on the soil sample, the soil can be classified as high degree of expansiveness (Sridharan and Prakash, 2000). According to USCS classification system, the soil is classified as clay of high plasticity (CH).

In order to understand the mineralogical constituents, X-Ray diffraction (XRD) analyses has been done for the soil sample. The air-dried soil sample is sieved through ASTM standard sieve No. 200 (75 μm) and about 10 g of soil containing silt and clay fraction was thoroughly mixed with one litre of sodium hexametaphosphate solution followed by sedimentation process. After the sedimentation process, the soil suspension was air-dried and thoroughly crushed to collect the powdered particles. The collected suspension particles were then centrifuged to separate out the clay fraction ($< 2\,\mu m$) and used to carry out XRD test (Burnett, 1995; Lin et al., 2013). The diffraction data were collected from 10° to 45° (2θ degrees) at a rate of 0.05° 2θ/s. The result of the XRD plot is shown in Fig. 1. The dashed vertical lines in the figure, mark the mineral names and d-spacing value in square bracket (in the unit of Å). The intensity peaks indicate the presence of smectite group/expansible phyllosilicates mineral groups such as Montmorillonite (M) and Vermiculite (V). These are the causes for volume changes in expansive soils with some other mineral groups such as feldspars and oxides/hydroxides shows Anorthite (A) and Hematite (H) in the clay fraction (Harris and Norman White, 2008).

2.1.2. Waste EPS geofoam

The current research was conducted to investigate the recyclability of EPS geofoam in geotechnical applications by using waste EPS blocks. The blocks are converted into beads and were used for forming the granules column inclusion in the expansive soil. The cut pieces of waste EPS blocks of different sizes and densities were procured from nonproprietary at free of cost since the recyclable cost of cutting wastes is highly complex and uneconomical (Kan and Demirboğa, 2009a, 2009b). So, EPS manufacturers are still finding the feasibility of using