California Bearing Ratio (CBR) Tests on Soil Reinforced with Polyethylene (Plastic) Bag Waste Material

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ABSTRACT

In this study, California Bearing Ratio (CBR) tests were undertaken on Cape Flats sand samples randomly mixed with plastic strips to form composite specimens so as to ascertain the reinforcing effect of the plastic inclusions in the soil. The experimental programme involved performing a series of laboratory CBR tests on both plastic strip reinforced sand specimens as well as unreinforced plastic sand. Randomly distributed plastic strips were added to the different soil layers before compaction and the overall percentage plastic content of the specimen was varied from 0.1% to 0.4% by weight. The sand was compacted in the mould by placing it on a vibration table for a few minutes after which a surcharge plate was placed on the specimen before commencement of CBR penetration testing. The penetration loads were recorded as a function of penetration depth into the test specimen up to a total penetration of 12.5 mm. The CBR values and the secant modulus (defined as the ratio of load in kPa at a penetration of 5.0 mm to the depth of penetration) were determined from the load penetration curves. Results from the load-penetration curves for the soil-plastic composite samples revealed a consistent increase in the piston load at a given penetration indicating higher CBR values as compared with the unreinforced soil. Furthermore, the initial slope of the load-penetration curve representing the soil secant modulus was significantly improved due to the inclusion of plastic strips in sand. The results obtained in the study demonstrated that reinforcing sand with plastic strips enhances its strength and resistance to deformation suggesting possibility of utilising postconsumer plastic bags as a soil reinforcement material.

1. INTRODUCTION

1.1 Background

Stabilization of subgrade soils during construction is undertaken by addition of materials that improve the strength and bearing capacity of the soil. Civil engineering applications that would require soil stabilization include roadways, parking areas, site development projects, airstrips and many other projects where sub-soils are not suitable for construction. Traditional stabilization techniques involve inclusion of large amounts of additives measured by dry weight of soil material to improve engineering properties of the soil. Many of these techniques require specialized skills and equipment to ensure adequate performance of the ground. Other ground improvement techniques involve reinforcement of soil by inclusion of tensile resisting materials that are added to absorb any shear loads induced due to loading applied. Reinforced soil is generally comparable to reinforced concrete, however, the reinforcement in the concrete is designed in such a way that it carries all the tension in the structural element while in the case of soil, it’s likely that a completely compressive stress field will exist (Jones, 1985). Therefore the function of the reinforcement in soil is not to carry all the tensile forces, but is one of the anisotropic reduction or suppression of one normal strain rate producing the pseudo-cohesion as explained by Vidal (1969). Christopher et al (1990) suggests that there are two mechanisms by which stresses in reinforced soil are transferred between the reinforcement and the soil. One mechanism by which stresses are transferred is by passive resistance whereby the stresses are transferred from soil to reinforcement by bearing between the transverse elements against the soil. The other is by friction mechanism in which stresses are transferred from soil to reinforcement by shear along the interface and this mechanism is mostly dominant with linear reinforcements such as strips, rods and fabrics (Christopher et al, 1990).

Soil reinforcement elements have been categorized into inextensible and extensible material. The inextensible reinforcements such as steel members are expected to deform less than the surrounding soil for example while extensible reinforcements deform more than the soil. Extensible reinforcements may be categorized into metallic and non-metallic reinforcements. Metallic reinforcements consist of aluminium or mild steel while non-metallic reinforcements are polymeric materials such as polyethylene, polypropylene or polyester polymers (Christopher et al, 1990).

Geosynthetics are manufactured from synthetic polymers materials derived from crude petroleum oils; although rubber, fibre glass and other materials are also some-times used to manufacture geosynthetics (Shukla & Yin, 2006). Geosynthetics have emerged as the new materials that can be used in different civil engineering projects that are either envi-ronmental or geotechnical in nature (Koerner, 2012). In the past four decades, development has taken place in the area of geosynthetics and their applications. The general use of reinforced soils has grown due to the economic and technical advantages. Studies have shown that reinforced soil structures cost very low and provide the most sustainable form of construction (Koerner and Soong, 2001). Geosynthetics such as geogrids, geofoam and geomembranes have therefore been used to reinforce base course materials for aggregate-surfaced roads and flexible pavements. These material are quality control manufactured in a factory environment, they are cost competitive against using soil fill materials or other construction material and can be installed rapidly. The term 'Geosynthetics' has two parts: the prefix 'geo' referring to an end use associated with improving the performance of construction works that involve soil and the suffix 'synthetics' refers to the fact the materials are man-made (Shukla & Yin, 2006). Advantages of reinforced soil structures include the ease of construction because of simple and rapid construction methods, little space and site preparation for construction operations as installation doesn't require large equipment.

1.2 Objective of the Study

While the use of geosynthetics have been extensively researched and widely applied, the reinforcement of soil with randomly oriented discrete polymer based materials for pavement applications is increasingly being investigated. Of these is high density polyethylene material which is abundantly used as shopping bag material and discarded after only single usage. In order promote reuse and recycling as advocated for in the international waste hierarchy for purposes of environmental sustainability, alternative applications for polyethylene plastic material in construction as soil reinforcement material are currently being explored. The main objective of this study is therefore for examine the effect of polyethylene plastic waste material inclusions on the California Bearing Ratio (CBR) of soil. CBR is an index is used to assess the stiffness modulus and shear strength of a material by measuring its resistance to penetration of a standard plunger under controlled density and moisture conditions. It is mainly used to test granular materials in base, subbase and subgrade layers of roads and airfield pavements (Al-Amoudi et al., 2002)

2. MATERIALS AND METHODS

2.1 Soil Material

Cape Flats sand was selected for use in the study based on its availability and predominance in the Western Cape Region of South Africa. The sand, sourced from the Philippi Quarry in Cape Flats area, is classified under Unified Soil Classification System (USCS) as a uniformly graded. Table 1 shows the soil physical properties of sand.

Table 1: Cape Flats Sand Physical Properties

Property	Unit	Value
Particle Density ,ρ	Mg/m3	2.66
Natural moisture content	%	1.31
Average densest dry density	kg/m3	1720
Average loose dry density	kg/m3	1538
Mean grain size,D50	mm	0.4
Coefficient of uniformity, Cu	-	2.143
Coefficient of curvature,Cc	-	1.223
Angle of friction,ϕ'	degrees	35,5

2.2 Plastic Material

The plastic material for study was obtained from 24 litre high density polyethylene (HDPE) shopping bags from a leading supermarket in South Africa. The mechanical and physical properties of the polyethylene material is as shown Table 2.

Table 2: Properties of the polyethylene (plastic) material

Property	Unit	Value
Average thickness	mm	0.02
Longitudinal tensile	MPa	16.78
Longitudinal strain	%	62.81
Transverse tensile	MPa	16.5
Transverse strain	%	7.55
Density	kg/m3	1265.15

2.3 Experimental Method

2.3.1 California Bearing Ratio (CBR) Test

The CBR test involves causing a cylindrical plunger of 50mm diameter to penetrate a material at a movement rate of 1mm/min and the force is recorded at penetration increments of 0.5mm. In order to conduct the CBR test, three specimens commonly referred to A, B, and C, are prepared at Optimum Moisture Content (OMC) (SANS3001-GR40:2013). Specimen A is compacted using the standard Maximum Dry Density (MDD) effort and two others specimens are prepared at reduced efforts to produce a range of densities between 93% and 100% of MDD. The test specimen are compacted as follows; Specimen A is prepared in three layers, 55 blows applied on each layer; Specimen B is prepared in five layers with a compaction effort of 22 blows per layer while Specimen C is prepared in five layers, with a compaction effort of 11 blows per layer (SANA3001-GR40:2013).

2.3.2 Sample Preparation

The Cape Flats sand was a clean cohesionless granular material and therefore, only specimen C was prepared for a compaction effort of 11 blows for each of the five layers which can be considered the least dense of the three recommended specimens. The test sample was compacted in the 152 mm diameter one litre open top specimen cylindrical mould manufactured from corrosion protected steel to withstand the high impact involved in the test (Figure 1b). The amount of sand and plastic strips required for the first layer were weighed separately using an electronic mass scale, the mass of the plastics was calculated using the concentration for the respective stage. The mass of sand for first layer was calculated to be 800g, the mass of the sand for the five layers differed because of the difference in the heights of each respective layer as specified by SANS 3001-GR40. The sand and plastics were then randomly mixed, and placed inside the mould to form the first layer. The first layer of the heterogeneous sand-plastic mixture was then compacted by applying 11 blows evenly across the surface using a standard 2.5 kg rammer (Figure 1a). The rammer is made up of a 2.5 kg hammer and a 350 mm long sleeve (Figure 39) that guides the rammer during its falling motion.

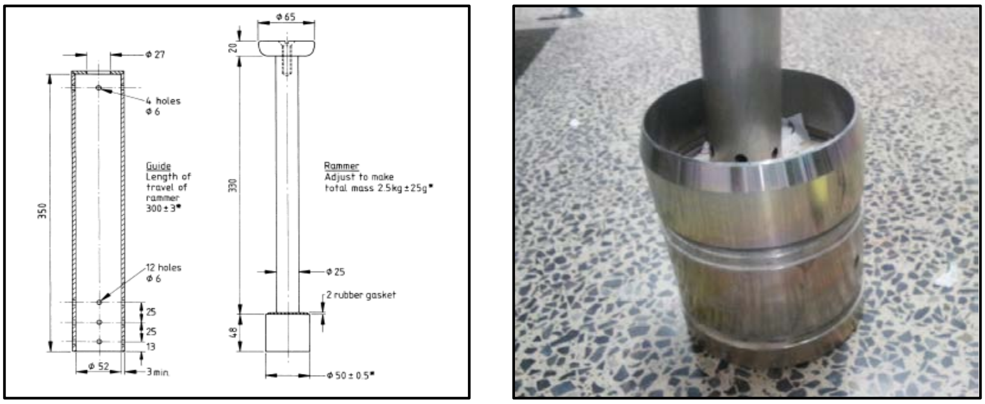

Figure 1. Compaction of soil-plastic composite specimen in the CBR mould

2.3.3 Test Procedure

The CBR tests were carried out with accordance to SANS 3001-GR40 using a manually operated California Bearing Ratio –Test 50 machine (Figure 4). The machine is mainly made up of hardware components which are operated manually throughout the tests. After preparation of the specimen, the CBR machine was set for placement of the mould by lowering the platen platform using the down-off-up switch. This was done to ensure that there was enough clearance space for the CBR mould to be placed on top of the platen without making any contact with the lower tip penetration piston. The stabilising bar was then adjusted up such that it was a distance from the top of the specimen so that it would have no effect on the movement of the piston during the test. After adjustment of the stabilising bar, the specimen was placed on the platen and aligned with the penetration piston while ensuring the right clearance distance space between the piston and platen. The up-off-down button was then pressed so that the platen could move up in order for the specimen to make contact with lower tip of the penetration piston. The adjustment and locking studs were then used to move the piston up or down so that it was on the surface of the specimen while the piston restrainer was used to lock the piston in the right position.

Figure 2. CBR Testing Equipment

3. RESULTS AND ANALYSIS

3.1 Load Penetration Curves

Load-penetration curves were plotted using data obtained from the tests with the graphs in Figure 3 representing the results obtained on addition of plastic material of different aspect ratios to the soil at different concentrations from 0% representing sand only, up to 1% plastic content by dry weight of the sand. For the control test carried out with no plastic added to the soil, at a penetration of 10 mm, the force recorded was 120.5 kN. On inclusion of plastic strips with an aspect ratio, AR=1 at a concentration of 0.20%, the penetration force required was 153 kN (Fig. 4a). Higher plastic content at the same AR increased the penetration load progressively from 173kN at 0.40%, 281kN at 0.80% up to 415kN for a concentration of 1%. At higher aspect ratios, AR=2 and AR = 3, even larger values of force required for the soil-plastic composite for the various depths of penetration was recorded as shown in Figures 4b and 4c.

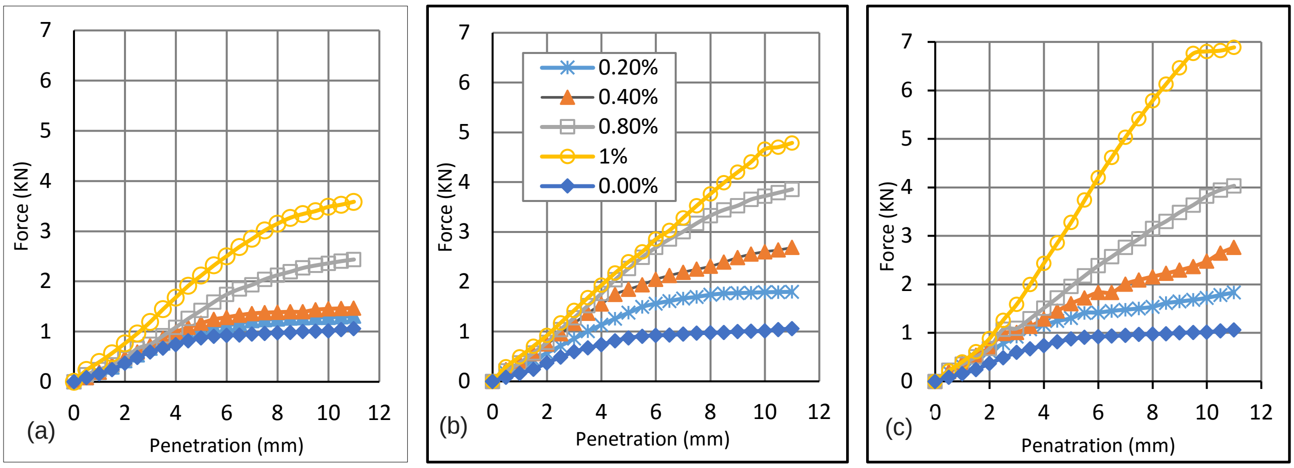

Figure 3. Graphs of Load vs Penetration for soil-plastic composite specimen with plastic strips of different aspect ratios and various plastic contents

3.2 CBR Value

According to SANS 3001-GR40, the CBR of a material is represented by the value at a penetration of 2.5 mm as determined from the load penetration curves. From the results obtained, the CBR value of the sand only control specimen was established as 3.66%.
Figure 4 shows a graph of the CBR values obtained at various concentrations of the plastic material for different strip lengths of 12mm, 24mm and 36mm. For a plastic content of 0.20% at a strip length of 12mm, the CBR was 4.04% while higher plastic content resulted in even higher values of CBR up to 4.48% at a concentration of 0.40%, 5.01% for the concentration of 0.80% and a significantly greater value of 7.26% for a 1% plastic content. For higher strip lengths of 24mm and 36mm, larger percentages of CBR were obtained at the different plastic content.

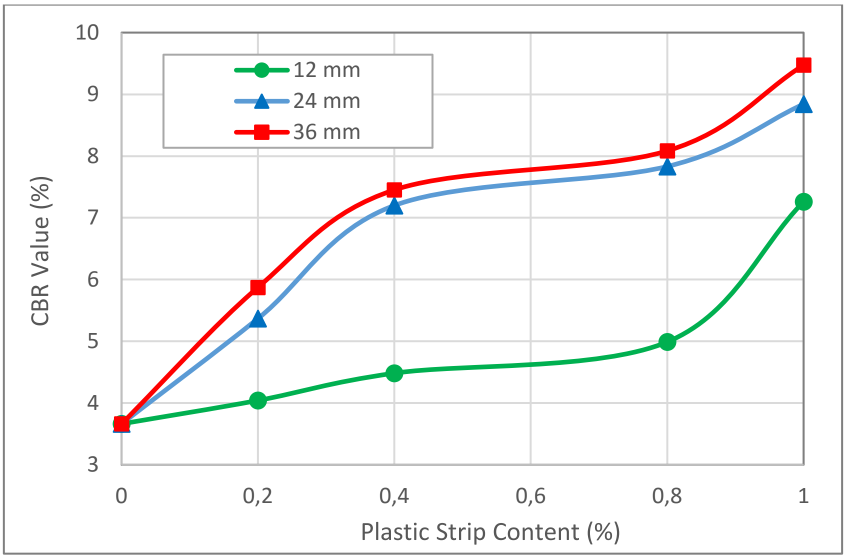

Figure 4. Graph of CBR vs Plastic Strip Content of Specimen

3.3 Secant Modulus, Piston Load Ratio and CBRI

The variation in secant modulus defined as the ratio of load in kPa at a penetration of 2.5 mm to the penetration of 2.5 mm of strip reinforced is shown in Figure 5a. The increase in piston load due to the presence of the plastic strips was also expressed in terms of a dimensionless term known as the piston load ratio (PLR) defined as the ratio of the maximum piston load at 11 mm penetration for the plastic strip reinforced sand (Lr) to the maximum piston load at the same penetration for unreinforced sand (Lu). The relationship between the PLR and strip concentration at different strip aspect ratios is shown in the graph in Figure 5c.

The relative increase in the CBR value as a result of the plastic strip inclusion was represented by the dimensionless factor, the Californian bearing ratio index (CBRI) defined as the ratio of the CBR value of the soil reinforced with plastic (CBR_r) to the CBR value of the unreinforced soil (CBR_u). Figure 5b demonstrates the variation of CBRI with different strip contents at various aspect ratios and from the graph it can be seen that an increase in plastic strip concentration improved the CBRI value.

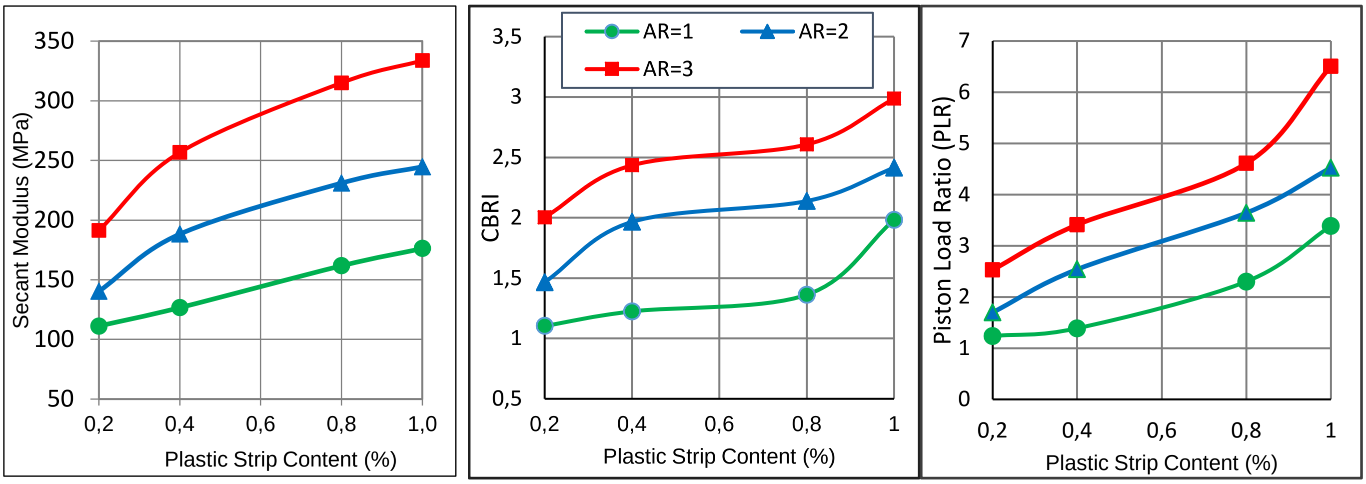

Figure 5. Graphs of different strength indexes vs plastic strip content at various aspect ratios

4. CONCLUSION

The reinforcing effect of plastic material from high density polyethylene (HDPE) was investigated by undertaking CBR tests on soil-plastic composite specimen made up of Cape Flats sand and plastic strips. The sand-plastic specimens for the tests were prepared at the same dry density as the unreinforced sand by compacting dry sand in layers in a steel CBR mould. The plastic strips were randomly distributed in the different soil layers before compaction with the overall percentage plastic content of the specimen varied from 0.1% to 0.4% by weight. The penetration loads were recorded as a function of penetration depth into the test specimen up to a total penetration of 12.5 mm. The CBR values and the secant modulus (defined as the ratio of load in kPa at a penetration of 5.0 mm to the depth of penetration) were determined from the load penetration curves. Results from the load-penetration curves for the soil-plastic composite samples revealed a consistent increase in the piston load at a given penetration indicating higher CBR values on inclusion of the plastic strips. Furthermore, the initial slope of the load-penetration curve representing the soil secant modulus was significantly improved due to the plastic strips in the sand.

The CBR values obtained for the sand only specimen was compared with the values obtained on addition of the plastic strips of various aspect ratios at different concentrations by dry weight of the sand. Based on the significant increase in the penetration resistance of the test plunger and a subsequent increase in the CBR value of the composite, the following conclusions can be drawn:

- The addition of plastic strips from HDPE plastic material to the sand tested increases the CBR value and secant modulus of the soil.
- The maximum improvement in the CBR value and secant modulus is obtained when the strip content is 1% and the aspect ratio 3.
- The reinforcement effect increases with addition of higher values of plastic strip content and higher strip lengths.
- The highest CBR value of the soil-plastic composite is approximately 3 times that of the sand only.

The results obtained in the study demonstrated that reinforcing sand with plastic strips enhances its strength and resistance to deformation suggesting possibility of utilising postconsumer plastic bags as a soil reinforcement material. As indicated from the improvement in the engineering strength properties of the soil such as the CBR in this study, postconsumer bag material may prove beneficial for soil reinforcement in highway sub-bases and subgrades. Further investigation is however necessary to better understand the behaviour of the soil-plastic composite and to optimize the plastic strip parameters. More comprehensive and larger scale testing in different soil types would provide additional insight into plastic reinforced soil such as durability and effects of creep loading.

5. REFERENCES

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