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LABORATORY INVESTIGATION ON RE-USING POLYETHYLENE (PLASTIC) BAG WASTE MATERIAL FOR SOIL REINFORCEMENT IN GEOTECHNICAL ENGINEERING

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ABSTRACT

This paper presents a laboratory investigation into the resultant increase in shear strength and bearing capacity of locally sourced sand due to random inclusion of strips of high density polyethylene material from plastic shopping bags.A series of direct shear tests and bench-scape plate loadingtests was undertaken on soil-plastic composites of two selected sandy soils: Klipheuwel and Cape Flats sands. Strips of shredded plastic material were used as reinforcement inclusions at concentrations of up to 0.3% by weight. The effect of varying dimensions of the strips was investigated by using strip lengths from 15 mm to 45 mm and strip widths from 6 mm to 18 mm. Soil strength parameters were obtained for composite specimen from which analyses were carried out to identify the extent of soil improvement.Laboratory results obtained favourably suggest that inclusion of this material in sandy soils would be effective for soil reinforcement in geotechnical engineering.

KEYWORDS

Plastic bags, Polyethylene, Re-use and Recycling, Soil reinforcement, Ground improvement, Soil strength

1. INTRODUCTION

The widespread increase of single-use plastics in day to day consumer applications continues to contribute to an ever growing volume of plastic material in municipal solid waste generated across the world. These plastics are used for disposable applications and therefore reach the waste stream more quickly as their usage life is shorter than that of the plastics used in the construction or automotive industry (Azapagic et al., 2003). Landfills are thus continually being filled up by plastic material that has been used for only a short time with more than 50% of the discarded plastics coming from packaging applications, a third of which consists of plastic shopping bags (Nhamo, 2008). Manufactured from polyethylene, a non-biodegradable polymer, plastic shopping bags are inexpensive, lightweight, durable and water resistant which make them a convenient and reliable packaging material for consumers worldwide. Owing to the favourable attributes plastics possess compared to other material types, global utilisation of the plastic shopping bags has escalated and is estimated by the United Nations Environment Program (UNEP) at up to one trillion annually. Extensive use and linear consumption patterns whereby the plastic bags are mostly used once and then discarded has resulted in the generation of millions of tonnes of waste leading to environmental challenges such as diminishing landfill space for disposal and marine and urban littering.

A substantial increase in the production of plastic bags as a result of high consumer demand has been reportedas fromabout 0.5 million tonnes in 1950 to over 260 million tonnes by 2008 with higher projections expected in the near future (Thompson et al., 2009). The raw material for production of the plastic bagsbeing from non-renewable petroleum and natural gas resources, the current pattern of consumption of the plastic bags involving only single use and disposal has raised the question of efficient use of natural resourcesthus inspiringthe modern day culture of recycling. However, while many communities have undertaken policies that encourage re-use, the success of any recycling program is ultimately dependent on a secondary market that will consume the reclaimed plastic materials (Benson and Khire, 1994). Large scale re-use of plastic bag waste is therefore essential to counter the production-disposal rate by lengthening the usage time of the plastic material in order to promote environmental sustainability. Chen et al. (2011) maintain that new approaches on the utilisation of plastic waste in cities as alternative materials for urban developmental programs, referred to as urban symbiosis, could help reduce green house gas emissions and fossil fuel consumption. Reinforcement of soil to improve its strength properties for civil engineering construction is a possible means to put to use the abundant plastic bag waste. This will tap into the plastic resource that possesses great versatility and yet in the same vein poses a danger to the environment if not well managed in terms of responsible disposal that involves resource recovery which is vital in contributing to sustainable development.

1.2 Background to the Study

Soil reinforcement is undertaken for a wide range of ground improvement schemes in geotechnical engineering applications that include backfill for earth retaining structures, repair of failed slopes, landfill liners and covers, stabilization of thin layers of soil and sub-grades for footings and pavements. The principle of soil reinforcement first developed by Henri Vidal in 1966 involves introducing tensile resisting materials into the soil to enhance its strength properties so as improve soil stability, increase bearing capacity and reduce lateral deformation. Technically, soil has an inherently low tensile strength but a high compressive strength which is only limited by the ability of the soil to resist applied shear stresses (BS 8006:1995). The objective of ground improvement using soil reinforcement is to make up for the inability of soil to absorb generated tensile loads and shear stresses by introducing reinforcement elements which reduce the loads that might otherwise cause the soil to fail in shear or due to excessive deformation. The stability and reliability of geotechnical structures may be achieved by reinforcing the soil using tensile elements randomly distributed throughout the soil mass. This concept can be traced back to ancient times when natural materials such as reeds, ropes, straws and timber were used as reinforcing elements by mixing them with soil used for construction of more stable structures. The mechanism of these tensile elements can be compared to the behaviour of plant and tree roots in providing strength and stability to soil layers (Diambra et al., 2010; Waldron, 1977).

The techniques of soil reinforcement are broadly categorised into macro-reinforcement and micro-reinforcement (Gregory and Chill, 1998; Morel and Gourc, 1997). Woven and non-woven polymeric materials referred to as geosynthetics widely used in the construction industry today are considered as macro-reinforcement material and their reinforcement mechanism is well established in literature (John, 1987; Koerner, 1999; Richardson and Koerner, 1990; Sarsby 2007). Micro-reinforcement, on the other hand, involves randomly incorporating small reinforcing elements into the soil mass with uniform distribution to produce a three-dimensional reinforcement system (Al-Refeai, 1991; Falorca and Pinto, 2011; Gray and Maher 1989; Ibraim and Fourmont, 2006,). Studies into the polypropylene fibres for micro-reinforcement have reported increases in peak shear strengths and reductions of post peak losses in soils (Consoli et al, 2007; Zornberg, 2002,). These fibres have also been found to improve compressive strength and ductility of soils (Maher and Ho 1994; Miller and Rifai, 2004; Santoni et al 2001). In field applications, fibre reinforced soil consisting of polypropylene fibres of lengths up to 70 mm have been successfully utilised on embankment slopes in the US (Gregory and Chill, 1998). Jones (1996) maintains that the attributes of soil reinforcement of particular advantage in civil engineering include reduction in project costs and ease of construction. Therefore, as the demand for more economical methods to improve soil continues to increase attention has been turned to reusable municipal waste as a potential source of materials for soil reinforcement. This is underscored by research efforts focused on exploring the reuse of waste materials for soil stabilisation. Benson and Khire (1994) investigated the inclusion of reclaimed high density polyethylene (HDPE) from milk jugs; Zornberg et al. (2004), Hataf and Rahimi (2006), Naeini and Sadjadi (2008) studied the addition of shredded waste tyres; Wang Y. (2006), Miraftab and Lickfold (2008) applied carpet waste. All these waste materials are abundant but are by and large destined for disposal or incineration and yet their unique properties can once again be beneficial in a sustainable geotechnical materials stream.

The need to find alternative uses for the reclaimed plastic bag waste resource coupled with the need to identify more affordable, easily accessible reinforcing material for soils in geotechnical engineering formed the basis of this study. The research specifically explored the possibility of reusing postconsumer shopping bags made from polyethylene as soil reinforcement material by undertaking a laboratory testing programme to investigate the effect of random inclusions of plastic material on the engineering strength properties of the soils.

2. RESEARCH MATERIALS AND SAMPLE PREPARATION

2.1Soil Material

Klipheuwel sand and Cape Flats sand, both locally available and predominant in the region of Western Cape Province, South Africa were selected for the study. Cape Flats sand is a medium dense quartz sand with round shaped particles while Klipheuwel sand i9s made up of angular shaped particles (Figure 1). Both sands were clean and consistent which ensured repeatability of results since identical samples could be reproduced.

Figure 1: a) Cape Flats Sand b) Klipheuwel Sand

Classification tests to characterise the sands and obtain the engineering propertiespresented in Table 1 were undertaken according to the British Standard, BS 1377: Part 2: 1990. The sands were both classified using the Unified Soil Classification System as poorly graded and contained little or no fines.Klipheuwel sand exhibited better grading with a greater range of particles than Cape Flats sand which had particles with more uniform grading. Sieve analysis of the sands yielded the particle size distribution curves shown in Figure 2.

Table 1: Sand physical properties

Property	Klipheuwel Sand	Cape Flats Sand
Specific Gravity	2.64	2.66
Natural Moisture content (%)	2.72	2.20
Optimum Moisture Content (%)	6.7	15.0
Maximum Dry density (kg/m^3)	1985	1710
Particle Range (mm)	0.075-2.36	0.075-1.18
Angle of friction, °	41.6	38.5
Cohesion, kN/m^2	4.8	8.4

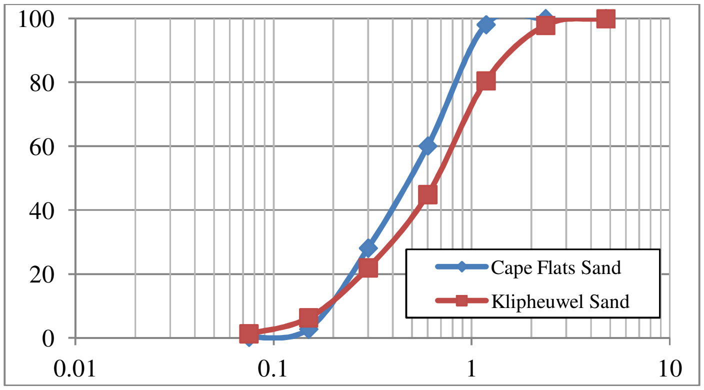

Figure 2: Grading Curves for Klipheuwel and Cape Flats sands

2.2Plastic Material

Polyethylene consumer bags produced by Transpaco Limited, a manufacturer and distributor of plastic packaging products(Figure 3a)in South Africawere used to obtain the plastic material for the study. The 24 litre bags selected for the study (Figure 3b), sourced from a local supermarkets in Cape Town, were labelled high-density polyethylene (PE-HD) with recycling number 2, as classifiedaccording to the plastics identification code by the American Society of the Plastics Industry (SPI).

Figure 3a) Samples of shopping bags b) Plastic bags selected for the study

Tensile strength tests on the polyethylene were carried out using a universal tensile testing machine (Figure 4). A tensile modulus of 389.7 MPa was obtained from the tests while the tensile strength ranged between 15 MPa and 20 MPa. The density of the plastic bag material was measured to be 743 kg/m^3 with an average thickness of 40 μm.

Figure 4: The universal testing machine used for tensile testing of polyethylene

2.3 Plastic Strips

Using a laser cutting machine, the plastic material was sliced into strips of distinct rectangular dimensions and mixed with the soils to form composite samples for which the soil tests were conducted (Figure 5).

Figure 5: Randomly mixed sand-plastic composite for testing.

2.3.1 Perforated Plastic Strips

Perforations of varied diameter were introduced on a portion of the strips added to the soil in order to examine the effect of the holes in the reinforcement on the soil strength parameters. The laser cutting machine used to slice the plastic material was also was used to make perforations of diameters 1 mm and 2 mm on strips of constant width with lengths of 15 mm, 30 mm and 45 mm (Figure 6).

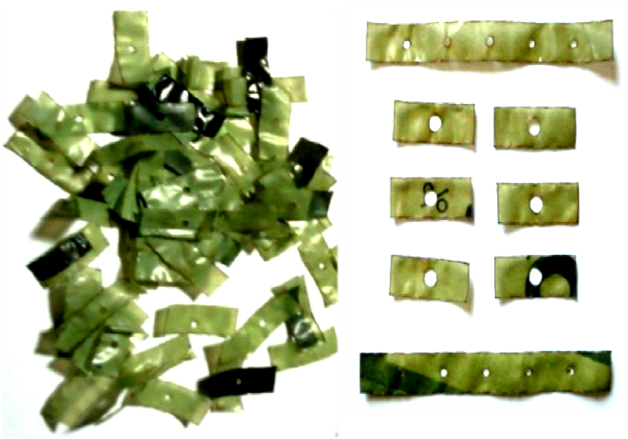

Figure 6: Plastic strips with perforations

3. EXPERIMENTAL INVESTIGATION

A testing program consisting of direct shear tests was undertaken to determine the soil strength parameters of the soil-plastic composite and establish the effect of randomly including the plastic strips in the soil as compared with unreinforced soil. Solid strips and perforated strips of varied length and width were added to dried soil samples in varying concentrations. Soil samples were oven dried at 105º C for 24 hours to eliminate the effects of moisture. The influence of the different plastic parameters of length, width, concentration and perforation diameter on the soil shear strength properties was examined.As part of the investigation, bench scale plate load tests were carried out on composite specimen for one of the soils, Klipheuwel sand, to ascertain any improvements in bearing capacity and vertical displacement at failure due to the plastic material inclusion.A stiffer response than that attained in non-reinforced sand was reported by Consoli et al. (2003) who carried out plate load tests on soil reinforced with polymeric fibres at relatively high bearing pressures.

3.1 Direct Shear Tests

The 100 mm x 100 mm square WykehamFarrance SB1 constant strain rate shear box was used to conduct direct shear testing of the soil-plastic composite samples (Figure 7).Direct shear tests measure soil strength parameters as calculated from the resistance of a soil sample to shear loading at the point of failure. The shear zone in the direct shear specimen is formed along the width of the shear box alongthe failure plane resulting in plain strain deformation (Shewbridge and Sitar, 1989, Sadek et al. 2010). The strength of soilsreinforced with various inclusions such as fibres and geosynthetics have been widely studied using the direct shear testing by comparing their responses to loadingwith that of the unreinforced soil.

The direct shear tests undertaken in the study involved shearing a sample of soil-plastic composite to failure under a constant normal pressure along a horizontal plane. The strength of the composite was determined at the centre of the sample where the soil experiences the highest shear stresses. The resistance to shear by the sample as the upper half slides relative to the lower half defines the specimen strength. This resistance was measured at regular intervals of displacement up to failure. The sample failed when the applied load exceeded the sample resistance to give the peak shear stress sustained by the soil. The strength parameters of friction and cohesion were evaluated using the ratio of the peak shear stress to the applied normal stress on the shear plane for different applied normal stresses provide the soil shear strength.

The laboratory programme consisted of 100 direct shear tests undertaken on composite samples of Cape Flats sand and Klipheuwel sand mixed with plastic strips. The strips were added at lengths of 15 mm, 30 mm, 45 mm, widths of 6 mm, 12 mm, 18 mm and concentrations of 0.1%, 0. 2%, 0.3% by weight and each sample compacted into the shear box in 3 layers before testing. For the perforated strips, the widths were kept constant at 6mm and the perforation diameters of 1mm and 2mm. For the perforated strips, the widths were kept constant at 6mm and the perforation diameters of 1mm and 2mm. The tests in the study were all conducted according to the British Standard, BS 1377: Part 7: 1990, under normal pressures of 25 kPa, 50 kPa and 100 kPa at a strain rate of 1.2 mm/min applied using a drive unit, shearing the specimen horizontally until failure occurred. The resistance of the sample against the displacement was monitored using the proving ring from which the test data was read off and the peak stress recorded at the point when the value reached the maximum shear load. A plot of the shear load versus displacement was generated from the test data obtained.

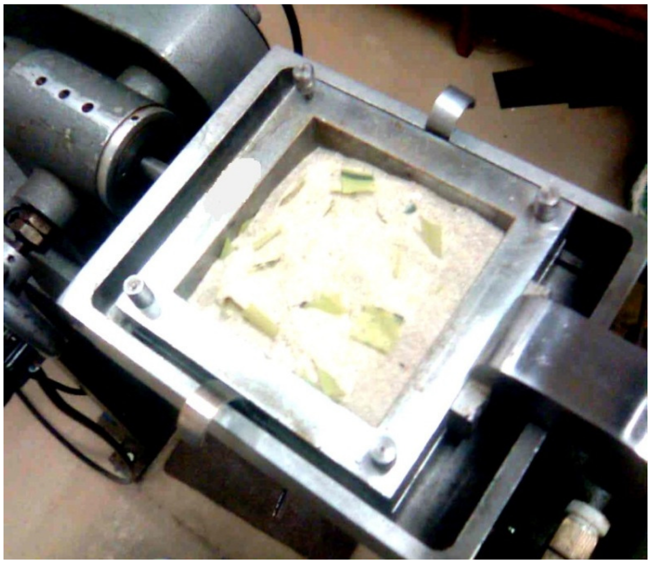

Figure 7: Soil-plastic composite sample placed in shear box for strength testing

Peak shear stresses from each test were obtained for the respective applied normal stresses and the values plotted against the normal stresses to determine the angles of internal friction from the failure envelope for each composite specimen. The response of the soils reinforced with perforated strips was compared with soil mixed with solid strips. For assurance of repeatability, three similar soil-plastic composites were prepared, subjected to a normal pressure of 100 kPa and the results of the compared for consistency. The average peak stress from the three experiments obtained was 92.5kN/m^3 with a deviation of approximately 1.54kN/m^3. The three composites composed of randomly distributed reinforcing strip elements, attained results of the repeatability tests that indicated consistency and reliability in the testing process. The graphs based on the results from the tests on the reinforced specimens with different plastic parameters of length, width, concentration and perforation diameters are presented in Figures 11a – 11f.

3.2 Bench-scale Plate Load Testing

Plate load tests determine the ultimate bearing capacity of soil and the settlements or vertical displacements under a given loading. An automated Universal Zwick tensile and compressive machine was used to undertake the plate load tests on one of soils, Klipheuwel sand,reinforcedwith plastic in orderto establish the effect of the strips on bearing capacity of the soil.The test apparatus consisted of a rigid base plate placed on the soil and the ultimate bearing capacity was obtained from the peak load of the readings as the base plate settled. For the study, 150 x 100 x 16 mm and 150 x 50 x 16 mm steel base plates simulated strip footings of a structure on soil with the axial compressive force from the Zwick machine providing the loading at a rate of 1.2 mm/min. The computer controlled machine applied a strain onto the base plates which were positioned on the soil specimen in a loading box of dimensions 495 x 150 x 956 mm with 20 mm thick wooden faces and a 16 mm Perspex face on one side to allow visual assessment (Figure 8). Braces made out of 40 x 40 x 5 mm steel sections were fitted on to each of the 1000 x 500 mm sides to reinforce the walls of the box to avoid any possible deflections arising from applied stresses during loading.

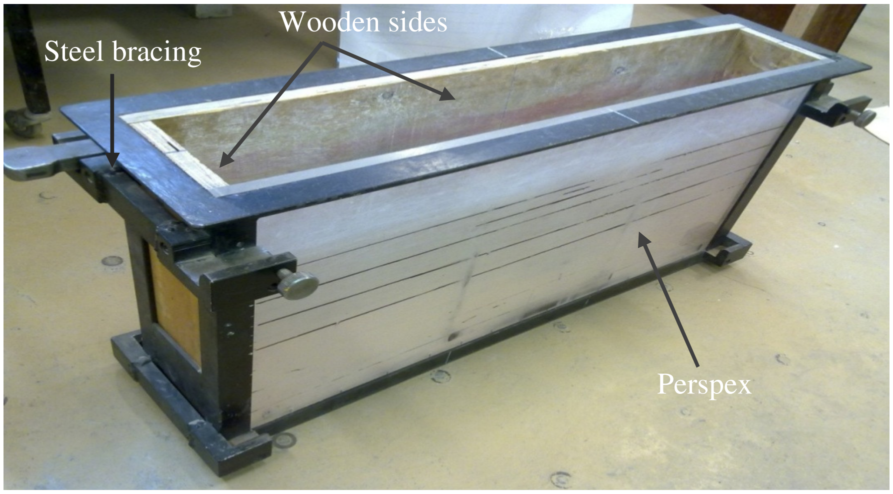

Figure 8: Loading box used for bearing capacity testing

For each test, a base plate was centrally positioned on the surface of the prepared sample (Figure 9) and the box containing the confined soil-plastic composite placed in the Zwick machine (Figure 10). Sand paper, with a roughness to match the roughness of thesand grains was glued to the base plates on the surface in contact with the sand to enhance bonding between the plates and the soil specimen. The compressive testing process commenced after vertical and horizontal alignment of the loading box with the compressive machine with test data captured in real time using the connected computer. The load was gradually increased till the sinking of the plates which was considered as the point of failure. The value of the ultimate bearing capacity of soil was obtained from the ratio of load on the plate at failure and the area of the steel plate.The results from the loading process were generated in the form of progressive force versus vertical displacement. These results were analysed and the progressive pressure determined by dividing the applied force by the cross sectional area of the respective base plates. The vertical displacement of the soil in the loading box at failure was recorded and the bearing capacity of the soil obtained from the peak pressures.Graphs of vertical displacement and bearing capacity against the different soil strength parameters of strip length, width and concentration are presented in Figures 12a – 12f.

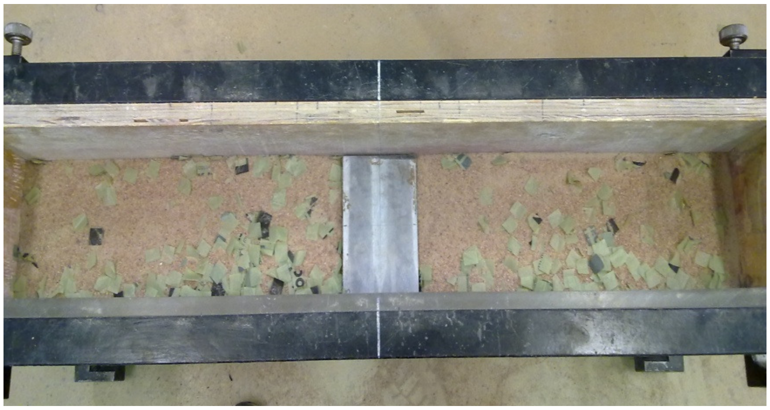

Figure 9: Composite material in loading box with steel base plate in position

Figure 10: Loading box placed in Zwick Machine

4. RESULTS AND DISCUSSION

4.1 Direct Shear Tests

The peak stresses of the composite specimen in the direct shear tests were recorded for respective applied normal stresses of 25 kPa, 50 kPa and 100 kPa from which relationships between the friction angle and the plastic parameters of length, width, concentration and perforation diameter were obtained (Figure 11). Analysis of the results revealed an immediate rise in the peak friction angles of the sands on addition of plastic strips with a notable increase from 38.5° to 41° in the Cape Flats sand and 41.6° to 44° for Klipheuwel sand. It is likely that as the composite sample is subjected to strain from the shear test, development of friction between soil and plastic cause tensile stresses in the plastic material which absorbs the extra load above and beyond the normal soil's capacity. However, it was noted that the response of the sands to the inclusion varied possibly due to the different soil physical properties such as particle shape, grading and texture of the sand particles.There are also particular thresholdsof plastic parameters beyond which the values of friction angle started to decrease. The maximum soil friction angles achieved in the composites were found to be greater in the Klipheuwel sand specimen owing to better grading and therefore exhibiting a higher initial shear strength.

Increasing the strip lengths and keeping the width constant at 6mm resulted in a non-linear correlation with the friction angle with each of the sands exhibiting a unique response (Figure 11a). In the Cape Flats sand, the shear strength improved with increased strip length over specified lengths of 15 mm and 45 mm, while the Klipheuwel sand showed increases in friction angle peaking when the 15 mm long strips were used. On introduction of perforations in the strips, using lengths of 30 mm increased the peak friction angle for Klipheuwel sand from 41.6° to 42.7° and 38.5° to 45.3° for the Cape Flats sand, an increase of up to 3.5% and 18.0% respectively (Figure 11d). Inclusion of the plastic strips generally had a bigger impact as regards improvement of the shear strength parameters for the more round shaped Cape Flats sand than for angular shaped Klipheuwel sand. Furthermore, the results suggest that the effect of varying the length of the plastic strips was comparatively more significant in Cape Flats sand. On varying strip widths, results indicate that beyond a reinforcement width of 6 mm, the peak friction angle of the composite decreased (Figure 11c). Due to the smooth texture of the plastic material used, longer and wider strips resulted in more contact and overlapping of the plastic during shearing. The interface friction in the composite was thus increasingly between the plastic strip material leading to a reduction in the effective soil-plastic interaction and a resultant decrease in strength.

A 0.1% strip concentration added to the Cape Flats sand initially improved the angle of friction from 38.5° to 41.7° with higher concentrations resulting in an approximately linear response (Figure 11b). In Klipheuwel sand, the plastic inclusion resulted in a higher peak friction than the unreinforced soil, however, beyond the reinforcement concentration of 0.1% the strength decreased. On introducing perforated strips, an increase in the peak friction angle of the soil from 38.5° to 45.0° for Cape Flats sand was obtained when the strips were added to the soil at a 0.1% concentration (Figure 11e). A concentration of 0.2% resulted in a slight decrease and a further increase in concentration to 0.3% provided a higher friction angle. For Klipheuwel sand, addition of the perforated plastic strips at a 0.1% concentration caused a slight improvement in friction angle but a decrease was observed for concentrations of 0.2% and 0.3%. It is apparent that the percentage concentration of plastic strips included had an influence on strength parameters of the sand-plastic composite.

A linear increase in the peak and residual friction angles with strip perforation diameter was observed for both Klipheuwel and Cape Flats sand (Figure 11f). Introducing perforations on the strips achieved higher friction angles of up to 14.7% in Klipheuwel sand as compared to using intact strips. For Cape flats sand, an increase of 8.5% was obtained representing 2° for a 1 mm enlargement in perforation diameter. The improvement in friction angle with perforation diameter can be attributed to interaction between the soil and the plastic in the composite as well as better bonding and interlocking between the soil particles through the perforations in the plastic strips. Klipheuwel sand responded better to increases in perforation diameter than Cape Flats Sand in which the variations in length and concentration had a bigger impact. This could be due to enhanced interlocking of the angular Klipheuwel sand particles through the plastic strip perforations resulting in higher strengths. Post-test visual inspection of the plastic strips revealed indentations caused by sand particles as they pressed in to form surface attachments with the plastic strips that resulted in the frictional bonding between the sands and plastic material and therefore achieving a higher angle of friction on inclusion. The results generally indicate that the strength behaviour of the plastic-reinforced soils is influenced by the soil characteristics such as gradation, particle size and shape as well as the plastic parameters such concentration in the specimen, the length and width and its physical properties.

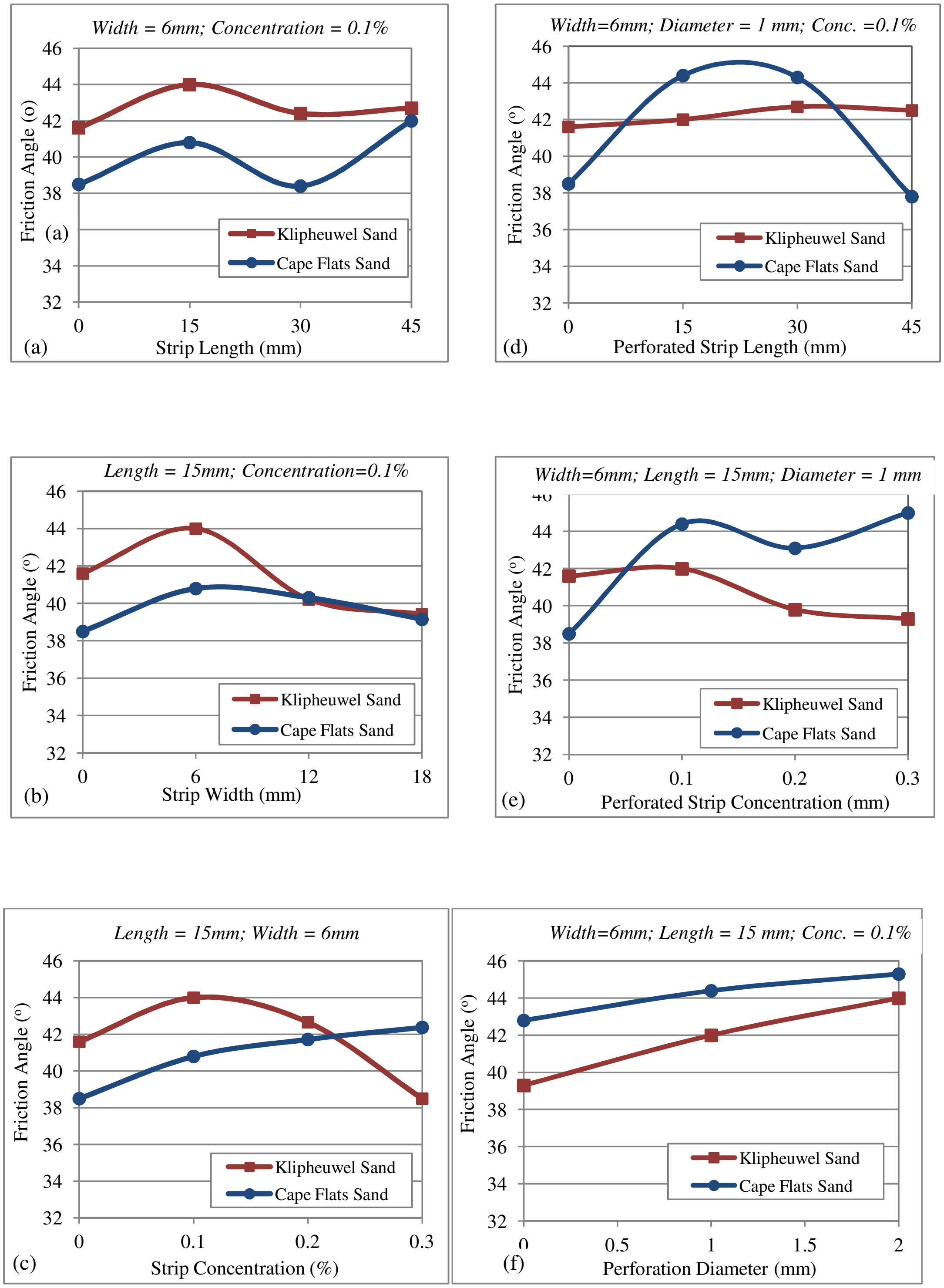

Figure 11:Graphs of Friction Angle against plastic strip parameters of Length, Width, Concentration and Perforation Diameter

4.2 Plate Load Tests

The graphs of vertical displacement against plastic parameters of length, width and concentration for Klipheuwel sand tested in the plate load tests using the 150 mm x 100 mm x 16 mm and 150 mm x 50 mm x 16 mm base plates are presented in Figures 12(a) to 12(c). The results show that the unreinforced soil specimen produced the least vertical displacement of 6.98 mm at failure on reaching peak pressure indicating low ductility of the soil without plastic material. An increase in vertical displacement before failure and therefore improvement in the ductility of the soil matrix was observed on inclusion of the plastic strips. Higher concentrations and lengthening of the strips achieved larger increases in the values of displacement before occurrence of failure for the 100 mm x 150 mm base plate. Wider strips resulted in comparatively less displacement before failure for the loading plate registering an increase from 6.98 mm to 13.25 mm. The increases in concentration provided the highest displacement and therefore larger deformation prior to failure for both base plates with the 100 mm x 150 mm base plate registering a better response to the plastic material of up to 16.84 mm. Generally, doubling the plate width resulted in almost twice the displacement at the point of failure for any concentration, length or width of the plastic strips. The plastic material in sand soils would have a positive effect of improving ductility which is particularly low due to the lack of cohesion between the sand particles. The increased ductility of the soil-plastic composite is essential for construction projects which involve large deformations. Using this material for reinforcement of sandy soils may therefore prove beneficial in slope stability, road embankments and other geotechnical works involving larger lateral loads and deformations.

The ultimate bearing capacity value for each composite sample was obtained at failure for both base plates with varying plastic parameters. The results revealed higher bearing capacity values as the strip concentration, strip lengths and widths progressively increased (Figures 12d - 12f). Improvements of up to 22.8% and 24.2% were observed for the 50mm x 150 mm and 100 mm x 150 mm base plates respectively due to changes in plastic concentration for the scope of tests carried out. As the strip lengths and widths were increased, higher bearing capacity values for the reinforced soil were achieved. However beyond approximate lengths of 30 mm and widths of 15 mm, an apparent reduction of bearing capacity was observed. This may be attributed to increased contact between the plastic strips and a resulting decrease in soil-plastic interaction. Bearing capacity improvements for the 50 mm x 150 mm and 100 mm x 150 mm base plates were 26.4% and 16.4% respectively on varying the strip lengths from 15 mm to 45 mm. Changes in strip widths achieved percentage increases of 22.2% and 22.4% indicating that the tensile strength of the plastic added to the soil helps to absorb the applied forces leading to higher soil strength capacity. This suggests that the inclusion of plastic elements in soil provides an improvement in load bearing capacity and the soil-plastic mixture takes longer to fail due to the reinforcing effect of the plastic material which takes up some of the strain from the applied pressure.

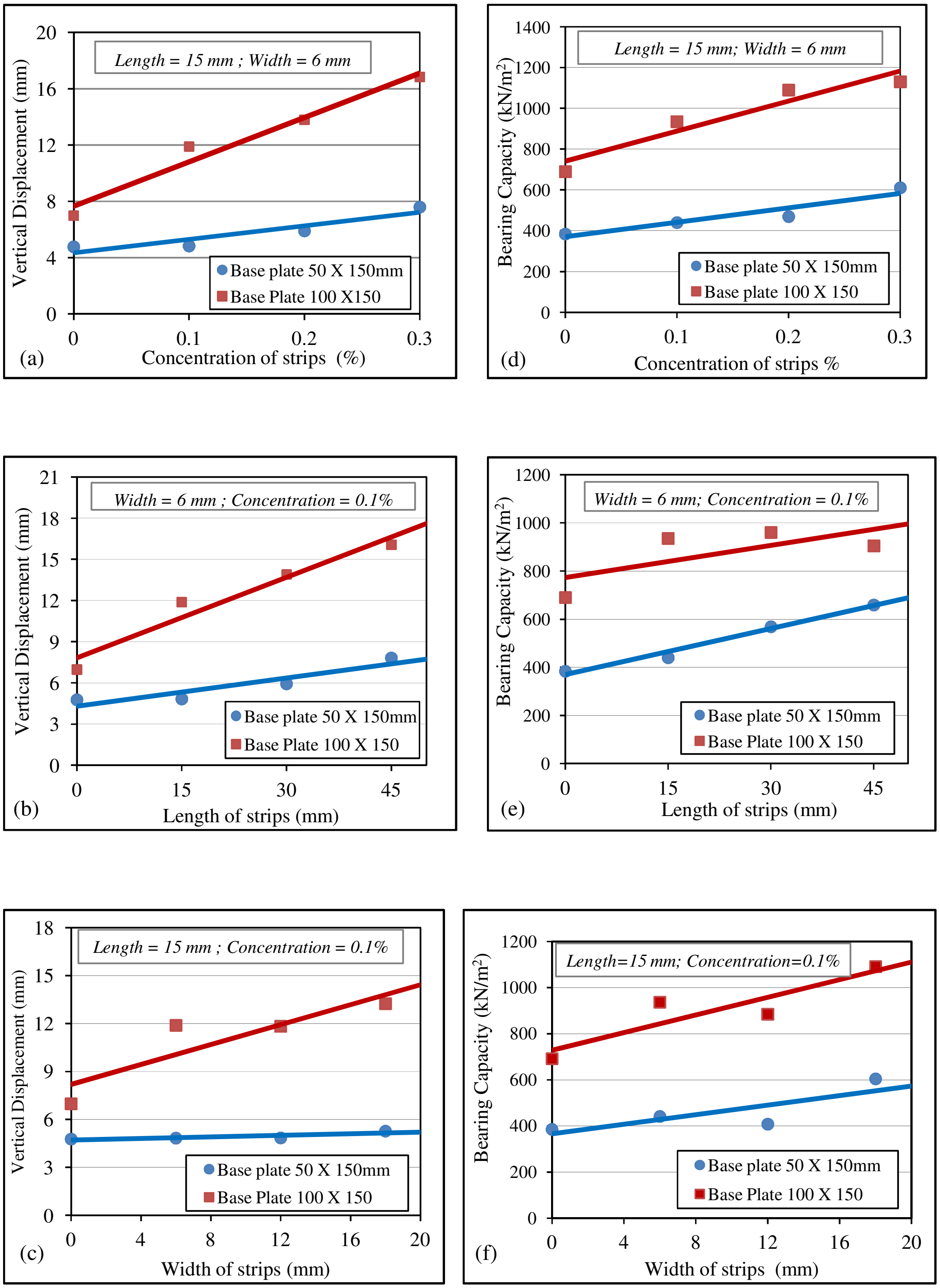

Figure 12:Graphs of Vertical Displacement and Bearing Capacity of Klipheuwel Sand against the various plastic strip parameters

5. CONCLUSIONS

A laboratory investigation involving a series of direct shear tests and plate loading tests was conducted on plastic reinforced soil specimen prepared from two sandy soils mixed with random inclusions of plastic strips obtained from high density polyethylene shopping bags. The effect of the plastic strips on the soil strength parameters was studied by adding strips at concentrations of up to 0.3% by weight and varying the lengths and widths.

From the direct shear test results, an increase of more than 20% in the soil strength parameter of internal friction angle was attained in the sandy soils implying an increase in the shear strength on addition of the plastic strips. For the Klipheuwel and Cape Flats sands, inclusion of the plastic strips improved the friction angle, however, at particular thresholds, longer and wider strips led to a strength reduction. Perforations of diameters 1 mm and 2 mm were introduced in the plastic strips to examine any changes or improvements in the shear strength parameters of the soil due to this modification. On addition of the perforated strips of varied lengths and concentrations in the different soils, further improvement in friction angle was observed. From the experiments conducted, optimum results were obtained from plastic strip parameters of length 15 mm, concentration 0.1% and perforation diameter of 2 mm for strip widths of 6mm. Furthermore, increasing the diameter of perforations on the plastic strips resulted in higher values of friction angle with average increases of 2° for every 1 mm in perforation diameter.

The plate loading tests carried out on the composite specimen of plastic strips and Klipheuwel sand using base plates of dimensions 50 mm x 150 mm and 100 mm x 150 mm indicated an increase in the bearing capacity on inclusion of plastic material and higher displacements before occurrence of failure. The two base plates placed on the soil specimen to transmit pressure onto the soil applied using a Universal Zwick Tensile and Compressive machine simulated a strip footing on soil. Peak pressure values and the associated vertical displacements of the soil composite before failure were obtained while studying the effects of varying the plastic parameters of length, width and concentration. The peak pressure values obtained represented the ultimate bearing capacity of the soil specimen while the vertical displacement at failure provided the settlement level at which the ultimate load was realised. An improvement in bearing capacity of up to 26% was observed for the 50 mm x 150 mm base plate on addition of longer plastic strips and 24% for the 100 mm x 150 mm base plate when the plastic concentration was increased from 0.1% to 0.3%. Doubling the plate width provided twice the displacement before occurrence of failure for the composite specimen at any reinforcement composition and configuration indicating higher ductility of the soil.

The results obtained from the testing programme suggested that addition of plastic elements in sandy soils provides an increase in the soil shear strength and load bearing capacity. A visual inspection of the plastic material after the tests and analysis indicates that the strength increase for the reinforced soil is due to tensile stresses mobilised in the reinforcements. The factors identified to have an influence on the efficiency of reinforcement material were the soil properties (gradation, particle size, shape) and the plastic properties (concentration, length, width of the strips). More comprehensive testing in a wider range of stresses with plastic material from varied sources is necessary to provide additional insight into the reinforcing capabilities of plastic bag waste material and to properly document the behaviour of soil-plastic composite. The influence of the soil properties and the boundary effects of the laboratory tests on the strength characteristics of plastic reinforced soil need to be fully examined. Further investigation using larger scale tests will be beneficial to better understand the reinforcement mechanism, eliminate scale effects on the results and optimize the plastic strip parameters for maximum strength increase in various soils types. The investigation yielded results that are a positive indication to the possibility of using the versatile plastic bag material for soil reinforcement and the viability needs to be further explored. Successful application could help to reduce on the amount of plastic waste disposed of to landfills and contribute to sustainable development by providing low-cost material to the resource intensive geotechnical industry.

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