Research Article

Physical stabilization of expansive subgrade soil using locally produced geogrid material

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Abstract

This paper illustrates application of a locally produced geogrid material for strength improvement of expansive subgrade soil. Samples of black, soft soil predominating the study area were collected from south western parts of Modjo town, inside the rift valley region of central parts of Ethiopia. X-Ray diffraction as well as index property tests were executed to identify and categorize the expansiveness of the highly plastic soft soil. The effects of two locally manufactured geogrid reinforcement materials; namely, polypropylene (PP) and high density polyethylene (HDPE) on the California bearing ratio (CBR) values of the expansive soil have been investigated. The test results indicated that the use of the geogrid reinforcement can significantly improve the bearing capacity of weak subgrade soil. The soaked CBR of the untreated soil sample, which was about 2.98%, was able to be raised to 10.16% and 7.48% by the application of PP and HDPE type of geogrid respectively, that were placed at 0.35H from the top of specimen. The research demonstrated the potential of using locally produced geogrid material for the improvement of weak subgrade soil.

Article Highlights

- The strength of weak subgrade soil was strongly improved after the introduction of two locally produced geogrid materials made of polypropylene and high density polyethylene, respectively
- The geogrid made from polypropylene raw material was found to improve the strength (CBR) of the subgrade better than that made from high density polyethylene
- Experimental investigations about the effectiveness of chemical stabilization using cement kiln dust (CKD) indicated that geogrid reinforcement is relatively more promising

Keywords Expansive soil · California bearing ratio · Geogrid · Subgrade soil

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1 Introduction

Quality and service life of pavement is extremely affected by the type of subgrade materials. Availability of appropriate subgrade materials that satisfy the requirements of international standards is one of the difficulties in the design and construction of pavements. Since the conventional practices call for materials of better quality to satisfy such requirements, it is inevitable to seek for alternative solutions that can provide economic advantages and at the same time improving the behavior of weaker subgrade soil.

The extent of damages caused by expansive soils is tremendous and alarming. Many Countries have been repeatedly reporting about the problems of expansive soil [4, 18]**.** In Ethiopia most of the roads being constructed face challenges related to weak and problematic soils. It has been frequently observed that, places where different construction activities going on are mostly covered with expansive soil [24]. Since the coverage of expansive soil in Ethiopia exceeds 40%, which includes the most populated and economically active areas, as shown in Fig. 1, the search for different solution mechanisms is important for solving the problems.

Each year, the amount of expansive soil discovered increases with the ever increasing construction activities. Due to the existence of minerals like montmorillonite and illite, which are constituents of expansive soil with swelling properties, such soils expand when saturated with water. When clay minerals get dried, the soil shrinks, leaving large voids in soil mass [4, 12]; such cyclic movement causes deformation, cracks and excessive settlement in buildings, roads, pipe network and the like. Tremendous structural damages due to expansive soils have been reported in the world in general and Ethiopia in particular [18, 24]. Pavements are extremely susceptible to damages from expansive soil because the wheel loads cannot balance the swelling pressure of the subgrade unlike the case of multistory structures [13].

Geosynthetic materials are mostly produced from polymers (hydrocarbons). Polyester, polypropylene, polyethylene, very low density polyethylene, medium density polyethylene, high density polyethylene and polyvinyl chlorides are the polymers which are the raw materials to produce geosynthetics [21]. The communal type of such materials are geogrids,geotextiles, geomembranes, geonets, geofoams and geocomposites, their primary function being reinforcement, separation, filtration, drainage and containment respectively [21]. Geogrids used within a pavement system perform two primary functions; namely, separation and reinforcement**.** Application of geogrid in roadway construction to reinforce the base of the structure over expansive soft subgrade soil nowadays become an alternative advantage than removing and replacing problematic soil [11, 20, 23]. In any case, since the traditional undercut and chemical stabilization solutions are often costly and time—consuming process, geogrids are often used as better alternatives of these traditional solutions, to increase the bearing capacity of expansive subgrade soil.

Different studies have indicated the potential of geogrid as weak subgrade and pavement section improvement material. Naeini et al. [16] found out that the use of geogrid reinforcement on three soft clay samples of various plasticity leads to a significant increase in soaked and unsoaked CBR values. Calvarano et al. [7] applied numerical analysis methods to show the improvement of geogrid reinforced on weak subgrade material. Currently, geogrid stabilization of weak subgrade soil gains for providing effective and economical solution for road rehabilitation and construction projects over weak pavement subgrades [23].This study is aimed at evaluating the efficiency of using two locally manufactured geogrid reinforcement materials for stabilization of subgrade soil. In order to investigate the effectiveness of the geogrid reinforcement in comparison to that of chemial stabilizers, the same subgrade soil was treated through application of Cement Kiln Dust (CKD) taking CBR as the control parameter since previous studies indicated clearly that swelling of expansive soils can be controlled properly by the use of geogrids [3]. Purely experimental methods have been followed to achieve the goals of the research whose results indicated the considerable potential of the two locally produced reinforcement geogrids. The comparative CBR results of the CKD material with that of the geogrids show the use of the chemical treatment is not appreciated due to its scarcity, practical application difficulty during rainy season, carbonation, time, sulfate attack and environmental impact. The paper first presents the objectives and methodology of the research together with

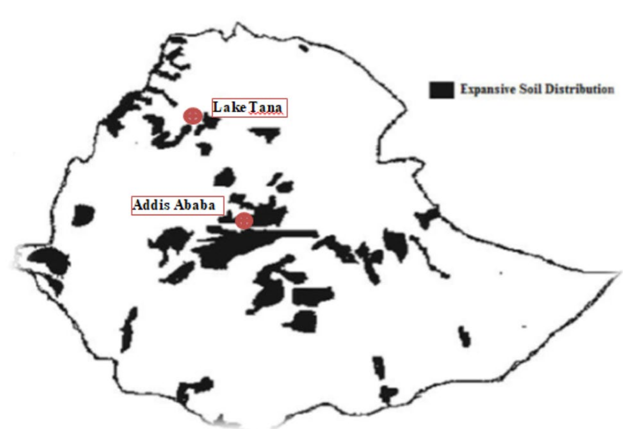

Fig. 1 Distribution of expansive soil in Ethiopia [24]

concise literature review. The results of the laboratory tests made on the original subgrade and geogrid materials for the purpose of classification are presented in the second chapter. The chemical composition of the cement kiln dust stabilizer used for the comparative study is also presented before the third chapter, which deals with the discussion of results of the stabilization. Finally, the conclusions of the research and future prospects are forwarded in the last chapter.

2 Laboratory investigations on the original subgrade and geogrid materials

In order to investigate the effects of geogrid reinforcement, basic classification and strength tests were performed both on the subgrade soil and geogrid materials. Atterberg limits, particle size determination, swelling potential and compaction tests have been carried out to characterize the in situ properties of the subgrade soil, while the strength improvement of the existing subgrade soil achieved due to geogrid reinforcement was further analyzed by performing CBR tests before and after treatment.

2.1 Expansive soil

Expansive soil samples used in this research work were collected from Modjo town below a depth of 1.5 m by avoiding the inclusion of organic matter. The soil is grayish black in color; highly plastic, fine material and rich in montmorillonite mineral as determined from X-ray diffraction (XRD) test shown in Fig. 2. From the two curves of the XRD test, the absolute peak magnitude of the 2 theta value is found to be 27.56°, which represents a chemical formula of $(Ca)_{0.33}(Mg)_2(Si_4O_{10})$ $(OH)_2.nH_2O$. This is an indication of the fact that the selected soil sample is rich in montmorillonite clay minerals. In such soil formation of a lattice structure the atoms are arranged in several sheets [12].

Among the series of laboratory tests performed on the untreated soil sample, the results of grain size distribution analysis and proctor test results are presented on Fig. 3a. Since the percentage of clay particles is 92.7%, the soil is dominantly fine grained clay. The maximum dry density (MDD) versus optimum moisture content (OMC) curve also indicates that the values are typical of such a material (Fig. 3b).

The set of laboratory test results of the untreated natural subgrade soil, which were used to identify some of the in-situ characteristics of the subgrade soil performed in accordance with ASTM standard are summarized in Table 1. The higher plasticity indices and the lower strength are typical for an expansive soil having montmorillonites as indicated by the XRD test results shown in Fig. 2.

2.2 Geogrid

Geogrids are commonly used to facilitate the construction of roads by improving the performance of unpaved low-volume roads on weak subgrades [6]. Even if it was planned to analyze the possible ranges of applicability of geogrids, it was unfortunately impossible to get any of the geogrid types during the research period in Ethiopia. Cooperational agreements were thus made with the Institution called Geosynthetics Industrial Works which produces geomembrane and pipes. The raw materials used to produce PP and HDPE type of geogrid were obtained from that institution and placed inside the melt mixing extruder with controlled temperature.Through extruding and stretching of the raw material inside the geomembrane production equipment, sheets of dissimilar thickness were produced first and then cut to the required dimensions. Finally, the geogrid was produced by welding the junctions of woven segment of extruded polymers with aperture opening size of 22 mm by 22 mm, which can be visualized in Fig. 5.

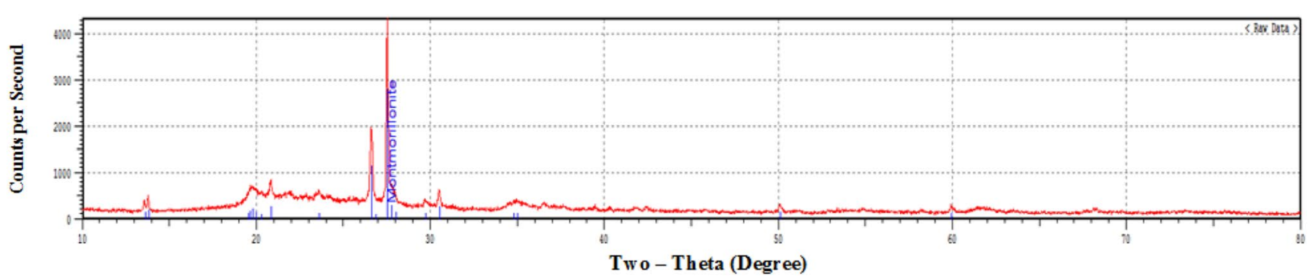

Fig. 2 X-ray diffraction counts per second versus two—theta pattern graph for expansive soil rich with montmorillonite

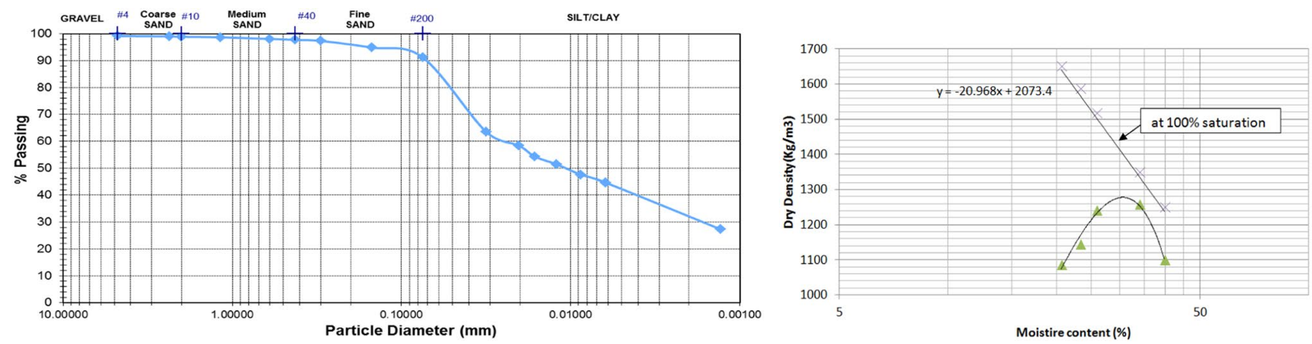

Fig. 3 **a** Wet sieve and hydrometer analysis gradation curve result **b** Compaction curve of expansive soil

Table 1 Properties of untreated natural soil

Property	Quantity
Unified Soil Classification System	CH
Liquid Limit (%)	74.05
Plastic Limit (%)	33.67
Plasticity Index (%)	40.38
Specific Gravity	2.49
Free Swell Index (%)	145
Maximum Dry Density (kg/m^3)	1280
Optimum Moisture Content (%)	33
UCS (kPa)	81
Unsoaked CBR (%)	16.26
Soaked CBR Swell (%)	4.57
Soaked CBR (%)	2.98

Fig. 4 Tensile and elongation test machine

2.2.1 Sample preparation and tensile test on geogrids

After manufacturing the geogrid, its ultimate strength and elongation properties must have been determined. For that purpose, the sample was prepared in the form of dogbone shape by using a cutting machine. Single rib tensile tests [5] were then carried out according to ASTM D6637 standard, at the facility of Geosynthetic Industrial Works as shown in Fig. 4.

2.2.2 CBR testing procedure

Being the standard strength parameter for subgrade materials in pavement construction, the CBR value has been taken as the control parameter in this research. To conduct one point CBR test before and after inclusion of geogrid, the required quantity of dry soil and water were determined based on maximum dry density (MDD) and optimum moisture content (OMC) of the soil (see Fig. 3b above). Dry soil was mixed thoroughly at the OMC value, by adding the required amount of water. Then, a single layer of the geogrid reinforcement made of PP and HDPE raw material was prepared with circular shape of 147 mm diameter which is slightly less than the internal diameter of the CBR mold. The position of the geogrid has been selected based on the findings of previous researchers [1, 2, 14, 19]. The geogrid is placed 35 mm below the top of the standard CBR mold in between the soil layers that were carefully compacted in order to achieve the required density (Fig. 5).

Placement of the geogrid reinforcement was carried out by following the procedure used in Useche and Martin [8], by fixing the geogrid with the CBR mold. This type of model depicts the actual in-situ conditions, in which the compressive forces from the soil are shared by the geogrid dominantly by membrane action. The stabilization of soil by the geogrid through this membrane action gives rise to the improvement of the stress–strain behavior of the soil -geogrid composite. This in-turn leads to a decrease in the settlement of the soil which is exhibited by the decrement of the CBR swell shown in Table 3.

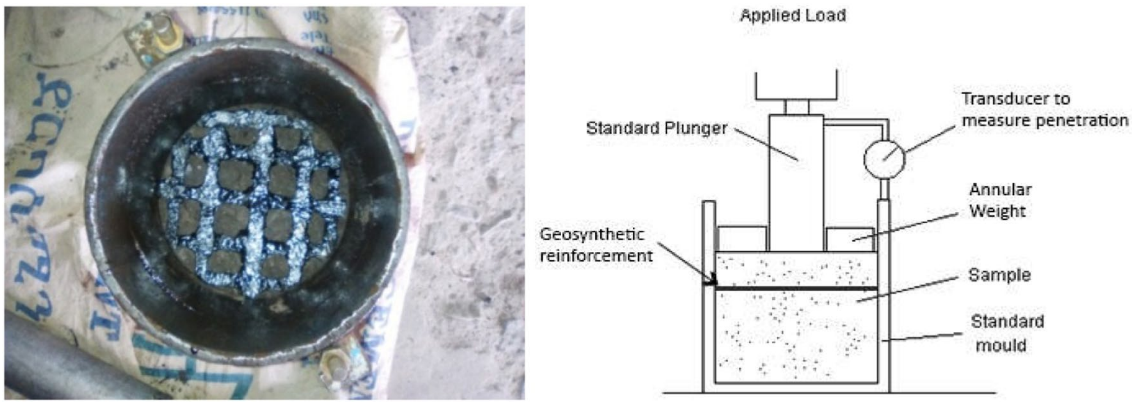

Fig. 5 Placement of Polypropylene (PP) and High Density Polyethylene (HDPE) type of geogrid material inside CBR mold 35 mm below Plunger bottom

2.3 Comparative study using cement kiln dust

With the purpose of assessing the significance of the geogrid stabilization in comparison with other options, stabilization of the same subgrade soil was investigated by using chemical stabilizer known as cement kiln dust (CKD). The cement kiln dust sample was first collected from **Dangote** Cement Industries in Ethiopia, whose oxide composition was analyzed using Rohbotic X-ray Fluorescent (XRF) testing machine. The chemical composition of the CKD material is presented in Fig. 6.

These results indicate that the dust is dominated by Calcium oxide (CaO) Silicon dioxide (SiO_2) which account for about 89% by weight of the CKD. In combination with the very low Free Lime and Loss in Ignition (LOI) accounting for 1.37% and 1.87% by weight, it gives rise to improvement of the expansive soil under consideration; i.e. increase in strength characteristics and reduction of the expansiveness.

3 Results and discussion of the stabilization process

3.1 Properties of Geogrid made from PP and HDPE

Many successful applications of high strength geogrid reinforcements are being reported frequently, due to the significant advantages in terms of economic and environmental factors as compared to other alternatives [25]. When interfacing soil with geogrid at a specified layer, the resistance increases against penetration of CBR plunger increases due to the load bearing capacity of the geogrid and widening of the area for distributing stresses to sub surface material [15].

Density is among the various factors differentiating PP from HDPE. According to raw material specification data which was obtained from Geosynthetics Industrial works in Ethiopia, both HDPE and PP material are thermoplastic material and their densities are 0.94 g/cm^3 and 0.895–0.92 g/cm^3 respectively. As shown in the summary of laboratory test results performed by GIW (Table 2**)**, the high tensile strength and minimum percent elongation of PP made geogrid, combined with its resistance to temperature and chemicals [9], makes it ideal reinforcement material than HDPE, which shows excessive elongations. The tensile strength of PP and HDPE made geogrid at the yield load are 176.53 MPa, 92.65 MPa; which are within the ranges of experience described in the literature [10]. The corresponding percent elongation values are 10.82%, 12.998% respectively; while a 670% increase in elongation was found for the HDPE geogrid at break load. Even though this is too large, further detailed investigations shall be performed to come to definite conclusions as loading until the ultimate limit is practically uncommon. Compared to many materials, PP has a good tensile strength [9]; which allows the material to withstand fairly

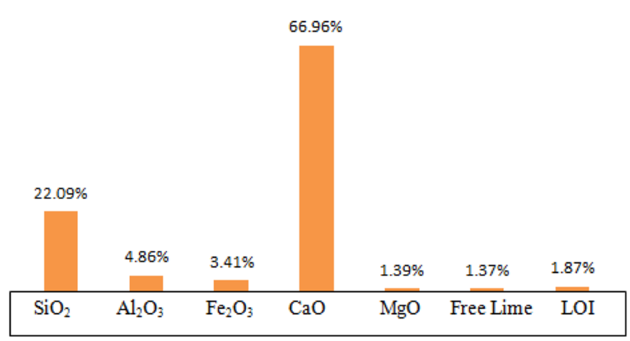

Fig. 6 Chemical composition of cement kiln dust material

heavy loads despite its light weight. Its impact resistance leaves something to be desired when compared to geogrid made of HDPE. The small amount of carbon content in raw material is also a factor to classify whether it is stiff or not [17]. Thus geogrid made from PP raw material has higher strength and lower elongation value than HDPE.

3.2 Chemical stabilization on the subgrade soil

Following similar procedures as the case of geogrid reinforcement, CBR tests were carried out to investigate the improvement potential of the subgrade soil using cement kiln dust by considering 0 to 13% by weight application. The soaked and unsoaked CBR tests results before and after treating with various amounts of cement kiln dust are presented in Fig. 7.

Due to low values of LOI and free lime of CKD material, the strength of the weak expansive subgrade soil increased after stabilization with CKD. Values of unsoaked and soaked CBR increased from 16.26% and 2.98% of untreated soil to 35.23% and 12.87% respectively for the uncured and cured specimen at the maximum CKD application. The mechanism of soil—CKD treatment involves cation—exchange, which leads to the flocculation and agglomeration of soil particles [22]. Even though it can be potentially used as a stabilizer and in this paper economic analysis is not yet included between geogrid and CKD; CKD treatment has a number of disadvantages, such as unavailability, practical application difficulty during rainy season, carbonation, time; sulfate attack and environment impact. Physical stabilization, using geogrid in particular, is thus proposed as a suitable alternative stabilizer to

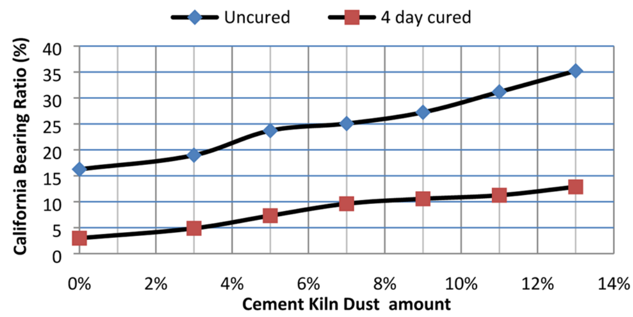

Fig. 7 Effect of CKD on soaked and unsoaked CBR values

overcome some of the disadvantages of using CKD in soil stabilization.

3.3 Effects of PP and HDPE geogrid reinforcement on CBR and CBR swell values of weak subgrade soil

The relationship between penetration stress and depth values for soaked and unsoaked CBR values when reinforced with PP and HDPE geogrid while placed at fixed position is shown in Fig. 8. Values of unsoaked and soaked CBR increased from 16.26% and 2.98% of untreated soil to 37.26% and 10.16% of the PP geogrid treated subgrade soil. This improvement was obtained by applying about 13% of CKD as shown in the previous section. Likewise, values of unsoaked and soaked CBR of weak subgrade soil also increased to 23.71% and 7.48% respectively after being reinforced with HDPE geogrid (see Fig. 8b). This improvement corresponds to about 7% of CKD by weight application.

Table 2 Laboratory test results for both geogrids

No		Unit	Test Results	
1	Sample type	–	PP	HDPE
2	Thickness	mm	1.2	2
3	Width	mm	13.8	13.5
4	Length	mm	94.3	116.4
5	Peak load at yielding	kg	298	255
6	Elongation at peak (yield) load	mm	10.2	15.13
7	Break load	kg	400	569
8	Elongation at break load	mm	40.85	779.88
9	Peak tensile strength at yield or stress at yield	kg/mm^2	17.995	9.444
10	Break tensile strength at break or stress at break load	kg/mm^2	24.155	21.074
11	Peak tensile strength at yield or stress at yield	MPa	176.53	92.65
12	Break tensile strength at break or stress at break load	MPa	236.96	206.74
13	Percent elongation at peak (yield) load or strain at yield	%	10.82	12.998
14	Percent elongation at break load or strain at break	%	43.319	670
15	Running speed of the testing machine	mm/min	50	50

The values of the CBR and CBR swell calculated from these penetration curves for the case of unsoaked sample are shown in Table 3 before and after treating the subgrade with the respective types of geogrid. Reinforcing the subgrade material with PP and HDPE led to a reduction in its soaked CBR swell of 4.57% to 1.64% and 2.1% respectively.

The improvement of the CBR values is probably due to the interlocking of the subgrade soil in the aperture opening of the geogrid and the associated confinement [20, 26]. This will lead to widening of the stress distribution area of the subgrade soil layer below the geogrid. The interaction between the geogrid and soils will also contribute to enhancement of the load bearing properties of the soil. Comparing the improvement obtained by the use of cement kiln dust with that of a single layer of geogrid material made of PP, similar CBR values were achieved at 13% by weight of CKD application.

4 Conclusions

This paper aimed at identifying the improvement potential of locally manufactured geogrid materials on a high plastic inorganic clay soil in Ethiopia. Relevant tests have been performed to investigate the material properties of the original subgrade soil and the geogrid materials according to international standards. Both types of geogrid considered in this research, namely, PP and HDPE have shown a great potential of improving the strength of the soil as well as reducing the swell significantly. In addition to the lower percent elongation records from the tensile tests, the PP type reinforcement has shown a better improvement of the subgrade material than the HDPE type, for the specific subgrade under consideration.

An additional chemical stabilizer, cement kiln dust, has also been assessed to stabilize the same expansive soil. Even though it showed its potential for the intended purpose, very large amount of CKD by weight is required to come to an equal amount of CBR obtained by a single layer of geogrid material. Due to the economic implications and scarcity of the CKD, the mechanical stabilization method using geogrid reinforcement is recommended according to the findings of this research.

Due to limitations in the production of both geogrids from the mentioned facility, the effect of reinforcement on CBR values was carried out by the inclusion of a single layer of geogrid material, in the current study. It is thus recommended to study the effect of multilayer geogrid reinforcement on the improvements of the CBR values of the subgrade material.

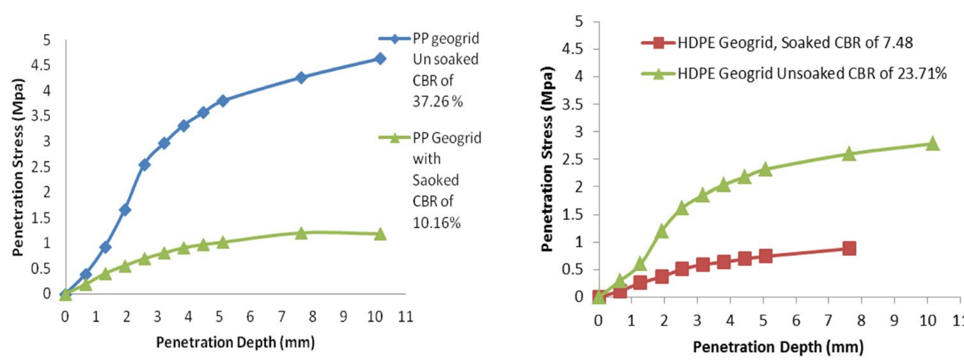

Fig. 8 Penetration stress versus penetration depth graph reinforced with inclusion of PP and HDPE geogrid

Table 3 Four days soaked CBR swell values with and without PP and HDPE geogrid inclusion

ID	Penetration (mm)	Load (kN)	Standard Load (kN)	CBR (%)	CBR Swell (%)
With no geogrid	2.54	0.204	13.2	2.98	4.57
PP geogrid	2.54	1.35	13.2	10.227	1.64
HDPE geogrid	2.54	0.987	13.2	7.48	2.1

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Declarations

Conflict of Interest The author declares that he has no conflict of interest.

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