



**Faculty of Engineering and Built Environment**

**Department of Civil Engineering**

**Laboratory Investigation of Soil Reinforcement using  
Shredded Waste Plastic Bottles**

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the requirement for the degree of Master of Science in Engineering**

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## **Dedication**

This thesis is dedicated to my beloved parents,

José Pinto Ting Yang Chim Jin and Adelaide Leal Diogo Trocado Rosa

Who educated me and enabled me to reach at this level, my wife Olga Chin and my daughter  
Jade Chim Jin.

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## **Abstract**

Plastic bottles were first used commercially in 1947 but remained relatively expensive until the early 1960s when high-density polyethylene was introduced, with its attractive characteristics such as being strong, lightweight, durable, cheap, and resistance to breakage. Decomposition of plastic bottles or other plastic products can last from 400 to 1000 years; before this process happens, the plastic waste becomes a problem to the environment continuing to clog our waterways, forest, oceans and others natural habitats. As the capacity of landfills decrease and urbanization leads to rapid growth rates in the human population, either in Africa or any part of the world, this concern brought forward the need for this study. The research aimed to present an end-use solution for plastic bottles by investigating the feasibility of utilizing the plastic bottles as reinforcing elements in problematic soils encountered in the construction industry.

In South Africa, plastic bottle waste has continued to increase despite efforts by government in the form of new waste legislation and taxes on plastic bottles. Hence, there is a need to find alternative uses for plastic bottle waste. The use of plastic bottle waste shreds as a soil reinforcement material in geotechnical engineering applications can help mitigate the disposal problems associated with plastics.

In this study, a series of direct shear tests were conducted to examine the effect of plastic waste shredded pieces on the engineering properties of Cape Flats and Klipheuwel Sand. The shredded plastic bottles that were used for this study were sourced from Kaytech (supplier and manufacturer of Geosynthetics) in South Africa.

The research was done to utilize this plastic through the inclusion of shredded plastic bottles as a form of soil reinforcement. The effects of introducing polyethylene shreds cut from used plastic bottles on the settlement parameters were investigated.

It was found that presence of plastic shreds improved the shear strength parameters of the sand soil and they tend to improve further with increasing in plastic shred dosage. The cohesion reached its maximum value for both sands at a shred dosage of 30% by dry mass of the soil.

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### Acronyms and annotations

Symbol	Unit	Description
	°	Angle of internal friction
$\sigma_n$	kPa	Normal stress
$\tau$	kPa	Shear Stress
ASTM		American Society for Testing and Materials
BS	-	British Standards
C	kPa	Cohesion
USCS	-	Unified Soil Classification System
CF	-	Cape Flats Sand
KS	-	Klipheuwel Sand
US	-	Unreinforced Soil
RS	-	Reinforced Soil
SP1, SP2, SP3..., SP7-		Shredded Plastic Concentrations of 2.5%, 5%, 7.5%, 10%, 12.5%, 15% and 20% respectively.
HDPE	-	High Density Polyethylene
LDPE	-	Low Density Polyethylene
PET	-	Polyethylene Terephthalate
PVC	-	Unplasticised Polyvinyl Chloride

### **Definition of Terms**

Angle of Internal Friction	A soil shear strength parameter denoted by $\phi$
Cohesion	A soil strength parameter denoted by $c$ .
Dry density	Mass of solids only per unit volume of soil (SI units: $\text{kg}/\text{m}^3$ ).
Moisture content	Ratio of the mass of water to the mass of dry solids in the soil.
Shear strength	The maximum shear stress which a material can withstand without significant plastic deformation or yielding.
Sieve Analysis	A sieving procedure used to evaluate the particle size distribution of a soil.

# CHAPTER 1

---

## 1 INTRODUCTION

### 1.1 Background

According to International Bottled Water Association (IBWA), plastic bottles consumption increased by 500% over last 10 years and more than 1.5million tons of plastic have been used to bottle water every year Babu, Sivakumar (2011). A huge amount of plastic bottles waste is ending up in landfills, ocean, lakes and streams, where they may never fully decay.

It is estimated that a total of 10,198,000 tons of waste is received at landfill sites across South Africa per annum (Department of Water Affairs and Forestry, 2005). Because of the environmental problems, many attempts are being made to utilize the plastic bottles waste as a geotechnical material to solve geotechnical and environmental problems caused by use of plastic bottles.

On the other hand, the use of waste material as soil reinforcement in civil engineering is not new, for many years, studies have been conducted about the use of waste material as reinforcing soil to improve the shear strength. An example is Marandi et al, (2008) and Mustapha, (2008) which used palm fibers and bamboo as soil reinforcement, Kalumba and Chebet, (2013) Utilized plastic shopping bags waste for soil improvement in sandy soils, and the use of Carpet Waste in Reinforcement of Substandard Soils by (Miraftab & Lickfold, 2008).

Studies on soil reinforcement using shredded polyethylene plastic strips reported by Petersen, in 2009 showed that this inclusion does in fact improve the shear strength of the soil, this due to increase in friction between plastic bottles waste and soil and the tensile stress in plastic bottles (Babu & Chouksey, 2011).

The aim of this research is to present a simple way of reusing waste plastic bottles in field of geotechnical engineering as soil reinforcement material, and further studies will be necessary to provide more information on the behavior of sand plastic composite such as the chemical test on plastic chips for potential leaching in the ground and the effect of these plastic chips on longer than 5.6mm size, to observe the maximum friction angle that can be achieve.

## 1.2 Problem Statement

The ecosystem has been threatened with the use of plastic and waste diversion goals. Barely recyclable, plastic wastes have become one of the major problems for the world. Once discarded, they either enter our landfills or our marine ecosystem. As the world's population continues to grow, so does the amount of garbage that people produce. On-the-go lifestyles require easily disposable products, such as cans or bottles of water, but the accumulation of these products has led to increasing amounts of plastic pollution around the world. As plastic is composed of major toxic pollutants, it has the potential to cause great harm to the environment in the form of air, water and land pollution. The use of plastic as reinforcement will help to minimize the disposal of plastic waste on landfills, an issue that has escalated with time. Also, as several problems in civil engineering, concerning the reinforcement of soils, the use of plastics could not only help to alleviate the problem of plastic waste but could also provide cheap and available alternative as reinforcement on weak soils. Furthermore, the durability and water resistive properties of this material are favorable properties that can be beneficial in a sustainable material stream to complement the source-intensive geotechnical engineering industry. Figure 1-1 shows the plastic water bottles dumped in Cape Town landfill.



Figure 1-1: Dumped water bottles.

Furthermore, different studies where been carried out with techniques of ground improvement, these researches include for example stone columns, dynamic compaction, geosynthetics, etc., these have been used to enhance the geotechnical properties of soils in South Africa, but few information are available in how waste plastic bottles can be used to for ground improvement.

### **1.3 Justification of the study**

The reinforcement of soils using geosynthetics, natural resources such as palm fibers, bamboo (Marandi et al, 2008 and Mustapha, 2008) and waste such as tyres shreds (Banzibaganye, 2014 and Zornberg et al, 2004) has been in several studies due to the growing concern for the environment. Thus, there is a need for alternative use of waste such as PET plastics for reinforcement to protect the ecosystem.

Geosynthetics are used as reinforcement in soil in many engineering projects. However, they are expensive and unavailable in some areas. As such, the use of waste is also cost effective. Studies (Peterson, 2009; Consoli et al., 2002) on the inclusion of shredded polyethylene plastic strips in a non-cohesive soil have shown the shear strength of non-cohesive soils to increase with increasing plastic content.

Many techniques of ground improvement have been carried out, but no investigation has been conducted on PET plastic chips to improve the geotechnical properties of soils in South Africa. Due to all the reasons mentioned above, the investigation of the use of PET plastic chips waste to improve sandy soils of South Africa is undertaken.

Furthermore, the study was limited to laboratory investigations on soil shear strength based on the inclusion of PET chips from waste PET plastic materials in sand (Cape Flats sand and Klipheuwel sand). The enhancement of the shear strength will depend on the increase of cohesion and angle of internal friction.

### **1.4 Objective of study**

The main objective of the study was to undertake an investigation into the effect of inclusion of shredded plastic bottles on the shear strength parameters on South African soils.

More specifically, this work was aimed to investigate the:

- The effect of varying the shred concentration on the friction angle of the reinforced soil.
- Determine the effects on friction angle and cohesions.
- Compare the results from various plastic chips sizes.

### **1.5 Scope and Limitations of study**

The scope of this investigation included and was limited to:

- The study of reinforcing effect of plastic bottles on soil, particularly on Klipheuwel and Cape Flats sands.
- The evaluation of shear strength by means of direct shear.
- The limitation of one size plastic bottles type, local from Kaytech, as received from source.
- Direct shear method was performed to evaluate the shear strength of the specimens in the study; a shear box of 100 x 100mm will be used.

### **1.6 Thesis Overview**

This research provides a literature review on Chapter 2, which initially presents the background on the soil reinforcement, history and their benefits, and discusses different types of soil reinforcements. This is followed by previous research work with soil plastic shreds composites. The process of manufacturing PET plastic bottles and PET generation are also analyzed in Chapter 2. The mechanical properties of the research materials and the details of the experimental procedure for the small direct shear tests are given in Chapter 3. Results from the laboratories analysis and discussions are given in Chapter 4.

Proposals for the practical application consisting of the use of waste PET plastic in civil engineering in South Africa and a proposed guideline which could be followed are presented in Chapter 5. Finally, the conclusion and recommendations for further research are given in Chapter 6.

## CHAPTER 2

---

### 2 LITERATURE REVIEW

#### 2.1 Introduction

This section presents the literature reviewed in order to gain a deeper understanding of various relevant concepts, studies that have previously been conducted on the subject. The chapter begins with a history of soil reinforcement and a review of work done on the inclusions of tyres, carpet and plastic wastes as soil reinforcement material. The review concludes with a summary of the literature reviewed.

#### 2.2 Soil Reinforcement

##### 2.2.1 Background and History

Soil reinforcement is a technique that has been used for thousands of years. They were used in the construction of roads in Roman times to stabilize the roads and their edges (Jones, 1985). These first attempts were made from natural fibers, fabrics or mixed with soil to improve the quality of roads, especially when roads were built on unstable ground vegetation. They were also used to construct steep slopes as several pyramids of Egypt and the walls too.

The subject of soil reinforcement has evolved so much that it has now become a subject on its own in geotechnical engineering (Jones, 2006). Much developmental work has been carried out on the subject. There exist, today, many soil stabilization systems each with their own different mechanism of support. Some are externally stabilized systems and involves the use of an external structural wall for earth retention whereas internally stabilized systems involve the installation of reinforcement elements in the soil, within and extending beyond the failure mass, (Jones, 2006).

The modern methods of soil reinforcement were pioneered by, French architect and engineer, Henri Vidal because of his research in the early 1960's which led to the invention and development of Reinforced Earth (Figure 2), a system in which steel strip reinforcement is used (Christopher et al., 1990). Since Vidal's introduction of Reinforced Earth, several other soil reinforcement systems have been developed (Craig, 2004). Other forms of reinforcement include rods, strips, grids and meshes of metallic or polymeric materials and sheets of geotextiles.

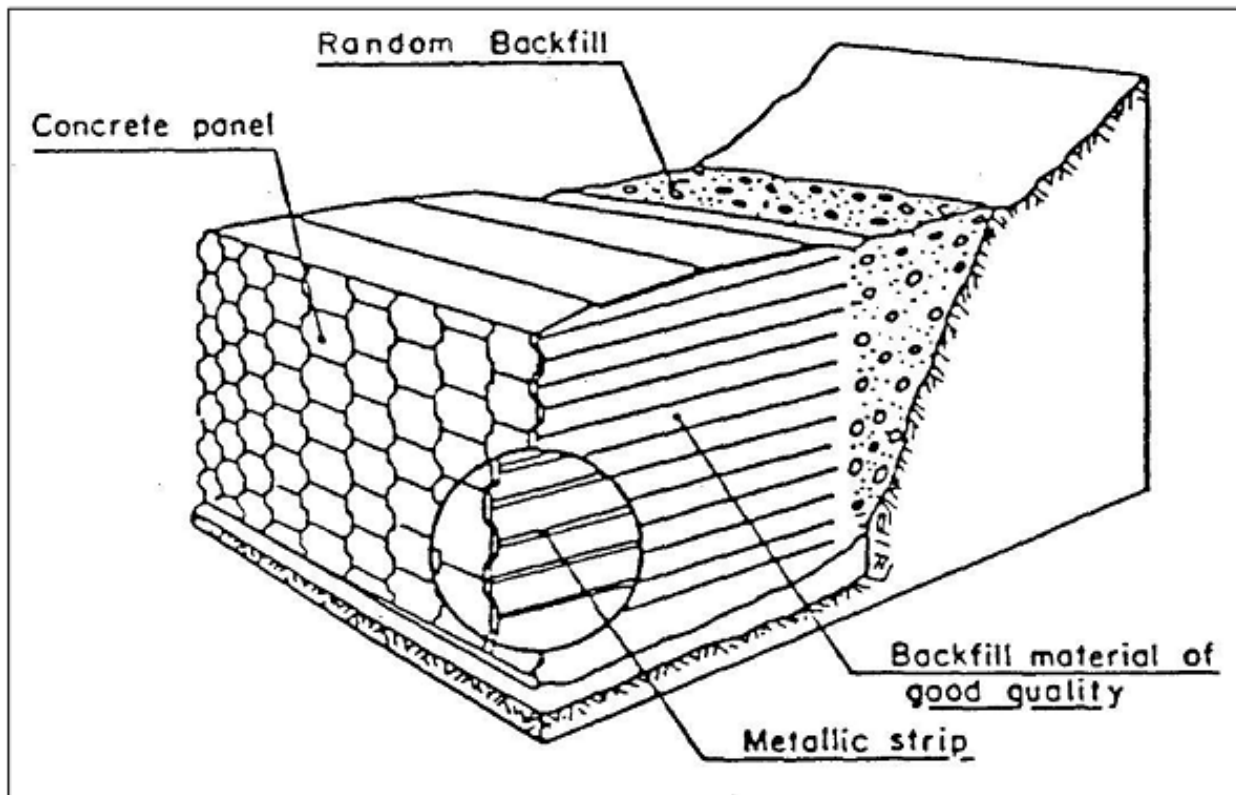


Figure 2-1: Schematic Diagram of Reinforced Earth Wall (Christopher et al., 1990)

### 2.2.2 Theory of Soil Reinforcement

By definition, soil reinforcement is based on increasing the angle of friction between the particles in a soil specimen, by reducing the rate of particle displacement in the specimen when a load is applied. Thus, there appears to be an increase in residual shear strength angle of the sand by adding fiber reinforcements (Salbas, 2002). Furthermore, Vidal (1969) mentions that reinforced sands exhibits cohesion in all directions which therefore allows the construction of reinforced sands structures in any desired shape. The reinforcement namely polyethylene shredded strips, mold themselves around the soil particles, thus increasing the interlocking forces between the particles, due to the high ductility of the material. The reinforcement element was a reduction mechanism described by Vidal (1966) and can be seen in Figure 3 showing soil particles interlocked in the reinforcement producing pseudo-cohesion.

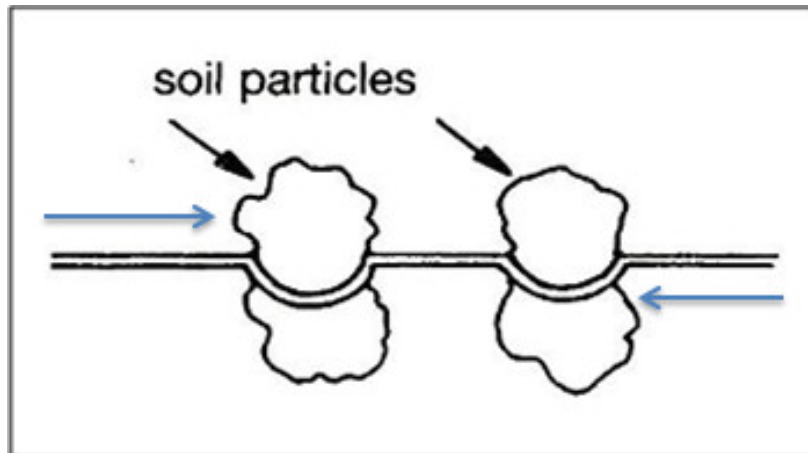


Figure 2-2: Diagrammatic presentation of reinforced soil.

The stability of a soil mass can further be explained in terms of its shear strength or shearing strength. Venkatramaiah (2006) describes this engineering property as the resistance to shearing stresses and a consequent tendency for shear deformation. The shear strength displayed in a soil can be attributed to:

- The resistance due to the interlocking of particles.
- Frictional resistance between the individual soil grains, which may be sliding friction, rolling friction, or both.
- Adhesion between soil particles or “cohesion.”

Falorca and Pinto (2011) in their study elaborate how proportional the contact area between coarse grained soil particles and the fibers pressed against each other is to the applied load before the fibers undergo plastic deformation. The plastic deformation results in surface imprints forming on the fibre, allowing a fibre-particle bond to take place. This reinforcing mechanism is illustrated in Figure 2-3 where initially the soil particles are packed tightly (Figure 2-3a) until the fibre plastically deforms, resulting in surface imprints which allow for adhesion to develop.

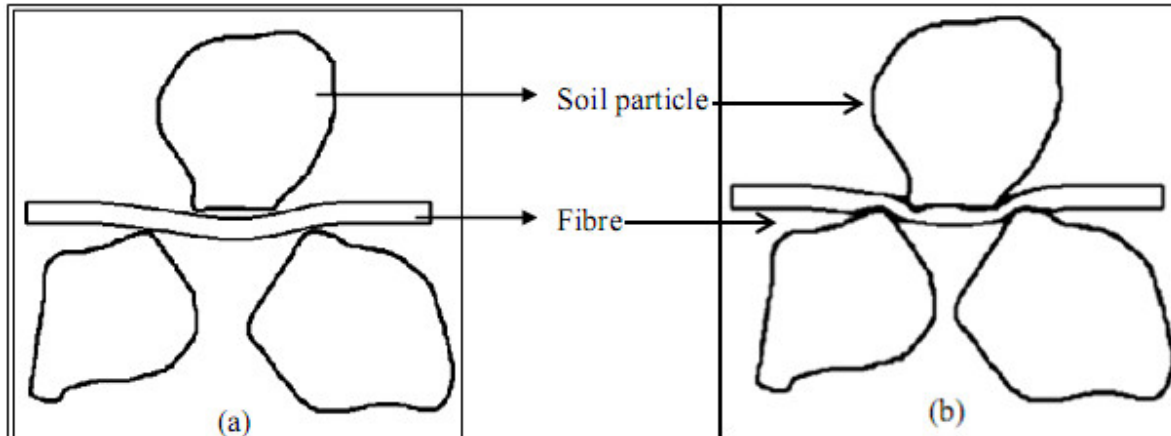


Figure 2-3: Interaction Mechanism between Fibre and Soil Particles (Falorca and Pinto, 2011)

Apart from stresses being transferred between soil particles and reinforcement by friction, another stress transfer mechanism which can take place is through passive resistance, depending on the reinforcement geometry (Christopher et al., 1990).

According to Christopher et al., (1990), passive resistance occurs when stresses are transferred from soil to reinforcement by bearing between the transverse elements against the soil. This mechanism occurs commonly in reinforcement containing many transverse elements of composite inclusions such as grids, wire mesh and mats (see Figure 2-4 below).

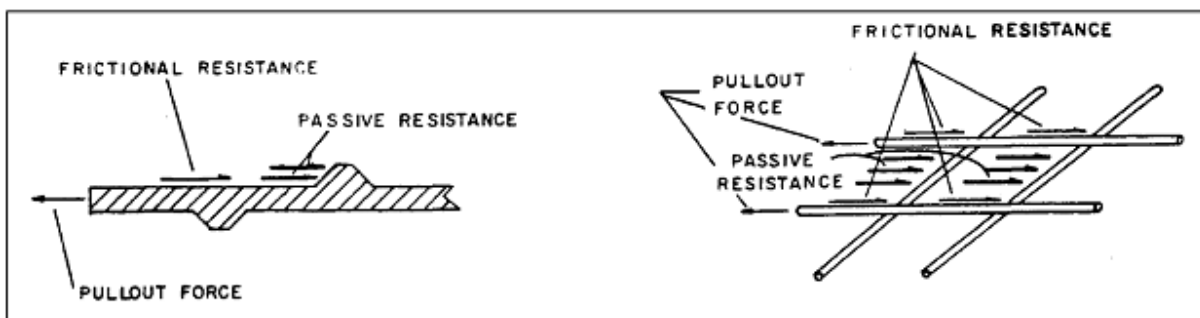


Figure 2-4: Soil Passive (Bearing) Resistance on Reinforcement Surfaces (Christopher et al., 1990).

Furthermore, the following factors govern the contribution of each stress transfer mechanism for a particular reinforcement: normal effective stress, surface roughness, grid opening dimensions, thickness of transverse members, and elongation properties of the reinforcement. Since interaction needs to take place between the soil and the reinforcement, it is worth noting that knowledge of the soil properties is equally important (Christopher et al., 1990).

### 2.2.3 Benefits of Soil Reinforcement

Soil reinforcement is one of the fast-growing ground improvement techniques. ease of construction, overall economy and availability of different options are ones of major advantages of soil reinforcement (Priyadarshee at.al, 2014).

The reinforced soil technique is the introduction of elements resistant to traction, convenient oriented mind that increases strength and decreases the deformability of the solid mass. In this method, referred to as soil reinforcement, the overall mass behavior is improved at the expense transfer efforts for the resistant elements.

Soils generally have high resistance to compressive forces, but low resistance to tensile stresses. When a mass of soil is loaded vertically, it undergoes deformations vertical compression and extension lateral deformation (draw). This deformations restriction is achieved through the development of tensile loads on the element reinforcement.

According to Christopher et al., (1990), And According to Jones, 2007, on page 12. And Zornberg et al. 2004 and Foose et al. 1996 on page 19. Reinforced soil structures and multi-anchored soil structures are more advantageous as compared to the conventional reinforced concrete and gravity retaining walls. Table 2-1 below provides a general summary of some of the main advantages as well as disadvantages associated with reinforced soil structures.

**Table 2-1: Advantages and Disadvantages Associated with Reinforced Soil Structures**

Advantages	Disadvantages
Allow for simple and rapid construction; no large equipment required.	Usually require drainage system. This may be difficult to construct and maintain.
Extremely versatile; able to meet specific technical requirements	May require permanent underground easements for soil nailing. May not be possible if required easement extend beneath existing structures
Require little space in front of structure for construction operations.	Requires large space behind wall face to obtain enough wall width for internal and external stability.
Very flexible; able to absorb deformations due to poor subsoil conditions.	Possibility of corrosion of steel elements and deterioration of other exposed elements due to ultraviolet (UV) rays.
Relatively inexpensive; compared to traditional retaining walls.	Require granular fill for many reinforcement systems. If granular

Adopted from Christopher et al. (1990).

## **2.3 Types of soil reinforcement**

Many methods of soil reinforcement are being used in engineering projects today; some being more effective than others. Bouhicha et al. (2005) points out how a vast amount of research is being investigated by various individuals and associations with a common goal to find a cheap, readily available material which can be used to reinforce soil.

This Section describes three forms of soil reinforcement material, namely: synthetic, natural and waste material. Previous research studies have been carried out on these materials and the aim is to highlight the various application properties each of these have in terms of soil reinforcement.

### **2.3.1 Synthetic: Geosynthetics materials in soil reinforcement**

Geosynthetics is the general term to describe polymeric products used in contact with soil, rock, earth, or other geotechnical related material to solve civil engineering problems, project, structure, or system (SANS ISO 10318:2013).

These products help to solve engineering problems including but not limited to erosion, slope failure, poor bearing capacity and shear strength. Conventional construction materials such as sand or gravel are considered more expensive. There are many types of geosynthetics, which are commonly used for soil reinforcement. These include but not limited to geotextiles, geogrids, geonets, geocell and geocomposites as shown in Figure 2-5.

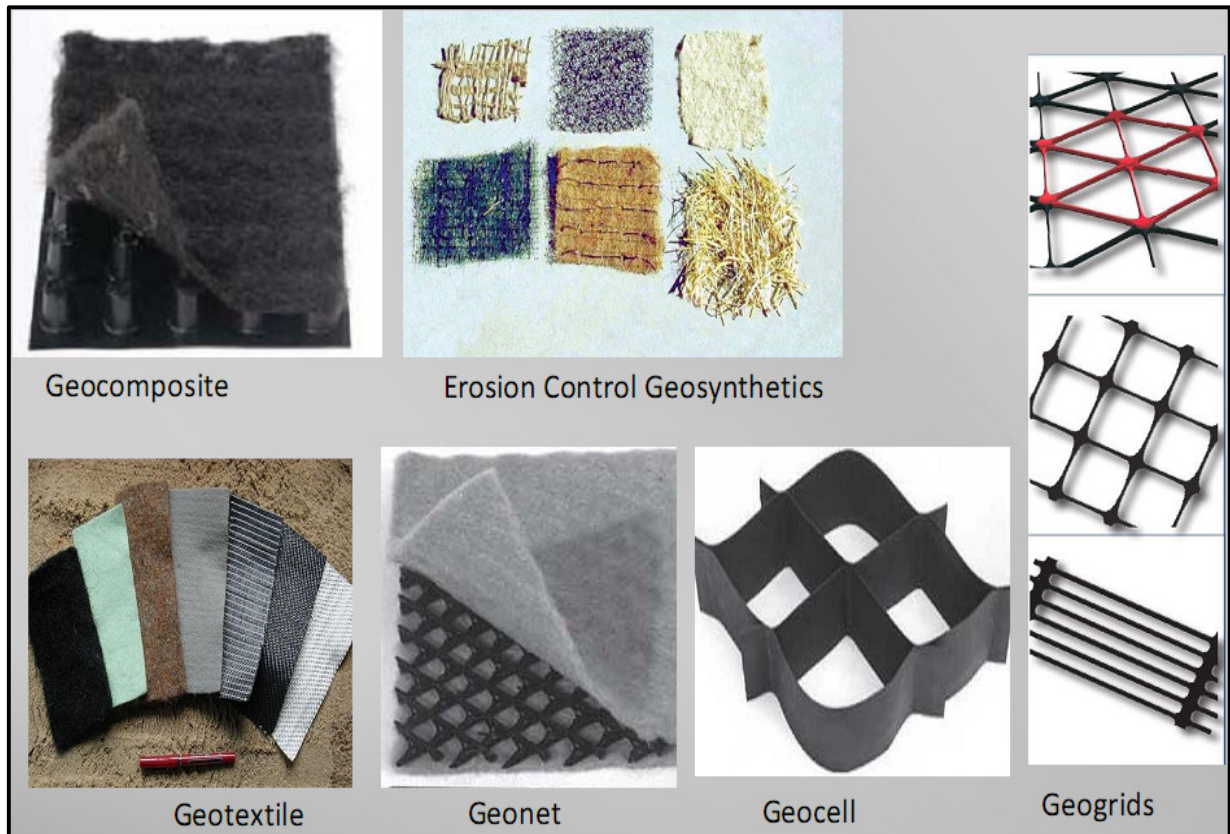


Figure 2-5: Collage of different types of geosynthetic products (Wekesa, 2013)

The soil reinforcement by geo-synthetics generates a mechanical improvement of the soil by supporting tensile forces. The reinforcing elements are flexible and, due to their low bending stiffness, can only absorb axial tensile loads. The improvement reduces the shear force that has to be carried by the soil, and to enhance the shearing resistance in the soil by increasing the normal stress acting on potential shear surfaces (Brau, 1975).

- **Functions of Geosynthetics**

Geosynthetics are generally designed for a particular application by considering the primary function that can be provided. The multiple functions of geosynthetics are dependent on the material they are manufactured from and also on the application intended. These functions include; separation, reinforcement, filtration, drainage, and containment as shown in Table 2-2.

**Table 2-2:** Identification of the primary functions for each type of geosynthetics product. Oriokot (2014)

Type of Geosynthetic	Separation	Reinforcement	Filtration	Drainage	Containment
Geotextile (GT)	X	X	X	X	
Geogrid (GG)		X			
Geonet (GN)				X	
Geomembrane (GM)					X
Geosynthetic Clay Liner (GCL)					X
Geofoam (GF)	X				
Geocells (GL)	X	X			
Geocomposite (GC)	X	X	X	X	X

According to Jones, 2007, geosynthetics materials play a passive role in soil reinforcement, e.g., geosynthetic barriers block the passage of liquids, geosynthetic reinforcement provides tensile resistance, but only after an initial strain has occurred; and geo-drains provide a passage for water but do not cause the water to flow. This process can be changed if the geosynthetics are designed to play an active role, like in the case of electrokinetic geosynthetics (EKGs) that drain the soil of excess pore water, and reinforce the structure thereafter.

### 2.3.1.1 Geogrids

A planar synthetic structure consisting of a regular open network of integrally connected tensile elements, which may be linked by extrusion, bonding or interlacing (e.g. knitted), used in contact with soil/rock and/or other geotechnical material in reinforcement applications. It is divided into junction stiff (welded bars) and flexible (e.g. PVC coated) geogrids.

#### Types of geogrids

- Uniaxial geogrids (UX) strength in the machine direction of reinforcements is predominant, used in wall and slope applications, help soils stand at virtually any desired angle in grade separation applications.



Figure 2-6: Uniaxial Geogrids

- Biaxial geogrids (BX) strength in the cross and machine directions of the geogrid is equal, used in roads to provide support by confining and distributing load forces, for the construction of access roads, highways, berms, dikes and structure applications, reduce the amount of excavation and extend roadway performance life, and also in sub base reinforcement applications to reduce aggregate thickness requirements.

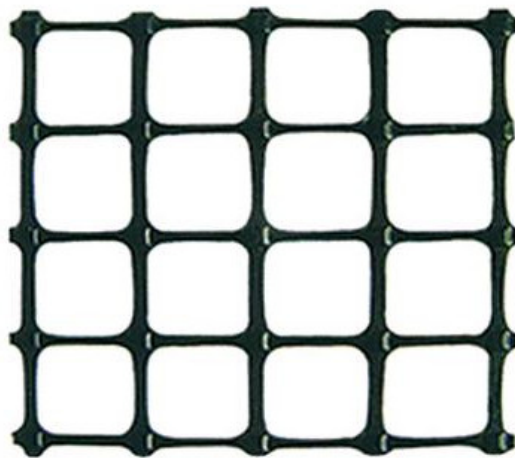


Figure 2-7: Biaxial Geogrids

- Multifunctional geogrids may include TriAx geogrids, which is a revolutionary new geogrid product from Tensar. It works in three dimensions, the triangular structure coupled with the increased rib thickness and junction efficiency, greatly improves aggregate interlock and confinement leading to optimal structural performance of the mechanically stabilized layer. Research indicates that TriAx geogrids reduce aggregate base/sub base requirement by 25% to 50%

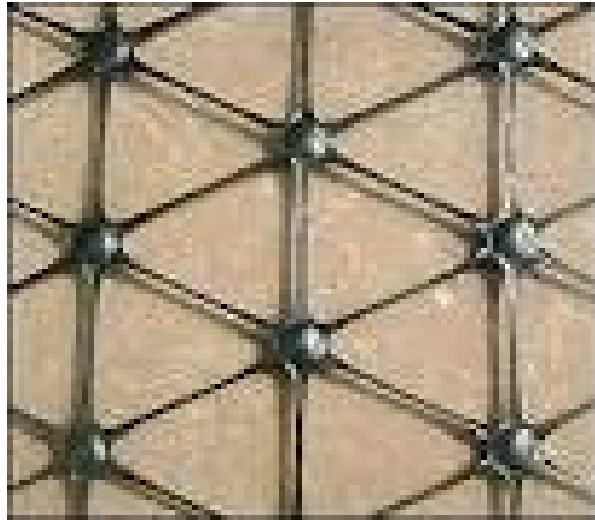


Figure 2-8: Tensar TriAx Geogrid

### 2.3.1.2 Geocomposites

These are simply a combination of two or more types of geosynthetics for increased efficiency and improvement of the properties of the original geosynthetics. This way the benefits of each of the individual geosynthetic are integrated into one material. An example of such a composite geosynthetic is shown in Figure 2-9 where a woven geotextile was combined with a geonet to form a composite geotextile.



Figure 2-9: Geocomposite (woven and geonet),  
(<http://en.atarfil.com>, Searched: 05/12/2015)

### 2.3.2 Natural material used as soil reinforcements

From an engineering perspective, natural material has the advantage of being a lot cheaper and environmentally friendly in comparison to hard engineered solutions, though their reinforcing effects are not as easy to quantify (Mickovski, 2009). The main disadvantage of using natural materials such as palm and bamboo fibers (Figure 2-10) to reinforce soils is that they are biodegradable.



Figure 2-10: Typical Palm Fibers (left) (Marandi et al., 2008.)  
And Typical Bamboo Fibers (right) (Swico Fil, 2014)

Below is a discussion on previous studies which were carried out to investigate the use of these materials for soil reinforcement.

#### 2.3.2.1 Bamboo

Mustapha (2008) undertook studies to investigate the UCS and modulus of rigidity of silty-clay soil specimens which were reinforced with thin circular bamboo plates. The selection of bamboo as a reinforcement material was on the basis that it is a cheap and abundant material possessing high tensile and compressive resistance properties. Despite the erratic trend of modulus of rigidity with percentage strain, the results indicated that generally, the UCS and modulus of rigidity of the tested specimens increased with increases in the number of bamboo specimens. Figure 2-11 shows the increase of UCS with the number of bamboo specimens and Figure 2-12 illustrates the variation of modulus of rigidity with the number of bamboo specimens.

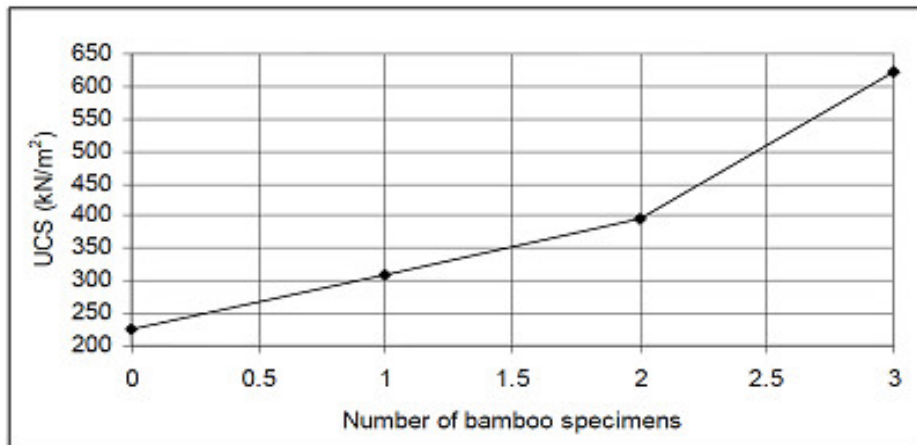


Figure 2-11: Variation of UCS with the number of bamboo specimens (Mustapha, 2008)

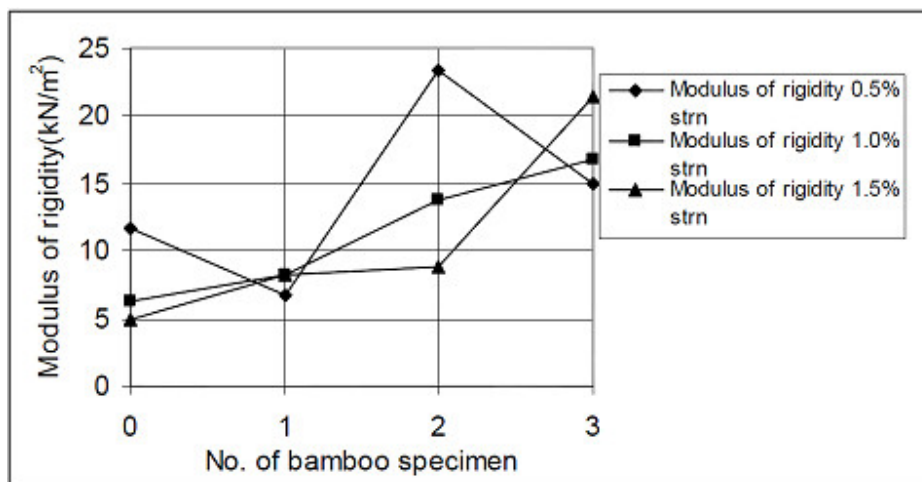


Figure 2-12: Variation of modulus of rigidity with No. of Bamboo specimen (Mustapha, 2008)

### 2.3.2.2 Palm fibers

Studies were carried out by Marandi et al. (2008) to investigate the resultant strength and ductility behavior of silty-sand soils when reinforced with randomly distributed palm fibers. The trials focused on observing the effects of changing the lengths and concentrations of the fibers.

Subsequent to testing the composite soils and examining for unconfined compression strength (UCS) and California Bearing Ratio (CBR), it was found that; the surface failure orientations, maximum residual strengths, ductility as well as the stress-strain relationship of the samples were significantly influenced by the addition of palm fibers. The results revealed that at a constant palm fibre length, with increasing fibre concentrations, the maximum strength and residual strength increase; this is illustrated in Figure 2-13 and Figure 2-14. Furthermore, the maximum strength of

the specimens was observed to increase with an increase in fibre length and fibre concentration; this is illustrated in Figure 2-15.

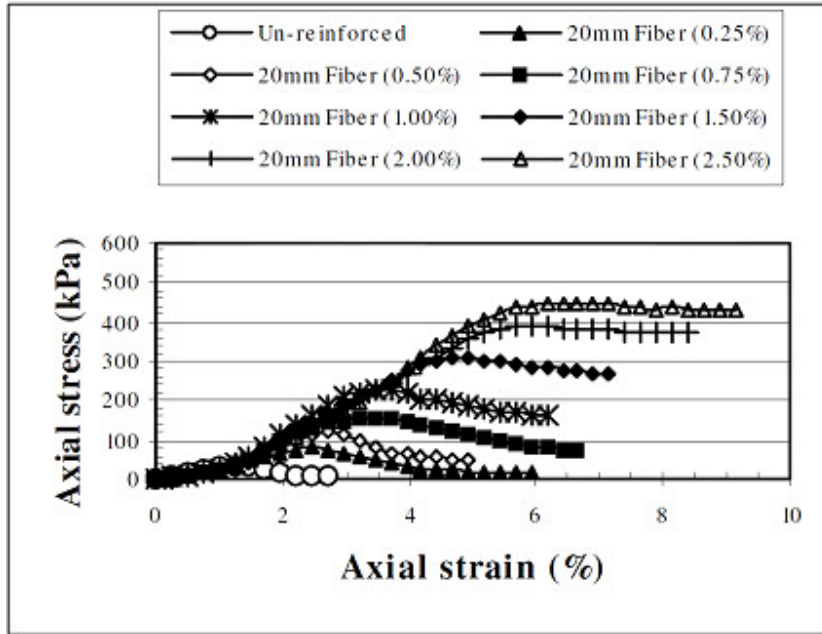


Figure 2-13: Stress-Strain Curves of Un-reinforced and Reinforced Soil Specimens in Unconfined Compression Tests (Marandi et al., 2008)

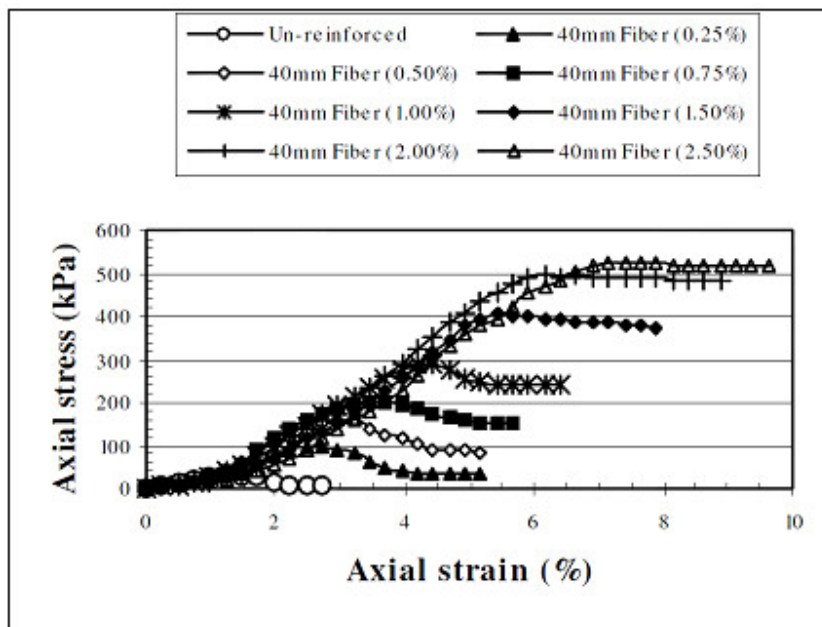


Figure 2-14: Stress-Strain Curves of Un-reinforced and Reinforced Soil Specimens in Unconfined Compression Tests (Marandi et al., 2008)

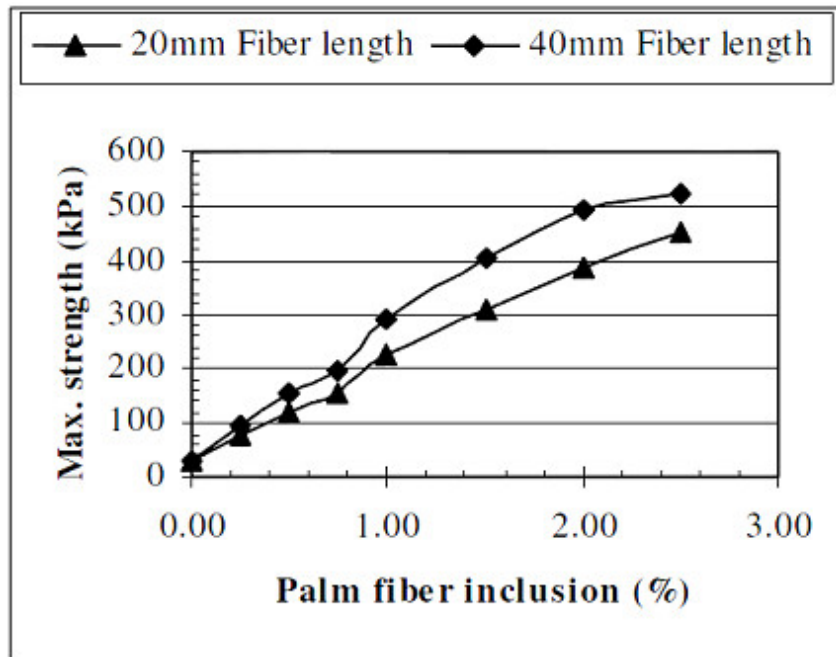


Figure 2-15: Maximum Strength versus Palm Fibre Inclusion (Marandi et al., 2008)

### 2.3.3 Waste material for soil reinforcement

#### 2.3.3.1 Tyre Waste

Tyres are residues that accumulate rapidly in large volumes, particularly in densely populated urban areas. The destination of tyres is a worldwide problem; there is growing concern about policies to encourage recycling, reduction and reuse of waste tyres. The use of used tyres in civil engineering works is presented as an alternative that combines the mechanical efficiency and low cost of the material, favoring the demand for waste that poses risks to the environment.

One of the first applications of tyres used in the practice of Civil Engineering took place in the 70s, with the reconstruction of a reinforced embankment with tyres on a highway in Northern California (Hausman, 1990). The horizontal layers of tyres were spaced vertically from 0,60m and intertwined with metal handles. The studies related to the use of so-called tyre technique and soil "pneusol" or ground-tyres were developed in France with the construction of a soil-tyre experimental wall in Langres (Long, 1984). The construction of this wall, with 5m high and 10m long, demonstrated the feasibility of implementing structures from the release of tyre layers filled with soil.

Zornberg et al. 2004 and Foose et al. 1996 concluded with addition of shredded Tyres increase the shear resistance of soil alone. Using direct shear with 64 x 64mm shear box, Foose et al. (1996) performed tests in order to establish which variables affect the strength of the soil-Tyre composites. The variables tested included; normal stress, sand matrix unit weight, shred content, shred length, and shred orientation.

The addition of shredded tyres to sand has significant influence on variation of cohesion. The graph below shows that as the concentration of threads increase so does the shear strength as was deduced by Zornberg et al.

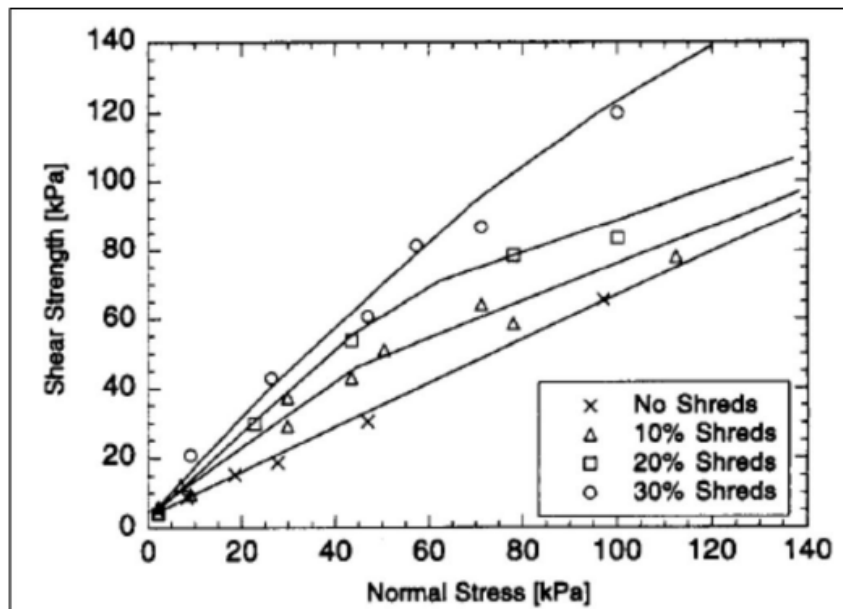


Figure 2-16: Strength envelope for dense sand with varying shred content (Foose et al., 1996)

Banzibaganye (2014) found that addition of tyre shreds of 50 to 60 mm size to Cape Flats and Klipheuwel sands improved their friction angle at a shred dosage of 10% by dry mass. He also observed that long tyre shreds for both selected sands showed better improvement compared to small shreds. Klipheuwel sand 50-60 mm tyre shred composites showed 41.6% of cohesion and a 2.5% higher friction angle than that for the composite samples with small tyre shreds as shown in Figure 2-17.

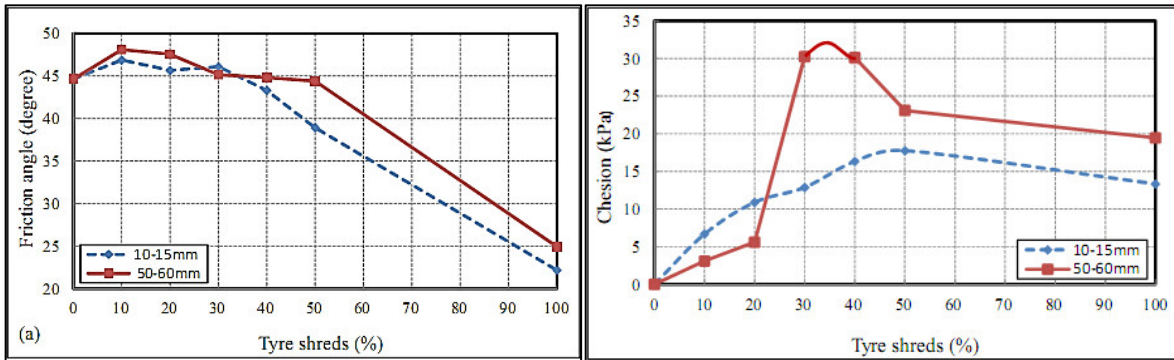


Figure 2-17: Comparison of (a) friction angle and (b) cohesion from 10-15 mm and 50-60 mm tyre shreds Klipheuwel sand (Banzibaganye, 2014)

### 2.3.3.2 Carpet Waste

Each year, all over the world, a vast amount of fibrous textile waste is discarded into landfills; carpets constitutes about half of this waste, with the main components being plastic and polymeric fiber (Ghiassian et al., 2004). This type of waste decays at a very slow rate and is difficult to deal with in landfill sites. The growing public concern for the environment and restrictions on landfill sites in recent years have obligated many carpet producers to find alternative uses for their inevitable waste (Miraftab & Lickfold, 2008). The Figure 2-18 gives a pictorial overview of the typical carpet waste discussed here.



Figure 2-18: Picture of carpet waste (from [www.mrw.co.uk](http://www.mrw.co.uk), 2012)

A promising reuse of carpet wastes have been discovered to lie in soil reinforcement and construction applications (Ghiassian et al., 2004). Ghiassian et al. (2004) report that there have been extensive studies that indicate that the inclusion of synthetic fibers in soil can improve the shear strength, load-bearing capacities and durability of the soil. In the study undertaken by Mirafatab & Lickfold (2008) it was concluded that soil reinforced with carpet waste fiber was stronger than soil without the reinforcement. It was also concluded that the strength of the soil increases as the fiber content is increased. Mirafatab & Lickfold (2008) and Wang et al. (1999 & 2000) did an investigation into the effect of moisture content and dry density on the strength of soil. Wang et al. (1999 & 2000) found that there is a proportional increase in moisture content with increasing fiber content, as shown in Figure 2-19, below. Mirafatab & Lickfold (2008) however, discovered that a soil with 8 % reinforced fiber had lower optimum moisture content than the plain soil and therefore concluded that there may not be a direct relationship between moisture content and increasing fiber content. Mirafatab & Lickfold (2008) goes further to state that it is likely that there is optimum water content, beyond which, any further increase in fiber content will result in lower moisture absorption.

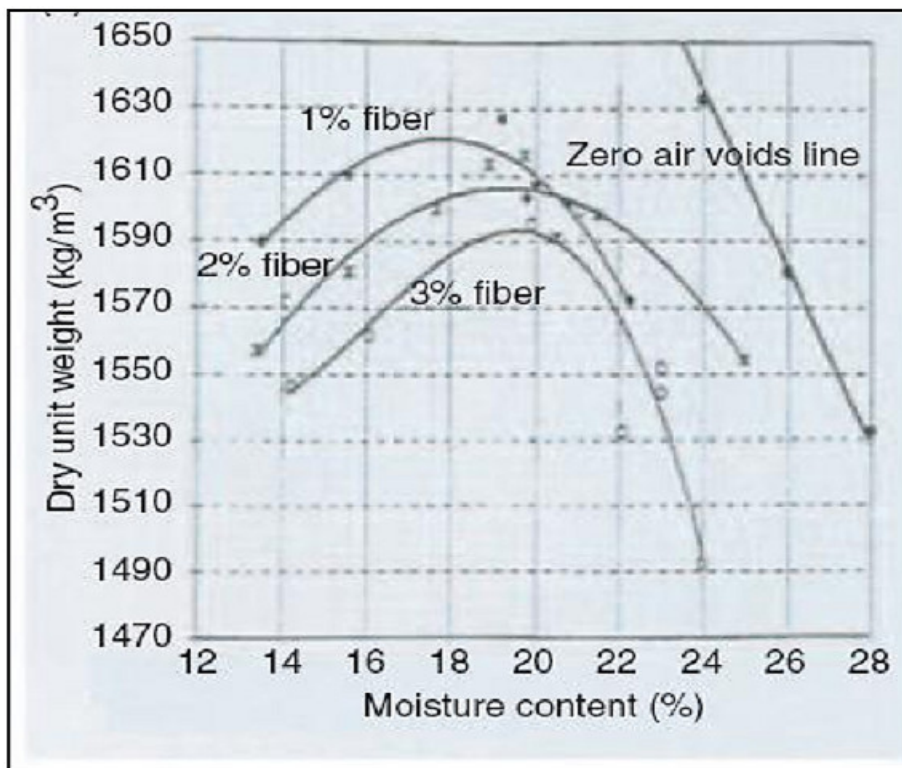










Figure 2-19: Max dry density and optimum moisture content (Wang et al., 1999 & 2000)

### **2.3.3.3 Plastic PET Waste**

PET, a plastic from the family of polyesters, is nowadays being used mainly in the food industry, for packing soft drinks, mineral water, milk, oil and other types of products. Apart from the multiple advantages these packages exhibit; there is also a number of disadvantages, among which is the great waste volume subsequent to the use, and especially the difficulty to reintroduce them in the natural circuit, as they are not biodegradable (Muntean Radu et al.2011).

Table 2-3: The Plastics Identification Code (The Plastics Federation of South Africa, 2011)

Symbol	Type of Plastic	Properties	Common Uses	Recycled in:
 PET	PET Polyethylene Terephthalate	Clear, tough, solvent resistant, barrier to gas and moisture, softens at 80°	Soft drink and water bottles, salad domes, biscuit trays, salad dressing and containers	Pillow and sleeping bag filling, clothing, soft drink bottles, carpeting, building insulation
 PE-HD	PE-HD High Density Polyethylene	Hard to semi-flexible, resistant to chemicals and moisture, waxy surface, opaque, softens at 75°C, easily coloured, processed and formed	Shopping bags, freezer bags, milk bottles, ice cream containers, juice bottles, shampoo, chemical and detergent bottles, buckets, rigid agricultural pipe, crates	Recycling bins, compost bins, buckets, detergent containers, posts, fencing, pipes, plastic timber
 PVC	PVC Unplasticised Polyvinyl Chloride PVC-U  Plasticised Polyvinyl Chloride PVC-P	Strong, tough, can be clear, can be solvent welded, softens at 80°C  Flexible, clear, elastic, can be solvent welded	Cosmetic containers, electrical conduit, plumbing pipes and fittings, blister packs, wall cladding, roof sheeting, bottles  Garden hose, shoe soles, cable sheathing, blood bags and tubing	Flooring, film and sheets, cables, speed bumps, packaging, binders, mud flaps and mats, new gumboots and shoes
 PE-LD	PE-LD Low density Polyethylene	Soft, flexible, waxy surface, translucent, softens at 70°C, scratches easily	Cling wrap, garbage bags, squeeze bottles, irrigation tubing, mulch film, refuse bags	Bin liners, pallet sheets
 PP	PP Polypropylene	Hard but still flexible, waxy surface, softens at 140°C, translucent, withstands solvents, versatile	Bottles and ice cream tubs, potato chip bags, straws, microwave dishes, kettles, garden furniture, lunch boxes, packaging tape	Pegs, bins, pipes, pallet sheets, oil funnels, car battery cases, trays
 PS  PS-E	PS Polystyrene  PS-E Expanded polystyrene	Clear, glassy, rigid, opaque, semi-tough, softens at 95°C. Affected by fat, acids and solvents, but resistant to alkalis, salt solutions. Low water absorption, when not pigmented is clear, is odour and taste free.  Special types of PS are available for special applications.	CD cases, plastic cutlery, imitation glassware, low cost brittle toys, video cases\  Foamed polystyrene cups, takeaway clamshells, foamed meat trays, protective packaging and building and food insulation	Coat hangers, coasters, white ware components, stationery trays and accessories, picture frames, seed trays, building products
 OTHER	OTHER Letter below indicate ISO code for plastic type e.g. SAN, ABS, PC, Nylon	Includes all resins and multi- materials (e.g. laminates). Properties dependent on plastic or combination of plastics	Automotive and appliance components, computers, electronics, cooler bottles, packaging	Automotive components, plastic timber

Nsaif (2013) and Falorca (2010) used plastic waste material cut in pieces for soil reinforcement concluding that shear strength of soil reinforced with plastics is higher than the unreinforced soil.

Pradhan et al. (2012) used triaxial method, with clayey soil also conclude that Cohesion (C) and Angle of internal friction  $\phi$  increase to 0.40% irrespective of the fiber length.

The investigation performed by Petersen in 2009 revealed that the reinforcement of soil with polyethylene strips improves the friction angle and therefore also improves the shear strength of the soil. It was concluded that the friction angle of the soil will increase until a maximum is reached, after which the friction angle will start to decrease. It was further discovered that the reinforcement affects different soil types in different ways. Petersen (2009) found that the Cape Flats sand increased by a maximum of 25 % whilst the Klipheuwel sand increased by a lower, 13%. It was also established that there is a relationship between the aspect ratio and the angle of friction of the sands. For both, the Klipheuwel and the Cape Flats sands, the maximum improvement in shear strength lie between an aspect ratio of 0.2 and 0.4 (Petersen, 2009). That study concluded that an increase in reinforcement concentration results in an initial increase in strength until the peak strength is reached. After the peak strength is reached the strength starts to decrease. This is as a result of the increased interaction between the polyethylene strips (Petersen, 2009).

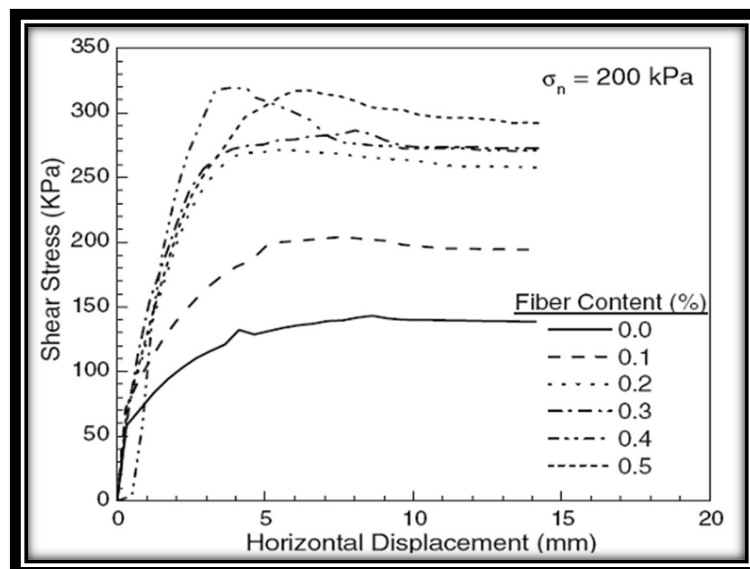


Figure 2-20: Stress-displacement curves for fiber- reinforced soil from direct shear test (Pradhan et al., 2012).

More experiments were conducted by Laskar and Pal (2013) with plastic bottle strips of length 10mm and widths of 1.25mm, 2.5mm and 5mm. Concentrations of 0.25%, 5% and 1% were mixed with soil composite of 40.15% sand, 30.90% silt and 28.95% clay. The investigation was conducted to determine the effects of plastic waste fibers on compaction and consolidation behavior of reinforced soil. A series of odometer tests were completed according to ASTM-D2435-04. It was concluded that according to Terzaghi's one dimensional consolidation concept, due to the rate of expulsion of pore water, the rate of consolidation increased (Laskar and Pal, 2013). They based the rate of expulsion of pore water to the increase in permeability due to the rise in plastic content.

### 2.3.3.3.1 Manufacturing process of PET

The Polyethylene terephthalate (PET) manufacturing process is shown in figure 2-22 and starts from material preparations which are separated manually or automated and cleaned out by removing the labels which can produce levels of cleanliness as high as 90%. It is followed by hydrocyclone classification to remove the cap and ring made from HDPE. In the process of scrubber to remove drink residue, glue and dirt some other decontaminations are followed, while in the final inspection, PET chips are storage and checked before shipping.



Figure 2-21: PET manufacturing process

### 2.3.3.3.2 Types of Plastic

#### - ***PET (Polyethylene Terephthalate)***

The polyethylene terephthalate (PET / PETE / PETP or PET-P) was invented in 1941, being initially used in the textile industry. As regards the production of packages for drinks, it started being used in the '70s.

The rapid development of the production for a series of products (especially agri-food ones), as well as the imposition of certain hygiene rules as regards their manipulation and preservation, have led to increasingly perfected disposable packages, especially made of plastic (MUNTEAN Radu et al.2011).

#### - ***High density polyethylene (HDPE)***

High-Density Polyethylene products are very safe and are not known to transmit any chemicals into foods or drinks. HDPE products are commonly recycled. Items made from this plastic include containers for milk, motor oil, shampoos and conditioners, soap bottles, detergents, and bleaches. It is NEVER safe to reuse an HDPE bottle as a food or drink container if it didn't originally contain food or drink. (Ryedale, 2013).

#### - ***Polyvinyl Chloride (PVC)***

Polyvinyl Chloride (PVC) is a major plastics material which finds widespread use in building, transport, packaging, electrical/electronic and healthcare applications. PVC is a very durable and long-lasting construction material which can be used in a variety of applications, rigid or flexible, white or black and a wide range of colors in between. Due to its very nature, PVC is used widely in many industries and provides very many popular and necessary products. (BPF, 2015).

#### - ***Low Density Polyethylene (LDPE)***

Low-Density Polyethylene is sometimes recycled. It is a very healthy plastic that tends to be both durable and flexible. Items such as cling-film, sandwich bags, squeezable bottles, and plastic grocery bags are made from LDPE.

The first of the polyolefin, Low Density Polyethylene (LDPE) was originally prepared some fifty years ago by the high-pressure polymerization of ethylene. Its comparatively low density arises from the presence of a small amount of branching in the chain (on about 2% of the carbon atoms). This gives a more open structure. Low Density Polyethylene (LDPE) is a most useful and widely used plastic especially in dispensing bottles or wash bottles (Dynalab, 2015).

- **Others**

These kinds of plastics are difficult to recycle, the copolymer of ethylene and vinyl acetate is mainly used in the manufacture of footwear, glues, adhesives, technical parts, wire and cable. (Ryedale, 2013).

**2.3.3.3 Waste PET generation, prevention and minimization**

The volume of PET bottle water is increasing every year, not less than 200 billion bottles of water are consumed around the world. Not more than 15% of this quantity is recycled in recycling plants around the globe while the remaining one end up on landfills, bins or open dumpsites across the globe (Wikipedia, 2011). The graph below shows the wasting PET bottles against Recycling from 1990 to 2006.

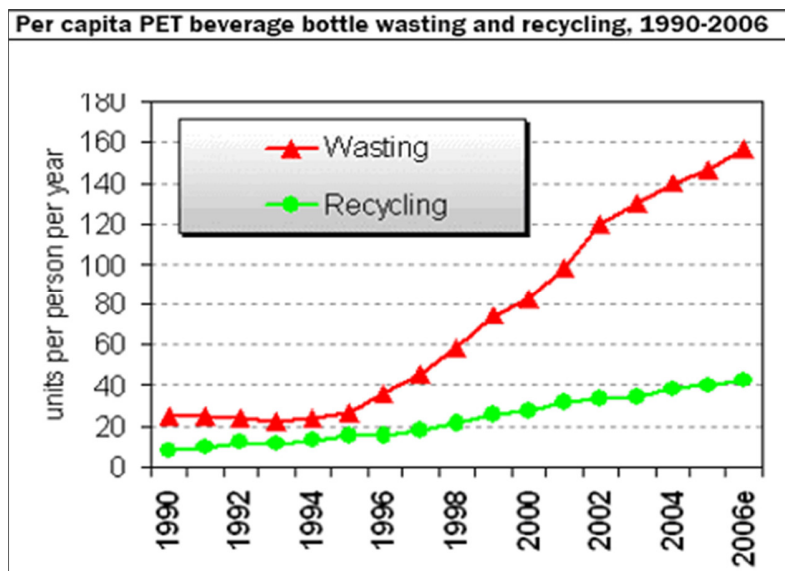


Figure 2-22: PET beverage bottle wasting and recycling

Source: Container Recycling Institute.

Unfortunately, the recycling level of PET bottles is still low, it is estimated that 1.6 million tons are not recycled per year (Abousleiman et al., 2012). To prevent this, it is necessary to reduce the quantity of PET bottles waste by eliminating unnecessary use of this material or minimize the use and substitute with more environmental alternatives (Reuse, Recycling and Recovery). At end everyone needs to learn how to avoid the excessive buying and consumption of plastic products (Abdulkarim et al., 2012).

When randomly dumped, waste PET bottles will cause environmental pollution but if properly managed they can be used directly in civil engineering application as proposed in this research. These applications include but are not limited to the construction of highway embankments over soft soils and backfill behind retaining structures. Also, can be used as raw material to produce different materials which are useful (Karen, 1996, Green et al., 1998). Although recycling is the best option and efficient once plastic take small landfill space since it is easily crushed and is not biologically degradable.

**Table 2-4:** Properties of PET plastic (Senhadji et al., 2013)

<b>Physical Properties PET</b>	
Tensile Strength at break (Mpa)	70
Elongation at break (%)	70
Flexural modulus (regidity) (Mpa)	2
Tensile modulus (Gpa)	2.9
Melting Point (°C)	260
Water absorption (%)	0

**Adapted from:** Senhadji et al. 2013

#### **2.3.3.3.4 Waste PET problems**

In South Africa, with an emerging economy the view on waste management has been changing in past 10 years. The usage of PET in South Africa is approximately 9% per annum according to Petco (Plastic recycling South Africa). Despite the economic growth, half of the population is living in poverty, and more than 80,000 people are living from collecting waste from dumpsites, streets and selling to recycling companies (Figure 2-23).



Figure 2-23: Collection of waste bottles by hand in S.A (source: PETCO)

The process of collection and recycling the PET bottles as no legal framework system available to facilitate the sustainable collection in South Africa, many waste stream organizations have started initiatives dedicated to growing recycling proportions in the country based on agreements with local government. The organization responsible for the recycling and collection process is PETCO and as reached notable results over last years as can be seen in Table 2-5. PETCO has improved its collection from 16% to 47% in 2013 and while waste plastic PET consumption in South Africa has doubled.

Table 2-5: Achievements and target of PET bottle collection and recycling

	Recycling achievements and target (as set by PETCO)			
	2004	2012	2013	Target 2017
PET bottles	16% (9,840 tons)	45% (50,274 tons)	47%	58%

Source: PETCO

Below are described the environmental and human health problems caused by improper management of waste PET plastic:

➤ **Human health problems**

The dumped or stockpiled waste PET can shelter pests which create conditions favourable to the survival and growth of microbial pathogens. The waste pickers are vulnerable to infections and chronic diseases with direct handling of the waste, stagnant water inside the PET water bottles also can be a breeding-site for mosquitoes. It is known that the deadly disease mostly transmitted by mosquitoes is malaria. In South America the diseases transmitted by mosquitoes are yellow fever and dengue fever, which affect a high number of the population (Technical Guidelines, 2011).

➤ **Environmental problems**

Environmental problems can be caused by discarding plastic on environment because they are not biodegradable, some of the environmental problems caused by waste PET are described below:

➤ **Land Pollution/Water Pollution**

According to American Chemical Society, chlorinated plastic can release harmful chemicals into soils, which can leach into ground water or the close water sources and also the ecosystem. Another problem is the amount of the pollution that are caused by plastic bottles manufactures where they use crude oil. Therefore, this causes serious problems to the species around that drink the water.

➤ **Air pollution**

When PET plastic waste is burned, complete combustion releases carbon dioxide and sulphur dioxide into the atmosphere while incomplete combustion emits dioxins and dioxious gases (Hoddinot, 1997). Other hazardous gases such as benzene, furans, arsenic, vanadium, hydrogen chloride, mercury, polynuclear aromatic hydrocarbons, polychlorinated biphenyls and chromium are released into the atmosphere (Mpanyana, 2009).

**2.3.3.3.5 Current use of PET plastic bottles.**

Figure 2-24 summarize the life cycle of plastic PET, which is divided into 3 phases: Packing, Manufacturing and Distribution. The first stage includes the extraction of raw material, at this stage the plastic bottles are separated accordingly to colours, and secondly manufacturing which involves the process of packing, treatments, storage and lastly are distributed around for many purposes.

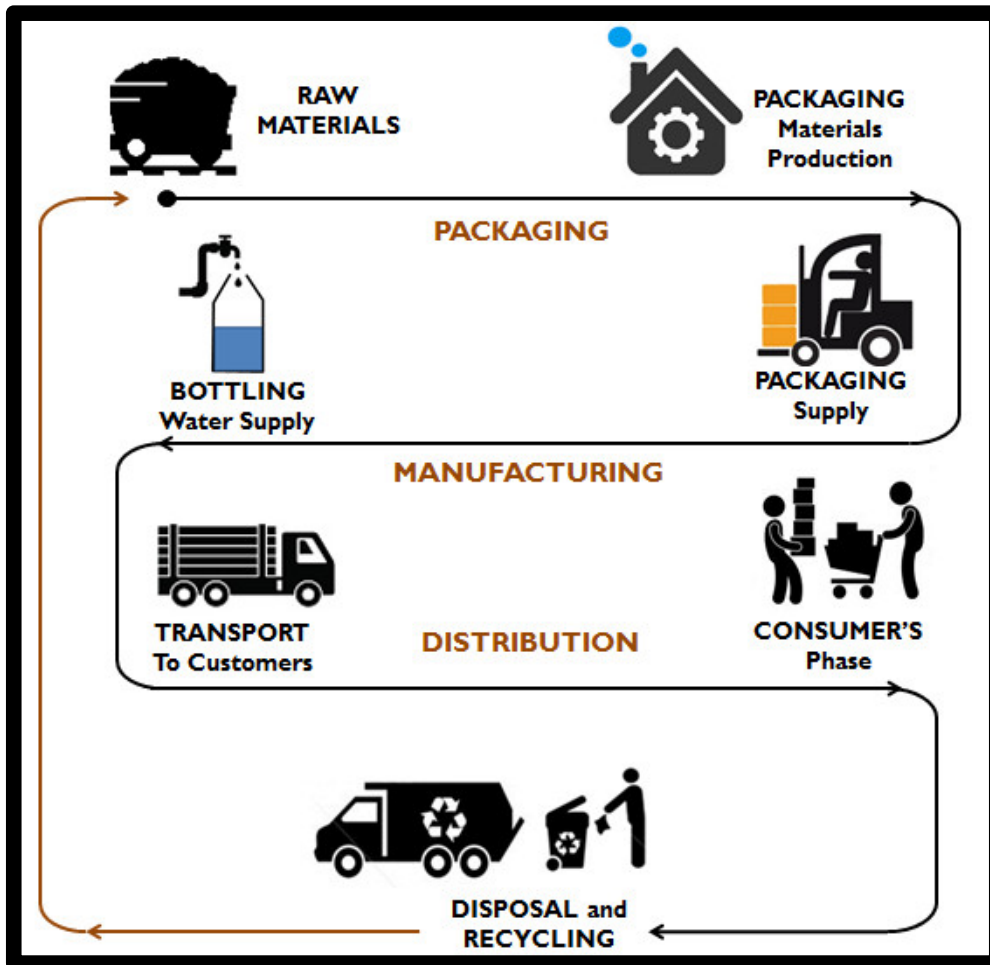


Figure 2-24: various stages in the life of a PET bottles (Adapted from: Nestle waters)

## 2.4 Direct Shear Test

### 2.4.1 Theory

The strength of soil is measured in terms of shear strength (Cohesion,  $C$  and angle of internal friction  $\phi$ ) for geotechnical structures and in terms of the California bearing ratio for pavements.

The shear resistance within a soil is mobilized by the cohesion and the angle of friction, and these known as the shear strength parameters. When shear stress surpasses the peak stress, or the maximum shear stress the soil can sustain, failure will occur at this point with large strains being the result.

A mathematical relationship between the peak stresses and shear strength parameters of a soil was proposed by Coulomb in 1776. This formula was redefined since shear stress is taken fully by the soil particles and not by the liquid within the voids. This defines the linear formula as incorporating only effective stress parameters (Aysen, 2002: 111-115). The formula states that the shear strength ( $\tau$ ) of a soil should be expressed as a linear function of effective normal stress ( $\sigma'$ ) at failure,

$$\tau = \sigma' \tan \phi' + c'$$

Equation 2-1: Coulomb's formula

where  $c'$  is referred to as the cohesion intercept and  $\phi'$  is known as the angle of internal friction, these are the shear strength parameters. In Figure 2-25 it displays the linear function expressed in equation above.

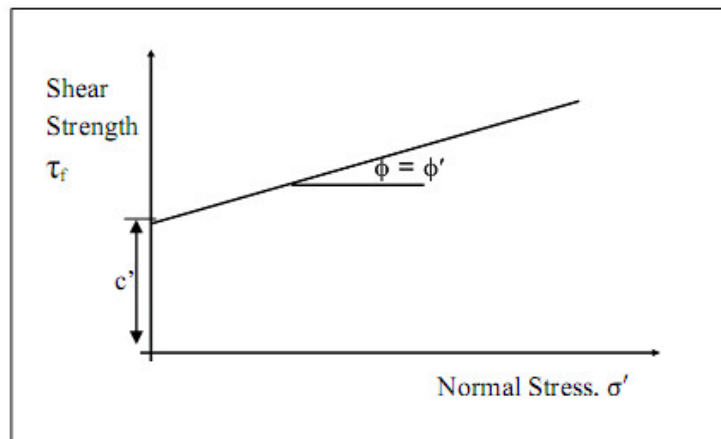


Figure 2-25: Linear function representing Coulomb's Law

When taking a representative sample of in-situ soil, the shear strength parameters can be determined by laboratory testing, namely the direct shear test (Craig, 2004: 95).

### 2.4.2 Mechanism of Direct Shear

The apparatus consists of a small metal box known as the shear box in which the sample is housed. The box is split horizontally at mid-height into an upper and lower box with a small clearance between each half to allow shearing of the specimen. A predetermined normal force is applied to the sample by the loading yoke which is placed on the loading cap of the box. This axial force is achieved by slotting weights onto the hanger and is kept constant throughout the test. The shear load is provided by a motorized drive unit which pushes the upper box at a constant rate of displacement. The top half reacts against the proving ring whilst a dial gauge provides readings of the horizontal displacement undergone by the sample. Figure 2-26 displays a schematic diagram of the direct shear apparatus.

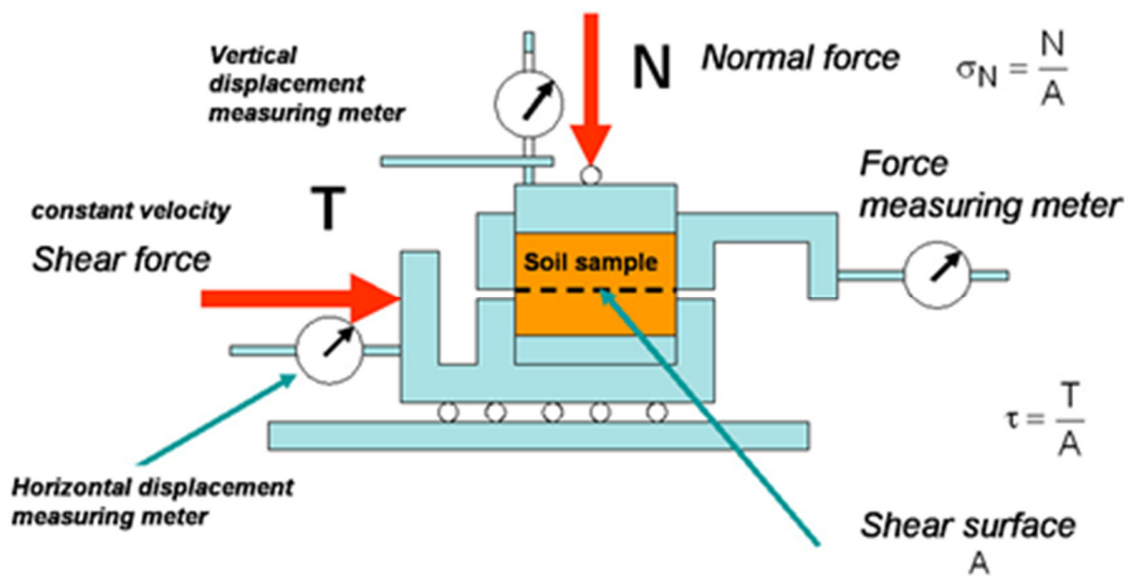


Figure 2-26: Schematic diagram of the direct shear apparatus (Messi, 2009)

Shear failure of the sample is indicated by a sudden drop or leveling of the readings provided by the dial gauge. The shear stress and normal stress are only measured on the horizontal plane and are undetermined on other surfaces; therefore, the stress path during testing cannot be represented (Head, Bowels and Whitlow, 2004). However, Mohr-Coulomb failure envelopes can be produced by plotting the relationship between the normal stress and the peak shear stress. The stress conditions

on the failure plane and the corresponding Mohr's circle for direct shear testing are illustrated in Figure 2-27

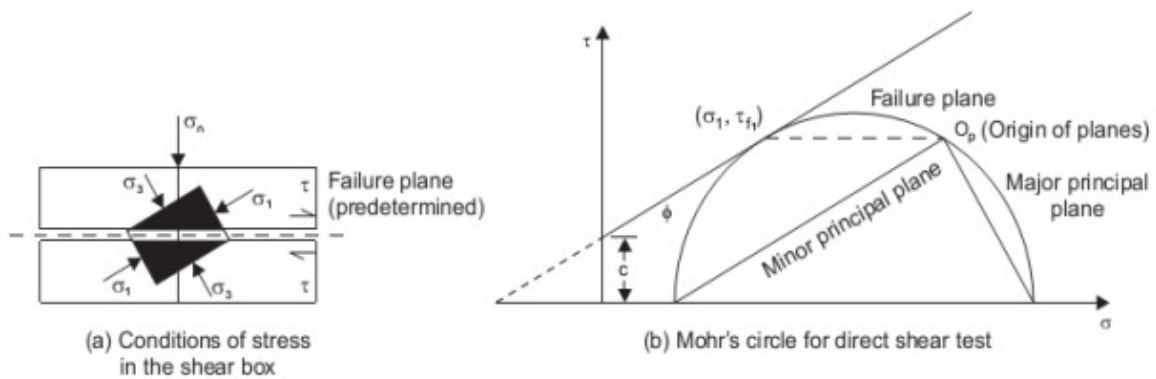


Figure 2-27: Mohr's Circle Representation of Stress Conditions in Direct Shear Test

(Venkatramaiah, 2006)

### 2.4.3 Orientation of Reinforcement Members in Shear Box.

The technique of soil reinforcement generally entails the inclusion of tensile elements placed in the failure zone of a soil mass. Mirafi (2010) had explained that for the reinforcement to be effective this had to be the case. However, the efficiency of the reinforcement is further dependent on the orientation of the elements within the soil mass as well.

Fibers contribute to the increase in shear strength by mobilizing tension along its length. It is assumed that fibers which are in compression do not contribute to the shear strength increase, and in some cases, can even slightly reduce this strength of the soil (Li, 2005). This was found by Michalowski and Cermak (2002), as cited by (Li, 2005), who observed that specimens containing horizontally oriented elements were higher in shear strength than those containing vertically placed elements. Gray and Ohashi (1983) conducted direct shear tests on samples including fibers which were intentionally placed at known inclinations to investigate its effects on the soil strength. They observed that fibers placed at small angles contributed least to the shear strength increase whilst fibers inclined at  $60^\circ$  to the failure surface contributed the most. This angle of inclination coincides with the direction of maximum principle tensile strain in the direct shear test.

The forces affecting an element embedded in a direct shear sample has been explained by Chen et al. (2011) with the use of the illustration as depicted in Figure 2-28.

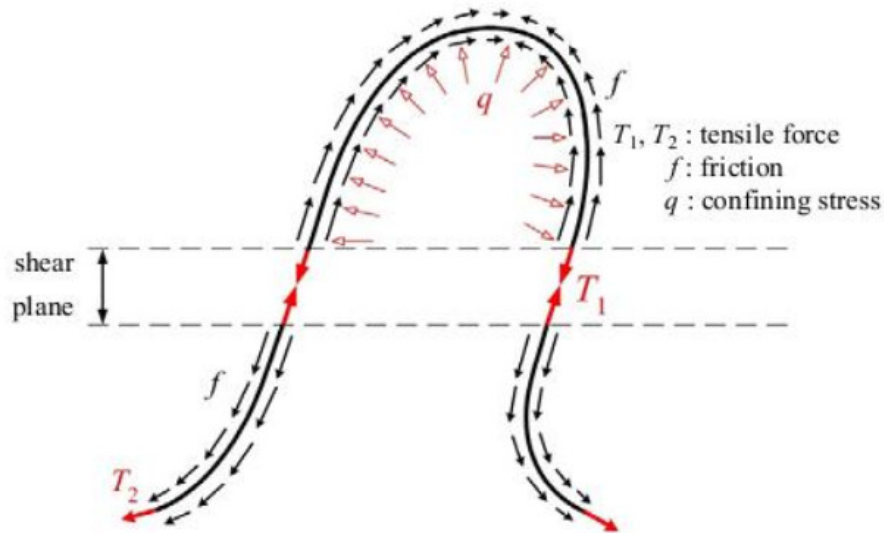


Figure 2-28: Free Body Diagram of a Fiber Embedded in Soil (Chen et al., 2011)

They concluded that resistance from the friction on its surface,  $f$ , was provided by the filament itself. This force along with the tensile force delivered in the filament,  $T_2$ , and the extra confining stresses,  $q$ , brought by the filament exerting on adjacent particles enabled improvement of the soil's cohesion.

Research has been completed on the effects of elements which are inclined, tangential and perpendicular to the failure surface. These have been from both a quantitative and and qualitative perspective. However, investigations into the behavior of failure planes in direct shear specimens with randomly orientated elements is very limited. Up to date, no theory has been published which quantifies these effects.

## CHAPTER 3

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### 3 RESEARCH MATERIALS, EQUIPMENT AND METHODOLOGY

#### 3.1 Introduction

The soil used for the research, Cape Flats and Klipheuwel sand, were selected based on their availability locally and for the range of grading and grain sizes. Both sands were clean, consistent and easy to work with which enhanced the repeatability of results.

#### 3.2 Research Materials

##### 3.2.1 Soil Characterization tests

Soil testing was conducted at the Geotechnical Laboratory in the Department of Civil Engineering, University of Cape Town. A list of classification tests are tabulated below with the respective standard code.

**Table 3-1:** Soil classification test conducted and standard codes

Soil Property	Test Method	British Standard Code
Specific Gravity	Small Pyknometer method	BS 1377: Part 2: 1990
Natural Moisture Content	Oven drying method	BS 1377: Part 2: 1990
Optimum Moisture Content	Standard Proctor Test	BS 1377: Part 4: 1990
Particle Grading	Dry Sieving Analysis	BS 1377: Part 2: 1990
Shear Strength	Direct Shear method	BS 1377: Part 7: 1990

Sieve analysis was performed on each type of soil to determine the relative proportions, by dry mass, of each size range in accordance with BS 1377: Part 2:1990 and provided grading curves of each soil. Classification of the soil was based on the Unified Soil Classification System (USCS). The Figure 3-1 below shows the particle size distribution curves for each soil.

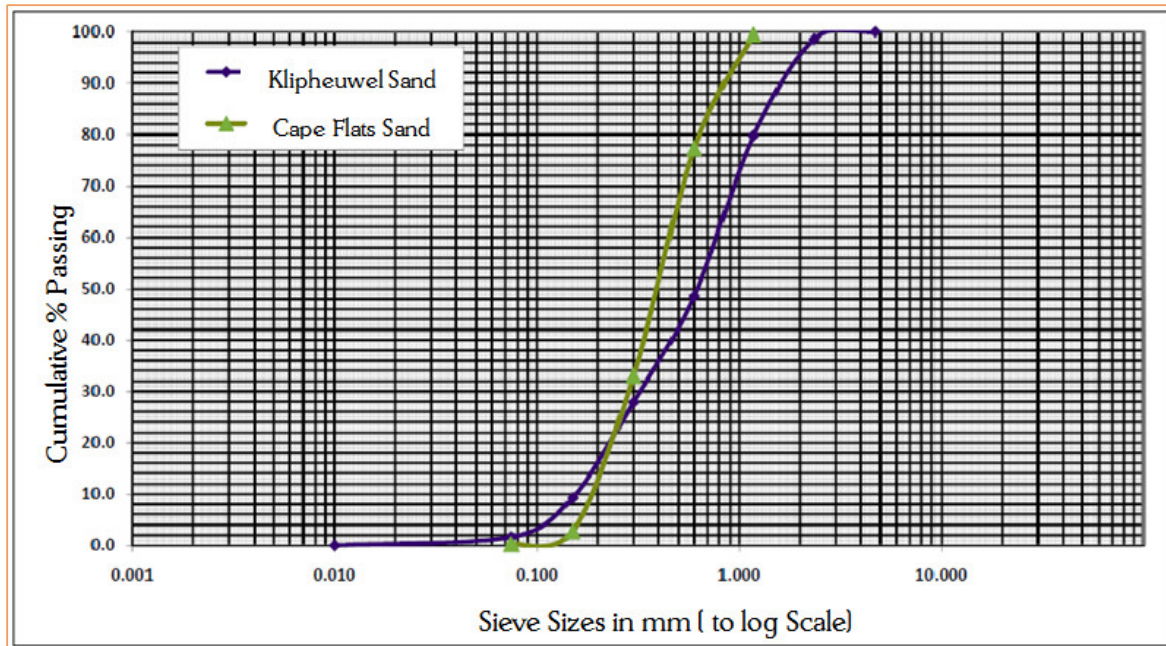


Figure 3-1: Particle size distribution graph for Cape Flats and Klipheuwel sand

From the grading curves in Figure 3-1 is evident that both, Cape Flats and Klipheuwel soils are coarse grained soils since more than 50% of soil grains particles are larger than 75 $\mu$ m and both soils are identified as sand. The used sand samples have a coefficient of uniformity greater than 6 and coefficient of curvature between 1 and 3 but the calculated coefficients of uniformity was determined to be 2.37 and 4.65 with a calculated coefficient of curvature of 0.98 and 1.00 for cape Flats and Klipheuwel sands respectively., They were both classified as poorly graded with little or no fines.

### 3.2.2 Soil materials

#### 3.2.2.1 Cape Flats Sands

The Cape Flats sand used for the tests was obtained from the Cape Flats region in Cape Town, South Africa at Philippi Quarry. It is medium dense, light grey, clean quartz sand, with larger grains sub rounded while the medium and small sized particles are sub angular as observed under a microscope (b). (Kalumba & Chebet, 2013) figure 3-2.

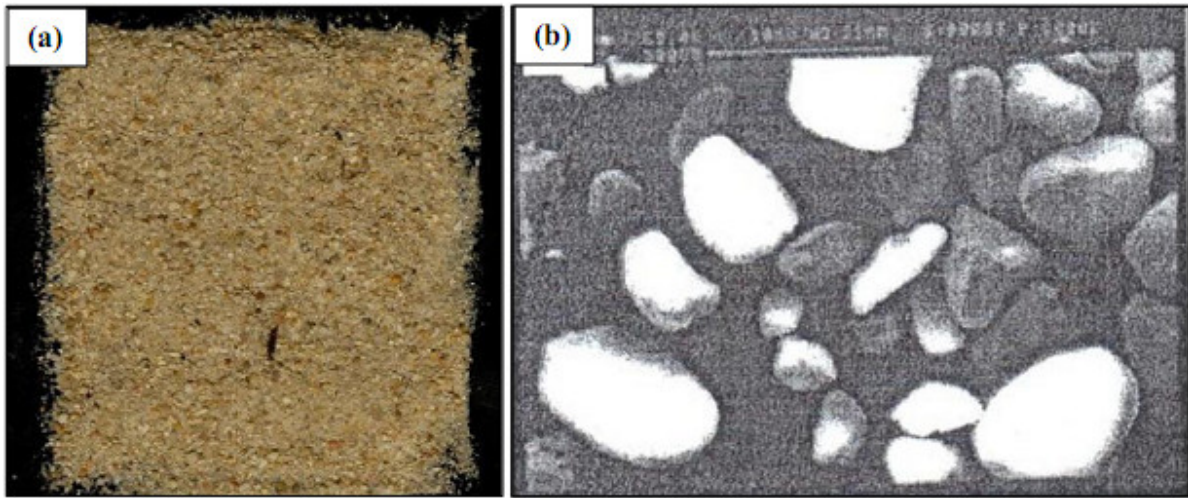


Figure 3-2: (a) Cape Flats Sand Particles (Chebet & Kalumba, 2014), (b) Microscopic view sand particles (Kalumba, 1998)

The following table summarizes the mechanical properties of the soil.

Table 3-2: Mechanical properties of the Cape Flats sand

Property	Unit	Cape Flats Sand
Particle Density, $\rho_s$	Mg/m <sup>3</sup>	2.66
Natural Moisture content	%	3
Average densest dry density	kg/m <sup>3</sup>	1720
Average loose dry density	kg/m <sup>3</sup>	1538
Optimum moisture content (Proctor)	%	15
Maximum Dry density (Proctor)	kg/m <sup>3</sup>	1710
Particle Range	mm	0.067-1.18
Mean Grain Size, D <sub>50</sub>	mm	0.4
Coefficient of uniformity, C <sub>u</sub>	-	2.37
Coefficient of curvature, C <sub>c</sub>	-	0.98
Angle of friction, $\phi'$	degrees	33.9
Residual Shear strength, $\phi_R'$	degrees	28
Cohesion, $c'$	kN/m <sup>2</sup>	9.4

### 3.2.2.2 Klipheuwel Sand

The Klipheuwel sand, sourced from quarry in Malmesbury, Cape Town, is uniformly graded medium dense, reddish brown sand that has particles ranging between 0.067 to 2.36 mm. The coefficient of uniformity is 4.65 and the coefficient of curvature is 1.00. Below are presented the Cape Flats sand, Figure 3-3 (a) and Klipheuwel sand, (b) used in this research.

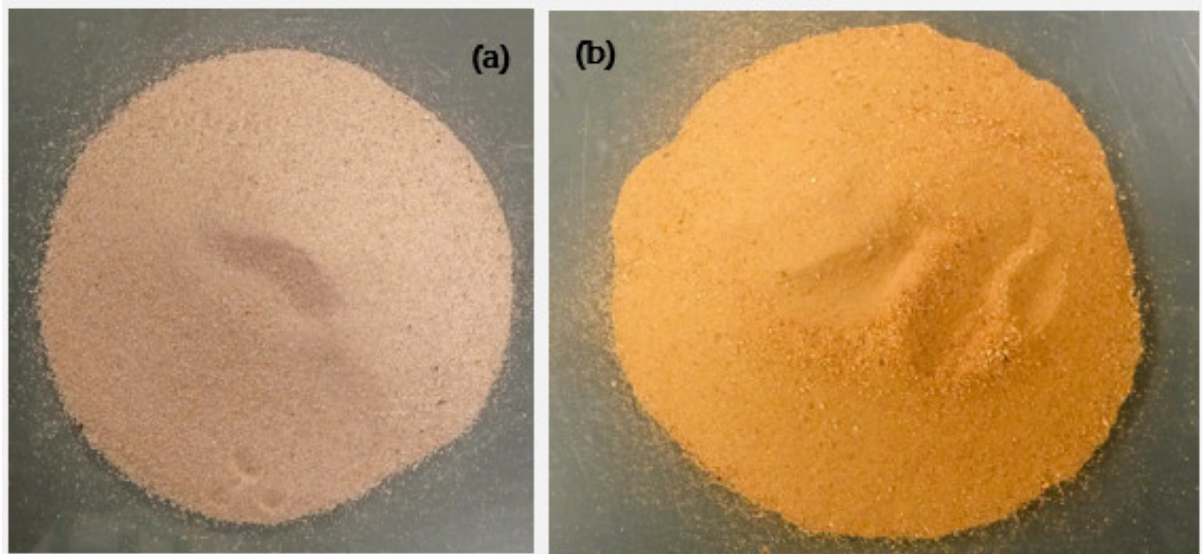


Figure 3-3: (a) Cape Flats Sand, (b) Klipheuwel Sand

Table 3-3: Mechanical properties of the Klipheuwel sand

Property	Unit	Klipheuwel Sand
Particle Density, $\rho_s$	Mg/m <sup>3</sup>	2.64
Natural Moisture content	%	2.72
Average densest dry density	kg/m <sup>3</sup>	1660
Average loose dry density	kg/m <sup>3</sup>	1434
Optimum moisture content (Proctor)	%	6.7
Maximum Dry density (Proctor)	kg/m <sup>3</sup>	1985
Particle Range	mm	0.075-2.36
Mean Grain Size, D <sub>50</sub>	mm	0.72
Coefficient of uniformity, C <sub>u</sub>	-	4.21
Coefficient of curvature, C <sub>c</sub>	-	1.05
Angle of friction, $\phi'$	degrees	41.6
Residual Shear strength, $\phi_R'$	degrees	28
Cohesion, c'	kN/m <sup>2</sup>	4.8

### 3.2.3 Plastic Material

#### 3.2.3.1 Choice of PET Plastic

The materials used in this study were green shredded PET plastic bottles, sourced from Kaytech Ltd, a local supplier and manufacturer of geosynthetics. The material was received in 3 buckets of 22 kg each. According to Siddique (2008), the shredded plastic bottles are obtained from a mixed plastic stream, therefore after shredding, the smaller pieces have to be washed and the labels, residue and others contaminants removed. The shredded plastic chips of various irregular sizes were separated through a stack of sieves following (Standard). Sieves sizes of 2.0mm, 4.75mm, and 5.6mm with the plastic chips (Figure 3-4) retained on them were then used for direct simple shear tests.

The aforementioned sieves were chosen based on material specification and availability. The chosen sieves retained more plastic chips compared to other sieve sizes.

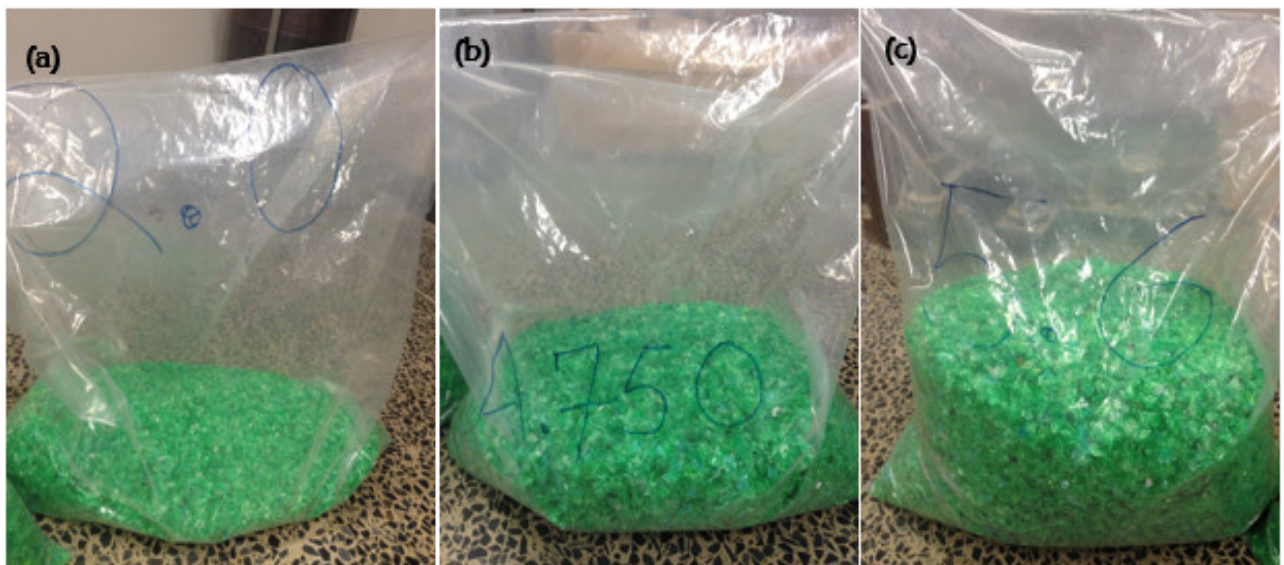


Figure: 3-4: (a) 2.0mm (b) 4.75mm and (c) 5.6mm Plastic chips

### **3.3 Test Equipment**

#### **3.3.1 Direct Shear**

The small Direct Shear (100 x 100mm by 30mm box) box test method was adopted as suitable for this study due to its simplicity to operate, ease of specimen preparation and is one of the oldest strength tests for soil material. Furthermore, it was chosen as adequate for the study as the soils used (Cape Flats and Klipheuwel Sand) were non-gravelly soils according to sieve analysis; as recommended in British Standards (BS: 1377 – 7: 1990).

All the laboratory tests were carried out using the small direct shear box method (100x100mm by 30mm box) in accordance with the British Standards (BS 1377-7: 1990). The tests were conducted at normal pressures of 25 kPa, 50 kPa and 100 kPa. The relationship between the Shear Stress and Horizontal Displacement was determined which gave the peak stress in every soil/shredded plastic composite. The stress/horizontal displacement relationship was used to determine the relationship between the peak stress and the normal loading, residual stress and normal loading.

The direct shear box equipment was a fully automated “ShearTrac-II” manufactured by Geocomp Corporation Company, USA.

The apparatus consists of two halves of the shear box which were assembled with the base plates and placed securely within the box in the carriage. The two halves were securely tightened by screws to avoid separation of the plates during shearing of the soil. The system loading mechanism to apply shear forces is moved left and right by combination of micro-stepper motor and worm gear. The maximum load capacity is 4.5kN (1,000 lbs.) capable of applying a maximum pressure of up to 8.9kN (2,000 lbs.). The machine is also capable of applying a constant strain rate or stress rate of up to 15mm per minute.

The ShearTrac-II is also capable of performing the tests under full automatic control. It also capable of displaying the all the tests status and graphs in real time. The system comes with software and hardware that records all tests input data and settings of selected test parameters during the shearing process. An expanded overview of the machine is as shown in the figure 3-5 below.

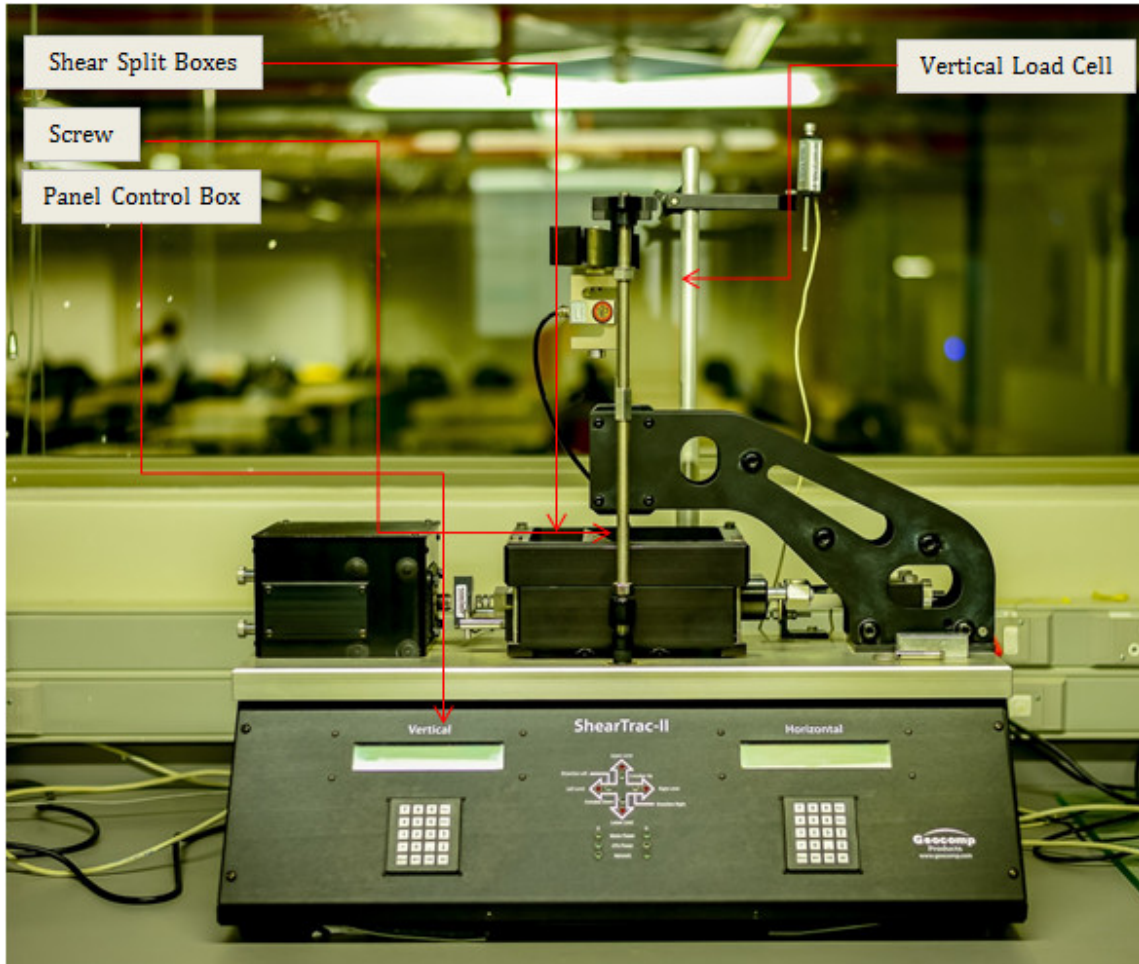


Figure 3-5: ShearTrac-II Components

### 3.3.2 Other apparatus

- Sieve Shaker

A mechanical shaker was used to separate the shredded plastic into 3 different sizes. The sieves were placed upon a mechanical shaker, seen in Figure 3-6 below, and the shredded plastic was poured onto the top sieve. The top was then covered with a lid and the apparatus was securely fastened the sieves were kept on the shaker for a minimum of 10 minutes.

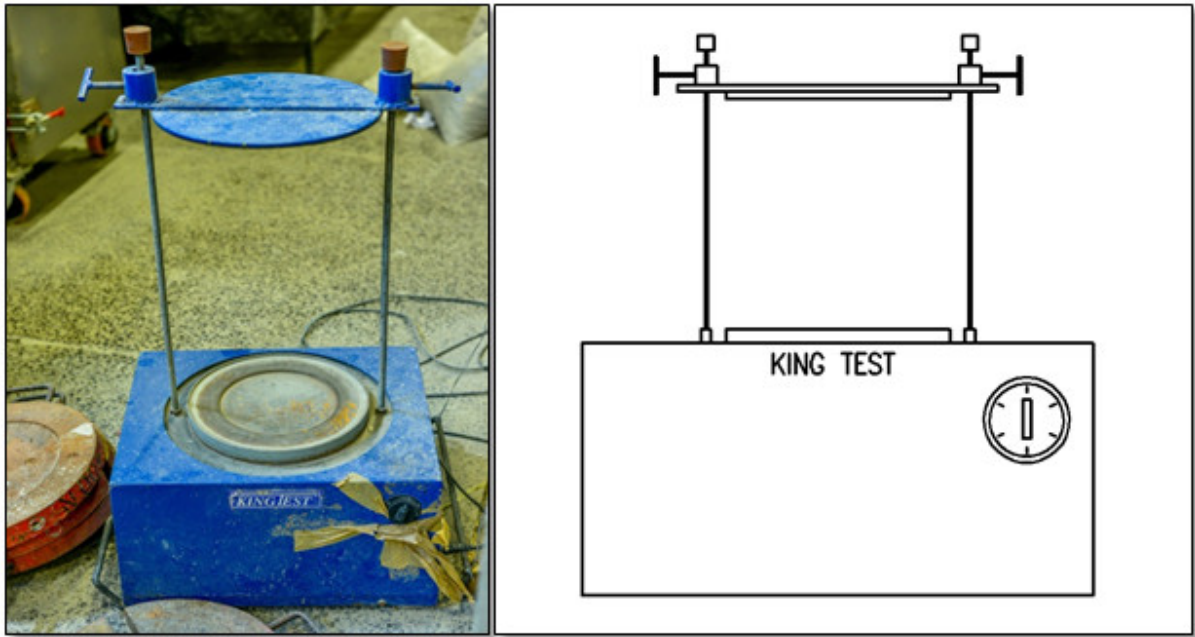


Figure 3-6: Mechanical shaking device.

- **Hand Tamper**

A hand tamper was used to compact the shredded plastic and sand, the tamper consisted a metal rod which was joined perpendicularly to a base of 100 X 100mm with a total weight of 1.1kg and drop weight of 350g to ensure a uniform distribution of the load during compaction. The sand was subjected to 10 tapings through a height of 150mm, to each of the 3 layers,.

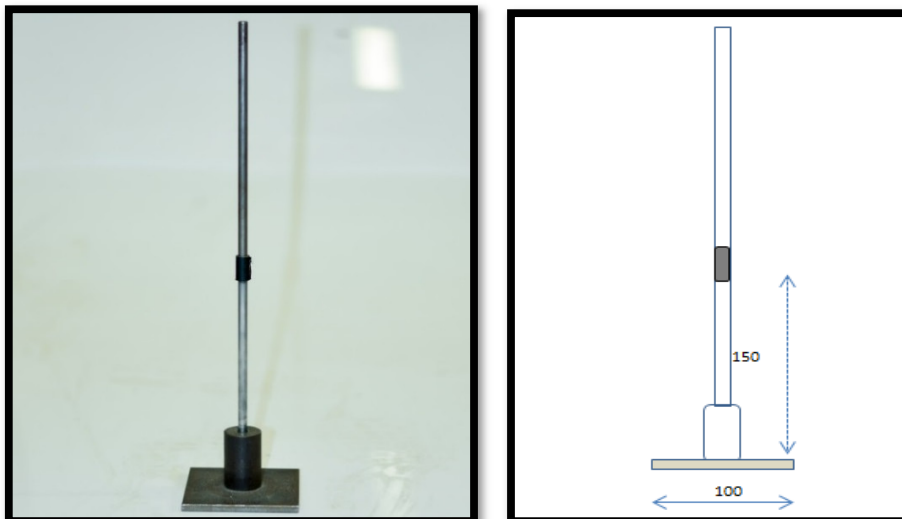


Figure 3-7: Hand Tamper, dimension in mm

### 3.4 Laboratory Tests

A total of 135 direct shear tests were carried out on dry soil to: 72 tests were performed on Cape Flats sands, which 21 tests on 2.0mm size shredded plastic, 21 tests for 4.75mm and 21 tests on 5.6mm shredded plastic, 6 control and 3 repeatability tests. 63 tests were conducted on Klipheuwel sand. The table below describes the symbols used in the schedules.

**Table 3-4:** Description of the codes used

<b>Code</b>	<b>Description</b>
CF	Cape Flats Sand
KS	Klipheuwel Sand
US	Unreinforced Soil
RS	Reinforced Soil
SP1, SP2, SP3, SP4, SP5, SP6, SP7	Shredded Plastic Concentrations of 2.5%, 5%, 7.5%,10%, 12.5%, 15% and 20% respectively
C50, C100, C200	Normal Pressure

Table 3-5: Direct shear testing schedule for Cape Flats Sands

Cape Flats Sand							
Number Tests	Soil State	Group	Test Code	Research Material	Normal Stress (kPa)	Parameters	
1	Dry	0	CF/C100/US	0% Plastic	100	Repeatability	
2			CF/C100/US		100		
3			CF/C100/US		100		
4		1	1	CF/C50/US	0% Plastic	50	Control
5				CF/C100/US		100	
6				CF/C200/US		200	
7		2	2	CF/C50/RS/SP1	2.5% Plastic	50	Shredded Plastic (2.0mm)
8				CF/C100/RS/SP1		100	
9				CF/C200/RS/SP1		200	
10		3	3	CF/C50/RS/SP2	5% Plastic	50	
11				CF/C100/RS/SP2		100	
12				CF/C200/RS/SP2		200	
13		4	4	CF/C50/RS/SP3	7.5% Plastic	50	
14				CF/C100/RS/SP3		100	
15				CF/C200/RS/SP3		200	
16		5	5	CF/C50/RS/SP4	10% Plastic	50	
17				CF/C100/RS/SP4		100	
18				CF/C200/RS/SP4		200	
19		6	6	CF/C50/RS/SP5	12.5% Plastic	50	
20				CF/C100/RS/SP5		100	
21				CF/C200/RS/SP5		200	
22		7	7	CF/C50/RS/SP6	15% Plastic	50	
23				CF/C100/RS/SP6		100	
24				CF/C200/RS/SP6		200	
25		8	8	CF/C50/RS/SP7	20% Plastic	50	
26				CF/C100/RS/SP7		100	
27				CF/C200/RS/SP7		200	

Table 3-6: Direct shear testing schedule for Cape Flats Sands

Cape Flats Sand						
Number Tests	Soil State	Group	Test Code	Research Material	Normal Stress (kPa)	Parameters
1	Dry	2	CF/C50/RS/SP1	2.5% Plastic	50	Shredded Plastic (4.75mm)
2			CF/C100/RS/SP1		100	
3			CF/C200/RS/SP1		200	
4		3	CF/C50/RS/SP2	5% Plastic	50	
5			CF/C100/RS/SP2		100	
6			CF/C200/RS/SP2		200	
7		4	CF/C50/RS/SP3	7.5% Plastic	50	
8			CF/C100/RS/SP3		100	
9			CF/C200/RS/SP3		200	
10		5	CF/C50/RS/SP4	10% Plastic	50	
11			CF/C100/RS/SP4		100	
12			CF/C200/RS/SP4		200	
13		6	CF/C50/RS/SP5	12.5% Plastic	50	
14			CF/C100/RS/SP5		100	
15			CF/C200/RS/SP5		200	
16		7	CF/C50/RS/SP6	15% Plastic	50	
17			CF/C100/RS/SP6		100	
18			CF/C200/RS/SP6		200	
19		8	CF/C50/RS/SP7	20% Plastic	50	
20			CF/C100/RS/SP7		100	
21			CF/C200/RS/SP7		200	

Table 3-7: Direct shear testing schedule for Cape Flats Sands

Cape Flats Sand						
Number Tests	Soil State	Group	Test Code	Research Material	Normal Stress (kPa)	Parameters
1	Dry	2	CF/C50/RS/SP1	2.5% Plastic	50	Shredded Plastic (5.6mm)
2			CF/C100/RS/SP1		100	
3			CF/C200/RS/SP1		200	
4		3	CF/C50/RS/SP2	5% Plastic	50	
5			CF/C100/RS/SP2		100	
6			CF/C200/RS/SP2		200	
7		4	CF/C50/RS/SP3	7.5% Plastic	50	
8			CF/C100/RS/SP3		100	
9			CF/C200/RS/SP3		200	
10		5	CF/C50/RS/SP4	10% Plastic	50	
11			CF/C100/RS/SP4		100	
12			CF/C200/RS/SP4		200	
13		6	CF/C50/RS/SP5	12.5% Plastic	50	
14			CF/C100/RS/SP5		100	
15			CF/C200/RS/SP5		200	
16		7	CF/C50/RS/SP6	15% Plastic	50	
17			CF/C100/RS/SP6		100	
18			CF/C200/RS/SP6		200	
19		8	CF/C50/RS/SP7	20% Plastic	50	
20			CF/C100/RS/SP7		100	
21			CF/C200/RS/SP7		200	

Table 3-8: Direct shear testing schedule for Klipheuwel Sand

Klipheuwel Sand						
Number Tests	Soil State	Group	Test Code	Research Material	Normal Stress (kPa)	Parameters
1	Dry	1	KS/C50/US	0% Plastic	50	Control
2			KS/C100/US		100	
3			KS/C200/US		200	
4		2	KS/C50/RS/SP1	2.5% Plastic	50	Shredded Plastic (2.0mm)
5			KS/C100/RS/SP1		100	
6			KS/C200/RS/SP1		200	
7		3	KS/C50/RS/SP2	5% Plastic	50	
8			KS/C100/RS/SP2		100	
9			KS/C200/RS/SP2		200	
10		4	KS/C50/RS/SP3	7.5% Plastic	50	
11			KS/C100/RS/SP3		100	
12			KS/C200/RS/SP3		200	
13		5	KS/C50/RS/SP4	10% Plastic	50	
14			KS/C100/RS/SP4		100	
15			KS/C200/RS/SP4		200	
16		6	KS/C50/RS/SP5	12.5% Plastic	50	
17			KS/C100/RS/SP5		100	
18			KS/C200/RS/SP5		200	
19		7	KS/C50/RS/SP6	15% Plastic	50	
20			KS/C100/RS/SP6		100	
21			KS/C200/RS/SP6		200	
22		8	KS/C50/RS/SP7	20% Plastic	50	
23			KS/C100/RS/SP7		100	
24			KS/C200/RS/SP7		200	

Table 3-9: Direct shear testing schedule for Klipheuwel Sand

Klipheuwel Sand						
Number Tests	Soil State	Group	Test Code	Research Material	Normal Stress (kPa)	Parameters
1	Dry	2	KS/C50/RS/SP1	2.5% Plastic	50	Shredded Plastic (4.75mm)
2			KS/C100/RS/SP1		100	
3			KS/C200/RS/SP1		200	
4		3	KS/C50/RS/SP2	5% Plastic	50	
5			KS/C100/RS/SP2		100	
6			KS/C200/RS/SP2		200	
7		4	KS/C50/RS/SP3	7.5% Plastic	50	
8			KS/C100/RS/SP3		100	
9			KS/C200/RS/SP3		200	
10		5	KS/C50/RS/SP4	10% Plastic	50	
11			KS/C100/RS/SP4		100	
12			KS/C200/RS/SP4		200	
13		6	KS/C50/RS/SP5	12.5% Plastic	50	
14			KS/C100/RS/SP5		100	
15			KS/C200/RS/SP5		200	
16		7	KS/C50/RS/SP6	15% Plastic	50	
17			KS/C100/RS/SP6		100	
18			KS/C200/RS/SP6		200	
19		8	KS/C50/RS/SP7	20% Plastic	50	
20			KS/C100/RS/SP7		100	
21			KS/C200/RS/SP7		200	

Table 3-10: Direct shear testing schedule for Klipheuwel Sand

Klipheuwel Sand						
Number Tests	Soil State	Group	Test Code	Research Material	Normal Stress (kPa)	Parameters
1	Dry	2	KS/C50/RS/SP1	2.5% Plastic	50	Shredded Plastic (5.6mm)
2			KS/C100/RS/SP1		100	
3			KS/C200/RS/SP1		200	
4		3	KS/C50/RS/SP2	5% Plastic	50	
5			KS/C100/RS/SP2		100	
6			KS/C200/RS/SP2		200	
7		4	KS/C50/RS/SP3	7.5% Plastic	50	
8			KS/C100/RS/SP3		100	
9			KS/C200/RS/SP3		200	
10		5	KS/C50/RS/SP4	10% Plastic	50	
11			KS/C100/RS/SP4		100	
12			KS/C200/RS/SP4		200	
13		6	KS/C50/RS/SP5	12.5% Plastic	50	
14			KS/C100/RS/SP5		100	
15			KS/C200/RS/SP5		200	
16		7	KS/C50/RS/SP6	15% Plastic	50	
17			KS/C100/RS/SP6		100	
18			KS/C200/RS/SP6		200	
19		8	KS/C50/RS/SP7	20% Plastic	50	
20			KS/C100/RS/SP7		100	
21			KS/C200/RS/SP7		200	

### 3.5 Direct shear testing

#### 3.5.1 Material preparation

The soil samples used for testing were oven dried, for 24 hours, at a temperature of 105°C to eliminate any effect due to moisture changes.

#### 3.5.2 Pure soil (0% plastic shreds)

Based on volume and the specific gravity of the shear box, a pre-estimated quantity of 500g was taken from the container and thoroughly mixed on a crucible using a scoop. The sand was compacted in three layers, using the standard proctor test procedure outlined in the ASTM D698-12. 10 blows were applied per layer using a hand tamper hammer having a standard weight of 350g from a free fall height of 150 mm Figure 3-9.



Figure 3-8: First layer of composite in shear box ready for compaction

The soil was compacted and using a metal scraper all the excess material trimmed off from the box, weighed and then subtracted from the total to get the compacted material in shear box prior

to the determination of the density achieved. From the height of 150mm, using the equation below the amount of energy used to compact each layer of the Cape Flats sand can be determined.

$$E = \frac{(B) \times (L) \times (H) \times (DH)}{V}$$

Equation 3-1: Energy used to compact

Which:

B- Number of blows per layer

L- Number of layers

H- Weight of hammer

DH- Height of drop of hammer

V- Volume of mold

The various components used for the shear test are given below in Figure 3-9

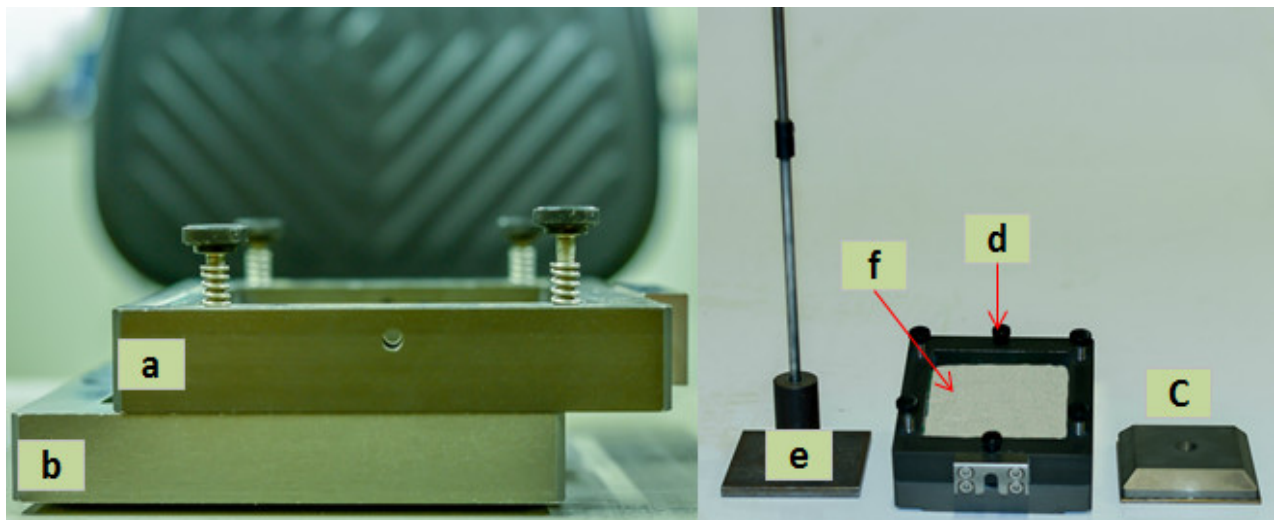
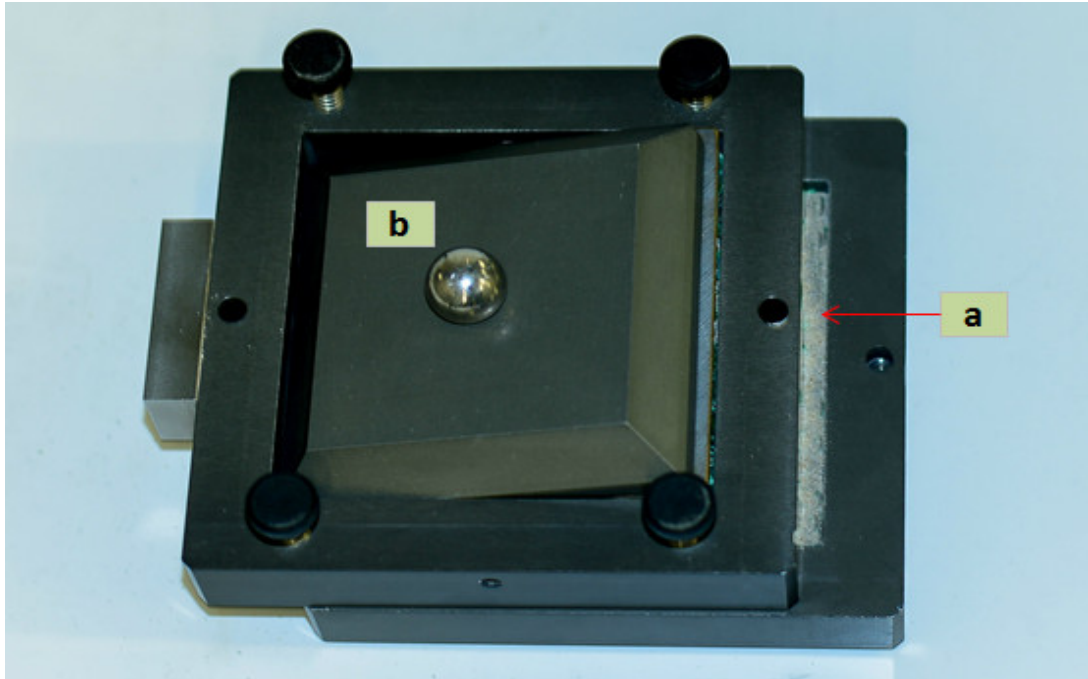


Figure 3-9: Component parts of the shear test for sand/sand: (a) top half shear box and; (b) bottom half shear box; (c) loading plate (top cap); (d) alignment screws; (e) Hand Compactor and (f) Cape Flats sand

After the shear box was filled with sand, a top cap was placed on top of the well-leveled sand surface for the purpose of spreading the applied normal pressure on the sample during the shear test. For each type of sand were prepared and tested at three different normal pressure of 50, 100 and 200 kPa. The compacted test specimen in the shear box is shown below in figure 3-10.



**Figure 3-10:** Prepared test specimen in shear box for pure sand (a) Cape Flats sand and (b) the sealed sample in the shear box with top cap

### 3.5.3 Soil-Shredded Plastic composite

Before compaction of the shredded plastic-soil composite, a mix design was undertaken using the equation below to obtain percentage concentrations.

$$\% \text{Conc.} = \frac{W_p}{W_s} \times 100$$

**Equation 3-2:** Percentage of Concentrations

Where  $W_p$  is the weight of Shredded plastic (g) and;  $W_s$  is the weight of total dry soil (g),

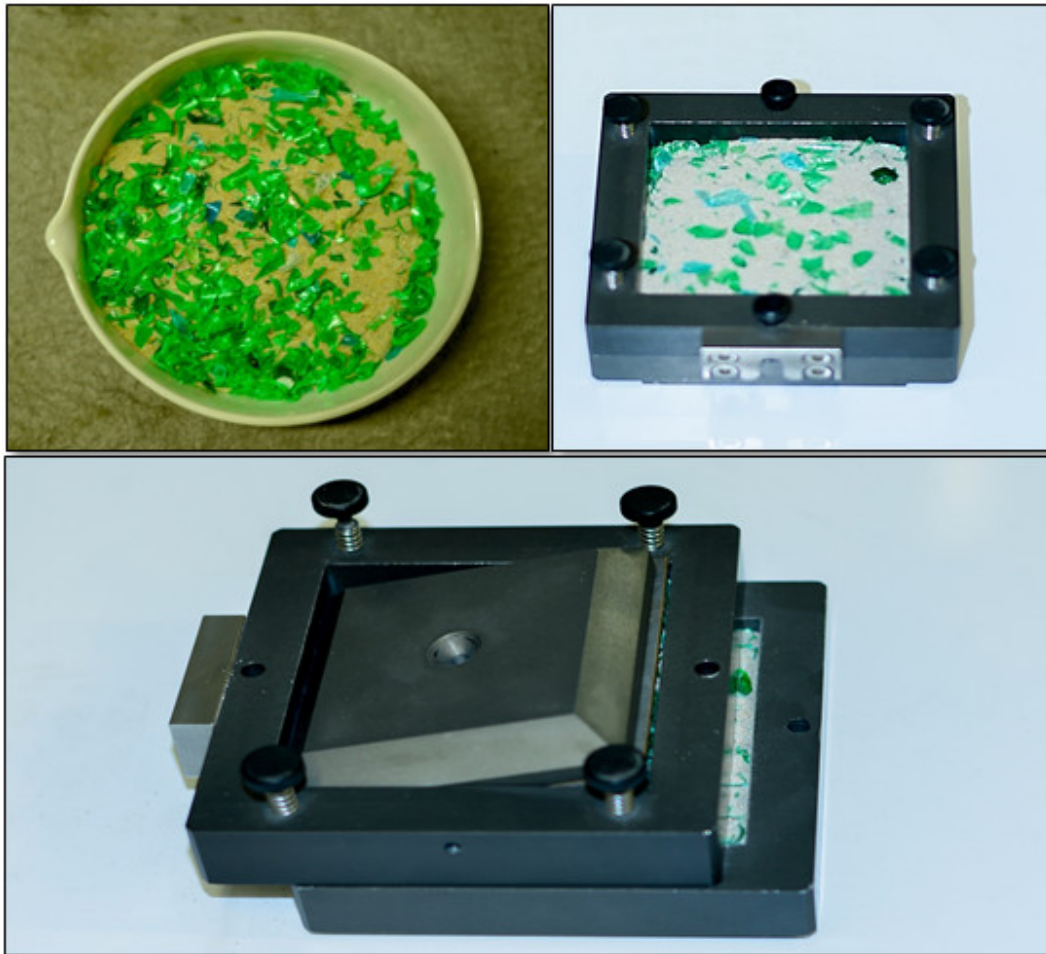
For instance, to get 15% shredded plastic concentration,

$$\% \text{Conc.} = \frac{65g}{435g} \times 100 = 14.94 \approx 15\%$$

**Equation 3-3:** Plastic Concentration

For the above mix design, a shredded plastic content of 2.5%, 5%, 10%, 12.5%, 15% and 20% was used in this study for both the Cape Flats and Klipheuwel sand.

The higher concentration of 20% was used in order to avoid plastic segregation during the tests. The figure 3-12 below shows the compacted sand and sample failure at the end of the test.



**Figure 3-11:** Sample preparation and end results

The two halves shear box were assembled on the standing table using the alignment screws and the plastic shreds sand composite was carefully transferred into the box in layers. Plastic shreds sand composite was prepared for 2.0, 4.75 and 5.6mm shreds size and each layer was compacted using the similar equipment used in the preparation of the pure sand sample. The volume of the specimen in the shear box was determined and consequently its mass and then the density achieved were calculated.

### 3.5.4 Assembly of the apparatus

The direct shear machine was first switched on to allow the assemblage, and then the shear box containing the specimen was pushed in the testing machine bed with the help of the horizontal loading system. Here, it was well positioned and tightened to the ShearTrac-II frame using various screws. The cross bar was lowered on the shear box by the vertical loading system to make careful contact between the vertical load cell and the stainless-steel ball resting symmetrically on the top cap. All the necessary connections including sensors for vertical and horizontal loads and displacements were checked to allow data measurement and recording.

### 3.5.5 Experimental Procedures

The testing commenced with 50kPa load for both the reinforced control test and unreinforced samples after entering the relevant input data for the soil sample as shown in Figure 3-12.

The screenshot shows the SHEAR software interface. The window title is "SHEAR". The menu bar includes "File", "View", "Run", "Calibrate", "Control", "Report", "Options", and "Help". Below the menu bar are several tabs: "Project", "Specimen", "Water Content", "Read Table", "Test Parameters", "Consolidation Table", and "Shear Table". The "Project" tab is selected, displaying a form with the following fields:

Project Number:	<input type="text"/>	Project Name:	<input type="text"/>	Client:	<input type="text"/>
Location:	<input type="text"/>	Depth:	<input type="text"/>	Elevation:	<input type="text"/>
Boring Number:	<input type="text"/>	Sample Number:	<input type="text"/>	Test Number:	<input type="text"/>
Preparation:	<input type="text"/>	Classification:	<input type="text"/>	Group Symbol:	<input type="text"/>
Tester:	<input type="text"/>	Test Date:	<input type="text"/>	Checker:	<input type="text"/>
				Check Date:	<input type="text"/>
Description:	<input type="text"/>		Remarks:	<input type="text"/>	
Comments:	<input type="text"/>				

Figure 3-12: ShearTrac-II software set-up screenshot

A Shearing stress rate was applied by maintaining a constant displacement rate of 1.3 mm/min and the maximum displacement of 50 mm was set for each test. This value of shear rate was obtained from Foose et al. (1996) for shearing plastic chips sand mixtures. After setting the test conditions, a template file was created before running the test to store the generated data.

### 3.5.6 Checklist and Test Procedure

Table 3-11 shows the checklist was used, and all the connections double-checked for the testing process.

**Table 3-11:** Checklist and experimental procedure

<b>Task</b>
Data Capturing
Height above top plate measured
Sample preparation
Loading sample to ShearTrac-II
Enter all testing information
Lower Crossbar
Calibrate the Shear
Consolidate
Remove the alignment screws
Calibrate horizontal LVDT
Shear to maximum displacement
Unload

### 3.5.7 Quality Assurance (QA)

In order to ensure that all the tests conditions were reproduced for each test and quality of the results, several factors were considered as elaborated below;

- All the layers were mixed with new plastic shreds for each test
- The sample preparation was done on the same day of testing
- The repeatability of the experiments testing procedures and results were verified
- No sample was re-used in the testing procedure. A fresh mix of soil and plastic shreds was used in every test.
- Repeatability tests were carried out before commencement of the experimental phase.
- All major research equipment's used were properly calibrated.

### 3.5.8 Data processing and calculation

The data calculation was in form of normal and shear stress, vertical and horizontal displacement with time till maximum displacement achieved.

**Normal Stress,  $\sigma_n$** , defined as the vertical applied pressure on a sample through the vertical loading plate is calculated from the following equation:

$$\sigma_n = \frac{N}{A}$$

Equation 3-4: Normal Stress

Where,

N is normal loading in kN,

A is the sample contact area in m<sup>2</sup> which remained constant throughout the testing.

#### **Shear stress, $\tau$ ,**

Shear stress acts parallel to the plane being considered and develops when applied forces tend to activate resisting forces in the plastic shred sand composite. It is computed from the following equation:

$$\tau = \frac{F}{A} \text{ (kN/m}^2\text{)}$$

Equation 3-5: Shear Stress

Where;

F is shearing load applied to one half of the sample in a horizontal direction while the other is restrained A, is the shear contact area which is the same as above (m<sup>2</sup>).

The inbuilt software generated the test data which was then analyzed to obtain stress strain curves and corresponding peak shear stress values for each test, the below picture shows an example from Cape Flats sands with 4.75mm plastic shred content.

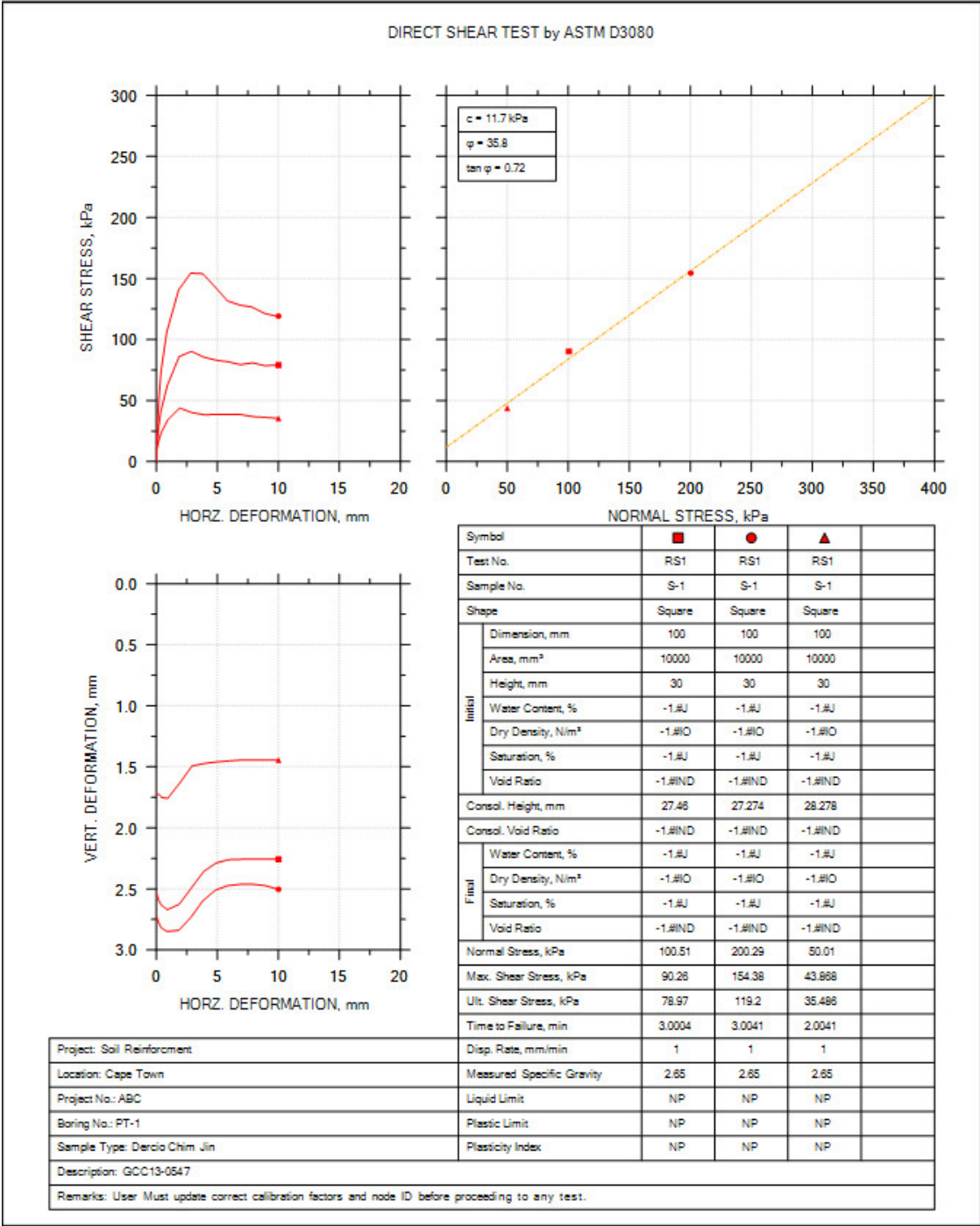


Figure 3-13: Software generated the test data

## 4 RESULTS, ANALYSIS AND DISCUSSIONS

### 4.1 Introduction

This chapter discusses the direct shear results conducted on Cape Flats sand and Klipheuwel sand reinforced with different concentrations of shredded plastic material. The results were presented in the manner to interpret the effects of shredded plastic on shear strength parameters of the selected soil.

### 4.2 Repeatability of results

Three tests were replicated test for cape flats sands reinforced with 2.5% plastic shreds and tested at 100kPa. The peak shear stress ranged from 75.82kPa to 77.58kPa with an average of 76.7kPa. All the tests peaked almost at the same horizontal displacement (2.9mm) and similar maximum shear stress. Experiments, 1, 2 and 3 exhibited the maximum shear stress of 76.05kPa, 76.07kPa, 76.1kPa respectively and peaked horizontal displacement of 2.89mm, 2.9mm and 2.91mm respectively. Based on these results, it was confirmed the methods and procedures used to run the shear strength tests generated repeatable results.

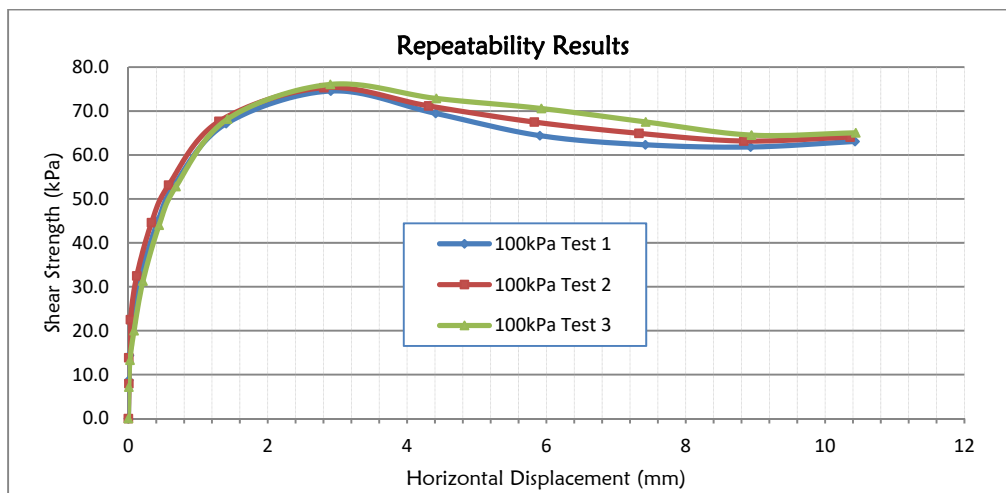


Figure 4-1: Repeatable results for three samples tested at 100 kPa

A maximum of 5% deviation was the target maximum in this research as the deviation was within the acceptable range, the repeatability results were analyzed and are presented in Table 4-1.

**Table 4-1: Repeatability results computations**

Test	Peak Strength	Mean	Deviation	Ultimate Strength (kPa)	Mean	Deviation
1	74.57		-1.01%	63.08		-1.57%
2	75.32	75.32	0	64.07	64.07	0
3	76.07		0.99%	65.06		1.52%

### 4.3 Control test results and discussion

Control tests were conducted in Cape Flats sands in order to determine the extent of shear strength improvement, unreinforced soil, and mean sand/sand in dry conditions. To obtain apparent cohesion and angle of internal friction, each one of the tests was repeated at normal pressures of 50, 100 and 200kPa. The results are analyzed in sub-section below.

- Soil at Dry State

Figure 4-2 presents the results from test done on the unreinforced sand. It should be noted that Cape Flats sands and Klipheuwel sand were compacted before shearing. A 1.0mm/min rate of shear was allowed up to a maximum displacement of 10mm. These parameters are shown in figure 3-13 above.

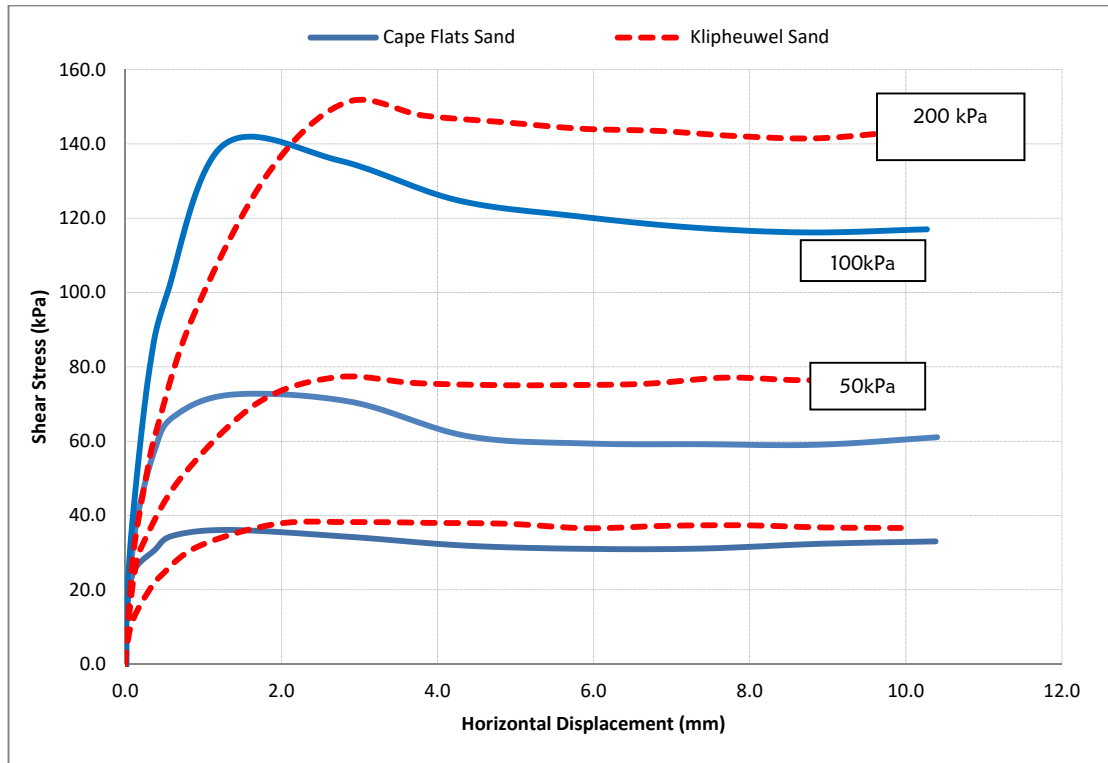


Figure 4-2: Control Test results

**Cape Flats Sand:** For normal pressures of 50kPa, 100kPa and 200kPa at peak stress, Cape Flats sand was found to have a displacement of about 1.8mm, 1.9mm and 2mm respectively. The corresponding peak stress for each displacement was 40kPa, 74.5kPa and 133kPa.

**Klipheuwel Sand:** At 50kPa, the peak stress was 42.95kPa at displacement 2.3mm. The peak stress at this normal pressure was slightly higher than for Cape Flats sand; however at 100kPa, the peak stress was same as Cape Flats at displacement of 2.0mm. Cape Flats sand showed a much lower peak stress than Klipheuwel sand at all normal pressures.

The Klipheuwel sands produced smooth curve while the Cape Flats sand and it was observed an increase in the rate of development of shear stress with displacement as the normal pressure increased.

#### **4.4 Direct Shear results on plastic shreds-soil composite**

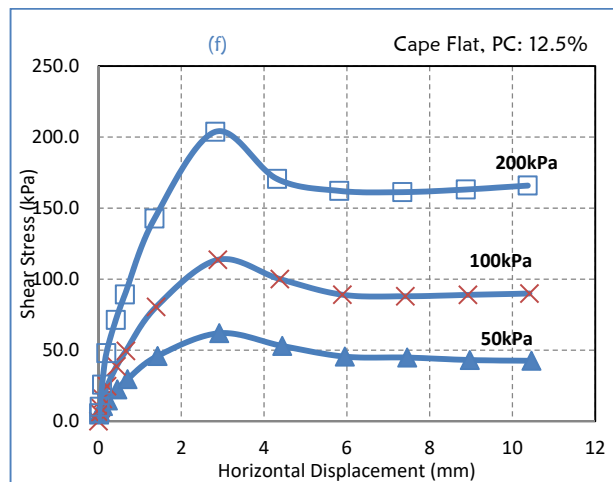
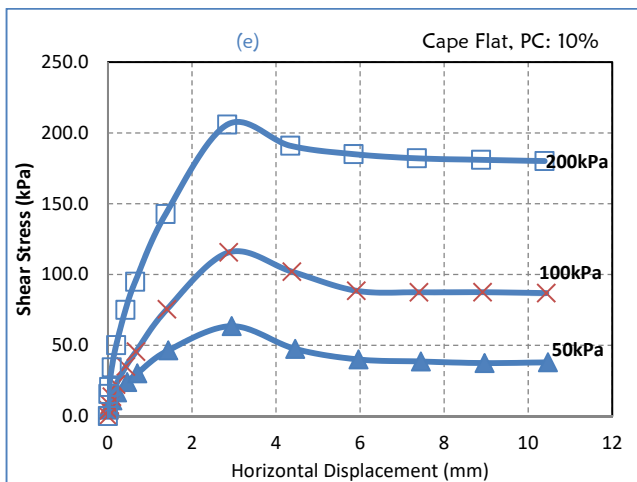
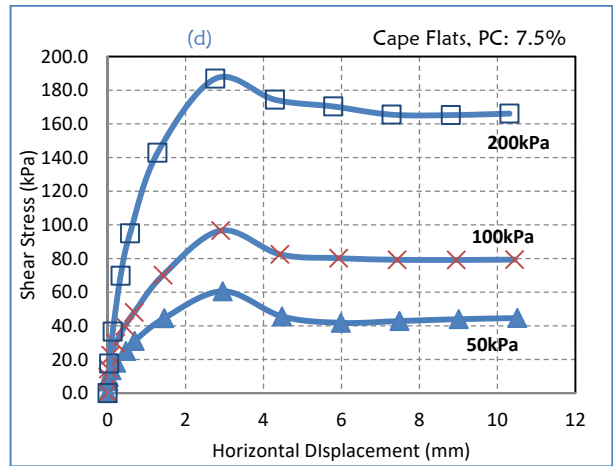
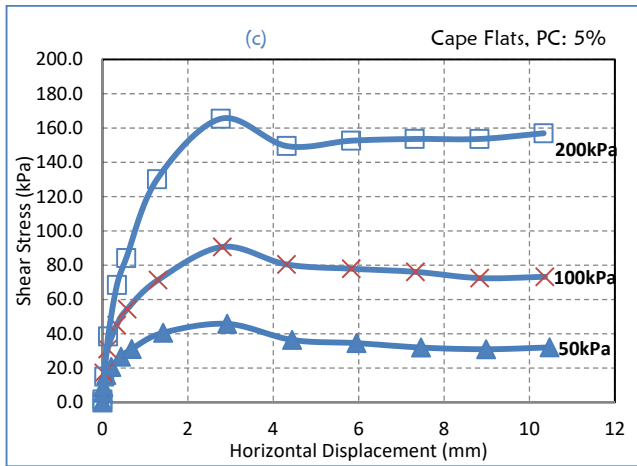
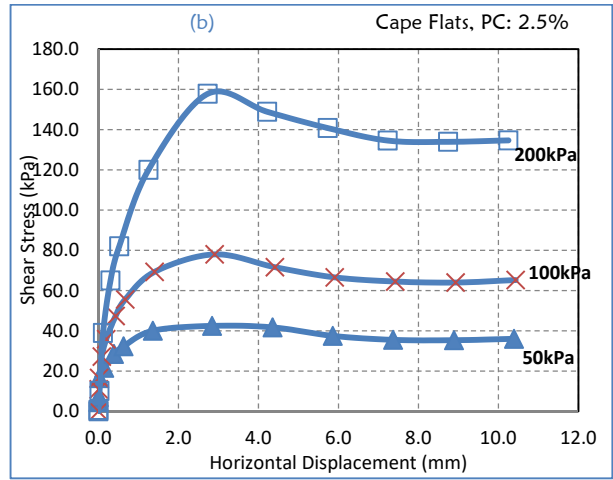
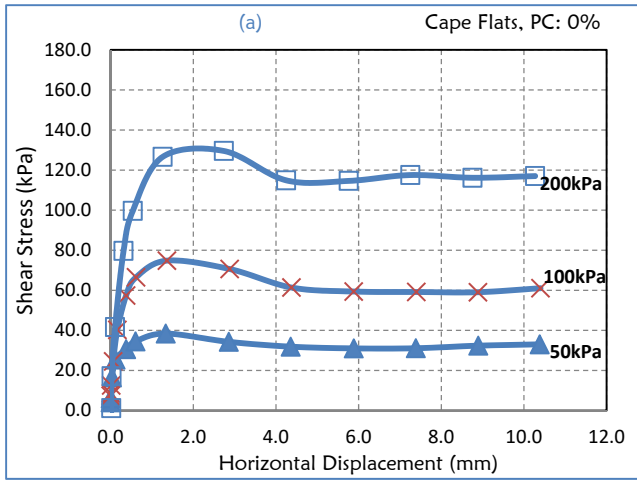
##### **4.4.1 Shear stress-displacement response for 2.0mm plastic shreds**

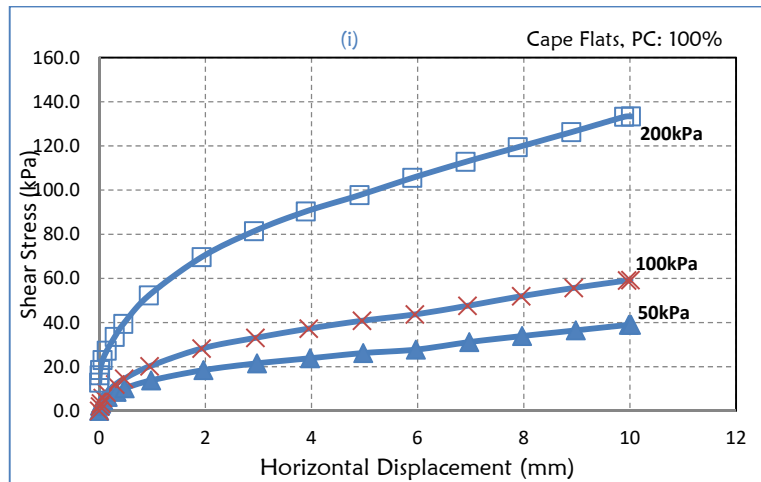
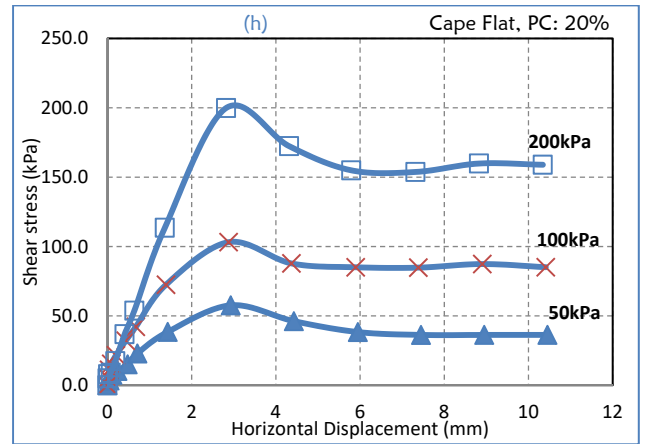
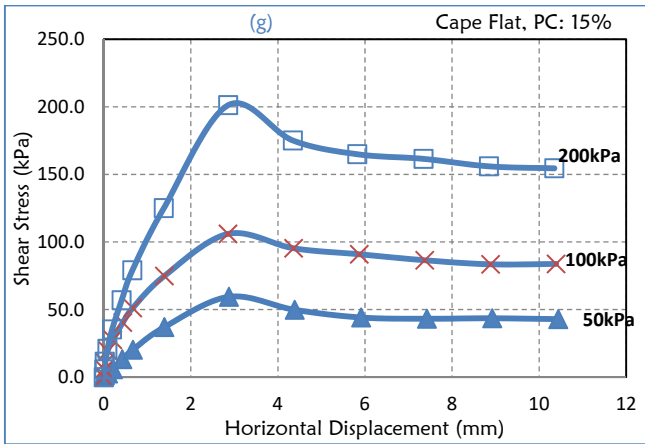
Figure 4-3 (a-i) and Figure 4-4 (a-g) presents the results from plastic shreds with Cape Flats sand and Klipheuwel sand composites obtained from direct shear tests. At all applied stresses the maximum shear stresses were recorded and presented in Table 4-1.

Initially the shear stress development from unreinforced sands was analyzed. It was seen from Figure 4-3 (a) and Figure 4-4 (a) (0% plastic shreds content with sand only) that Cape Flats sand exhibited lower peak shear stress than Klipheuwel sand. This was due to the fact that Klipheuwel sand is well-graded sand with some little fines and whereas Cape Flats Sand was found to be uniformly distributed sand ranging from medium to fine.

As shown in result graphs presented, for unreinforced sand the increased applied vertical confining pressures resulted in the maximum shear stress and all the results showed a pronounced peak. Furthermore, it is possible that an increase in vertical stress plane contributed to an increased degree of contact between sand particles, which in turn increased the shear resistance within the shear plane.

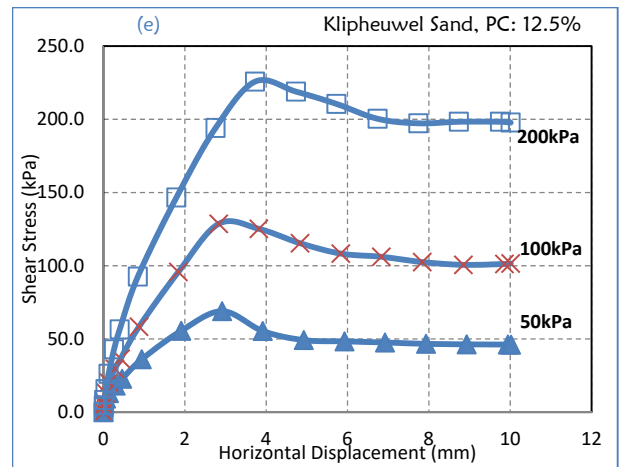
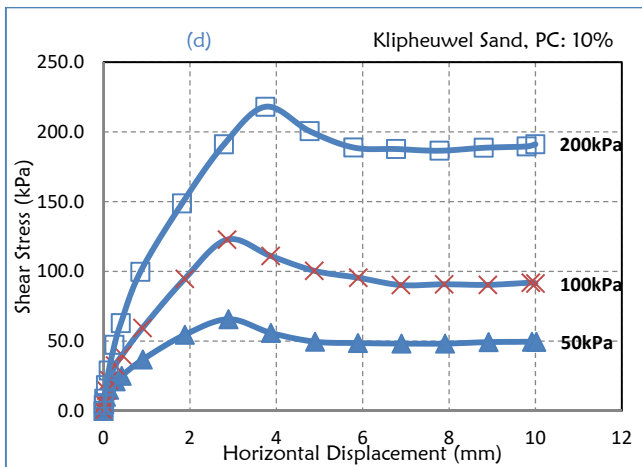
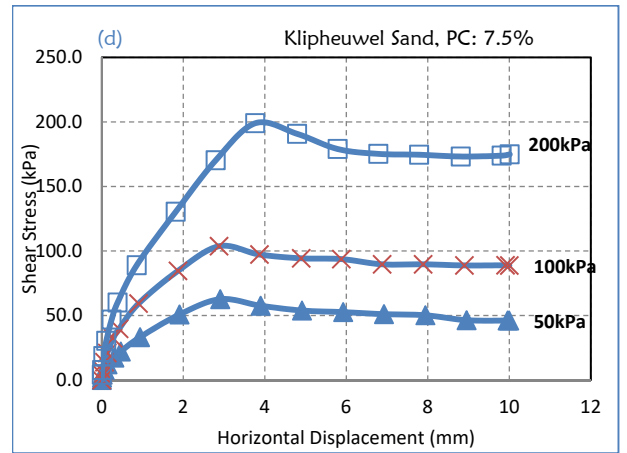
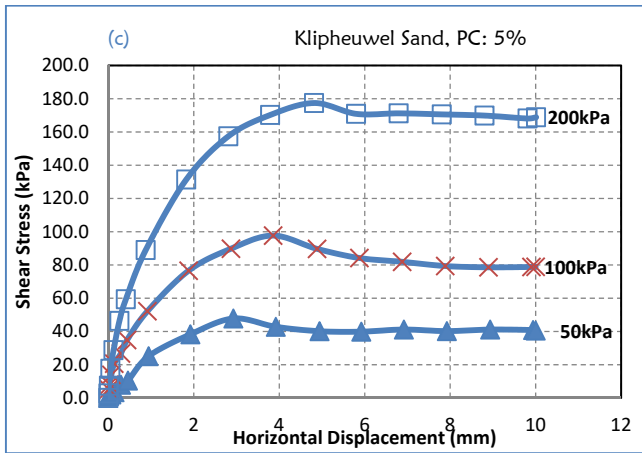
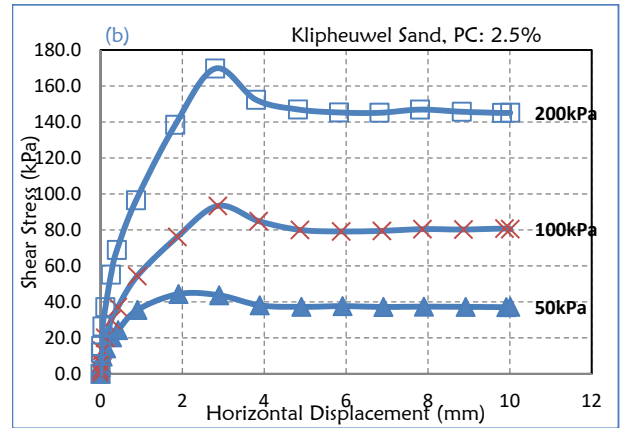
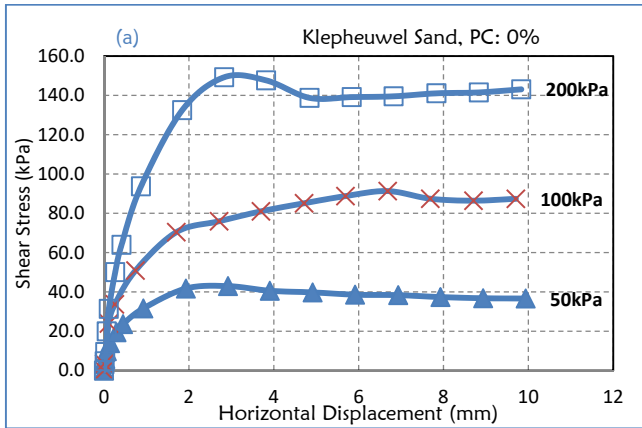
### Cape Flats Sand 2.0 mm

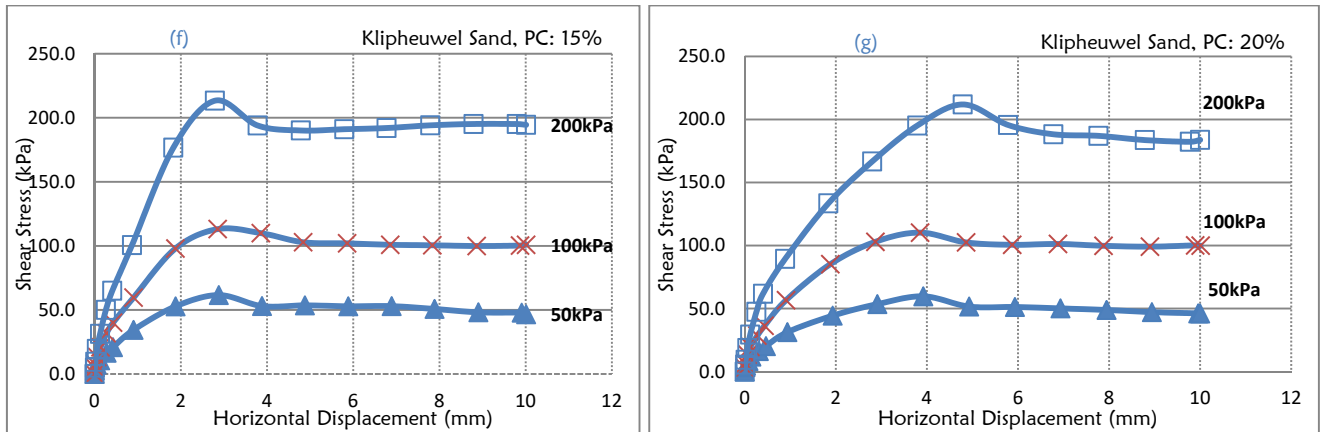




**Figure 4-3 :** Shear stress versus horizontal displacement for Cape Flats mixed with plastic Shred size of 2.0 mm at Plastic shred content of (a) unreinforced sand (0%), (b) 2.5, (c) 5, (d) 7.5, (e) 10, (f) 12.5, (g) 15 and (h) 20% by dry weight as well as (i) pure plastic shreds (100%)

### Klipheuwel Sand 2.0 mm





**Figure 4-4:** Shear stress versus horizontal displacement and vertical displacement against horizontal displacement for Klipheuwel sand mixed with Plastic shreds of the size 2.0 mm at Plastic shreds content of (a) unreinforced sand (0%), (b) 2.5, (c) 5, (d) 7.5, (e) 10, (g) 15, and (h) 20% by dry weight.

**Table 4-2:** Peak shear stresses for 2.0 mm Plastic Shreds

2.0mm						
Plastic % Content	Peak shear stresses (kPa)					
	Cape Flats Sand			Klipheuwel Sand		
	50kPa	100kPa	200kPa	50kPa	100kPa	200kPa
0.0	36.1	72.5	139.7	38.2	77.2	151.2
2.5	42.5	78.0	157.8	44.4	93.4	169.7
5.0	45.8	90.7	165.4	47.8	97.7	177.4
7.5	60.5	96.6	186.9	62.6	103.7	199.0
10.0	63.5	115.6	205.9	65.7	122.8	218.0
12.5	62.0	113.7	203.7	69.0	128.7	225.7
15.0	59.5	106.0	201.2	61.6	113.1	213.4
20.0	57.7	103.2	199.9	59.7	110.2	211.9
100.0	39.0	59.2	133.4	39.0	59.2	133.4

A considerable change in shear stress results was found to be influenced by the amount of plastic shreds added to sand. Generally, the addition of plastic to both Cape Flats and Klipheuwel sands improved their maximum shear stress up to an optimum dosage beyond which there was a drop.

The Cape Flats sand reinforced with 2.5% plastic shreds showed an improvement in its shear stresses at all the different normal pressures, the maximum shear changed from 36.1kPa to 42.5kPa for unreinforced and reinforced sand respectively at a normal pressure of 50kPa

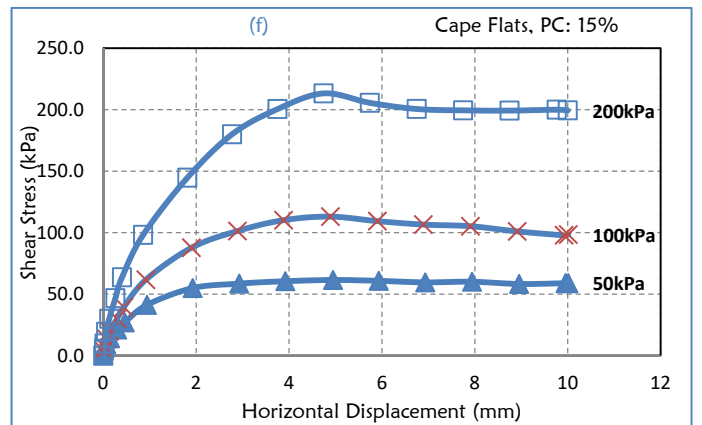
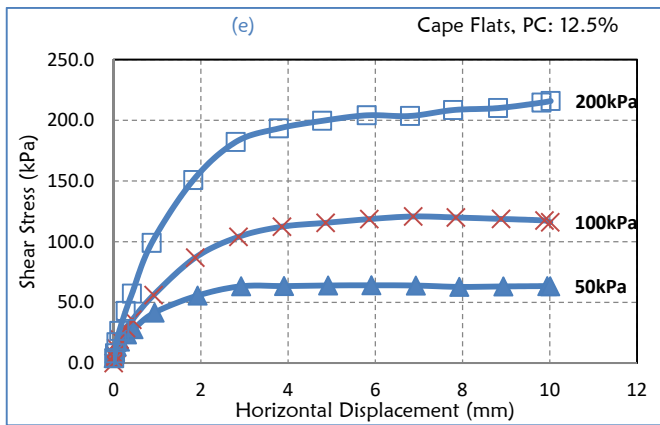
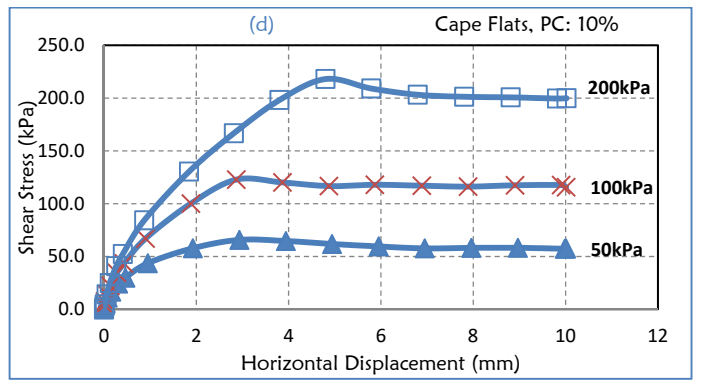
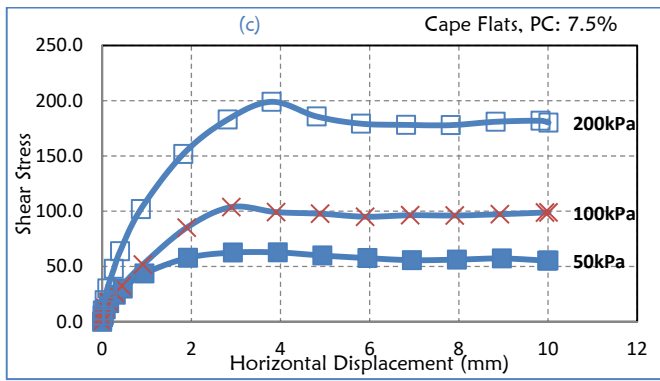
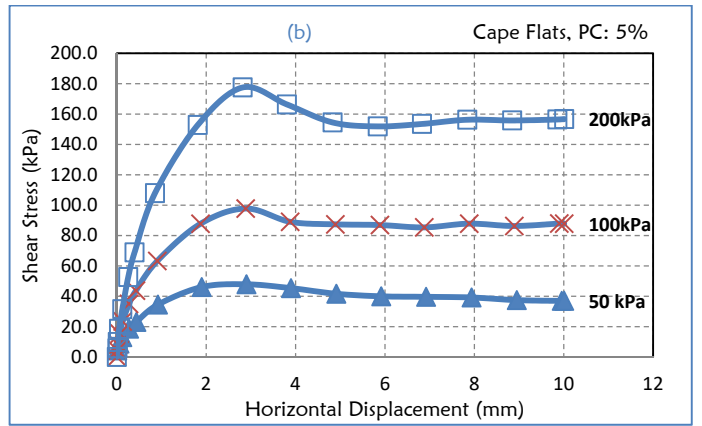
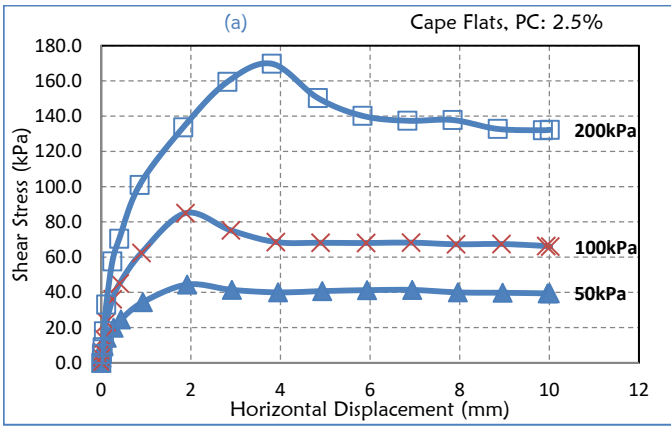
The increase in the amount of plastic shreds in the composite resulted in higher peak stresses up to an optimum content.

In the Cape Flats sand, the optimum plastic shred content for all applied normal pressures was 10% while for Klipheuwel sand composite and the optimum dosage was 12.5%. It is likely that the increased plastic shred content and normal loading enhanced the degree of interlock within the sample thereby contributing to the improved peak shear stress of the composite.

#### **4.4.2 Shear stress-displacement response for 4.75mm plastic shreds**

As with 2.0mm plastic shreds, both Cape Flats and Klipheuwel sands were mixed with 4.75mm plastic shreds with same plastic concentrations such as 2.5, 5, 7.5, 10, 12.5, 15 and 20%. The results are presented in the graphs in Figure 4-5.

### Cape Flats Sand 4.75mm



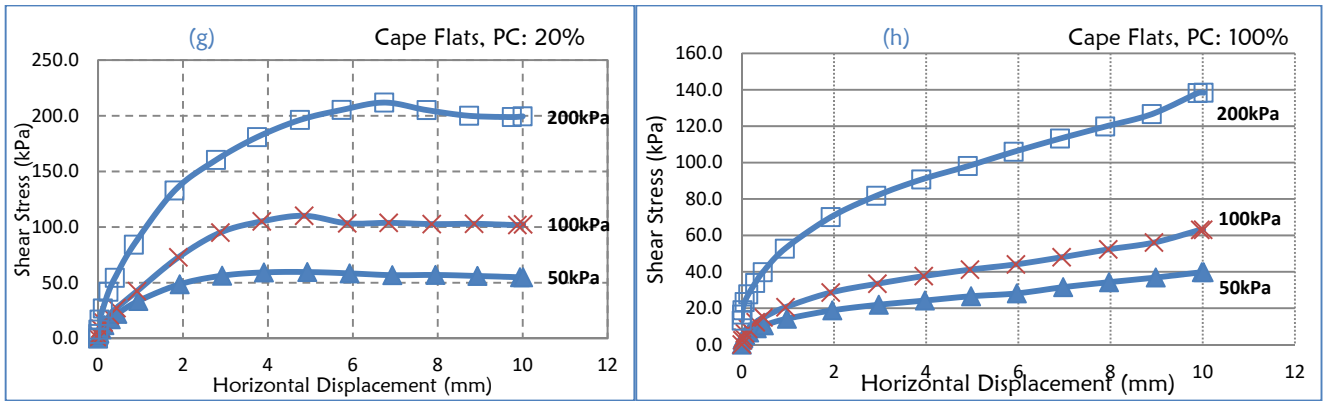
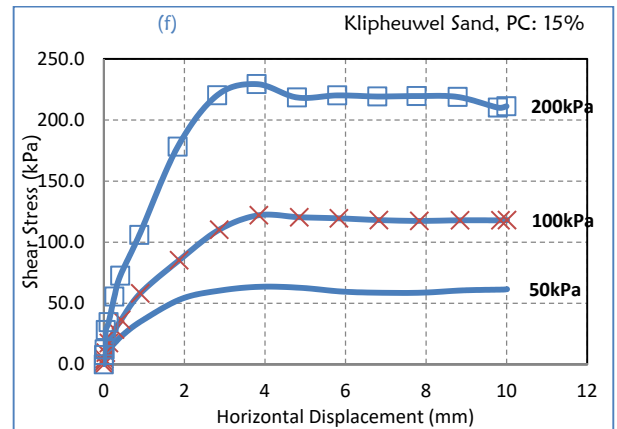
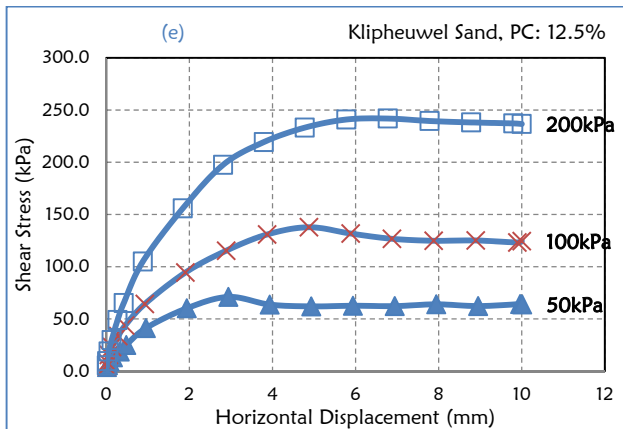
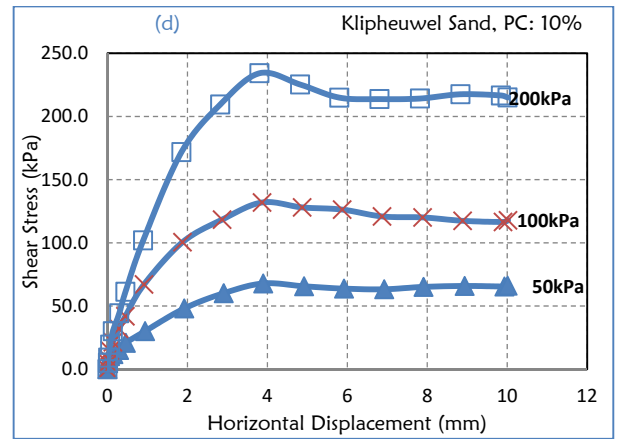
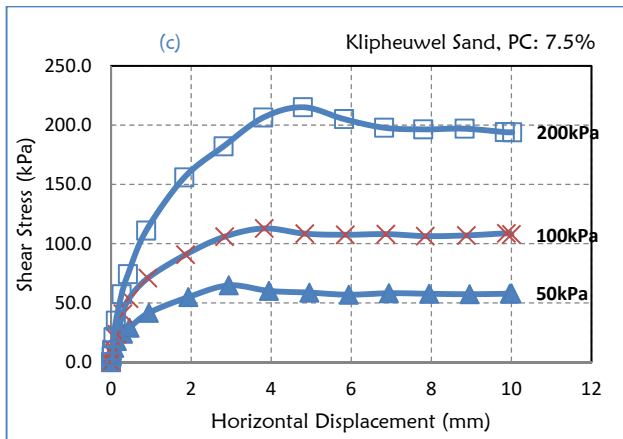
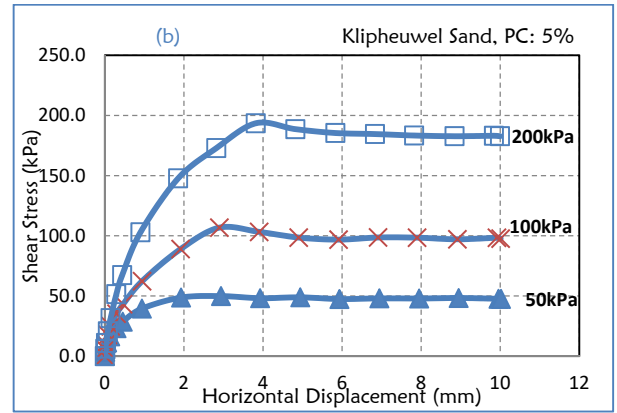
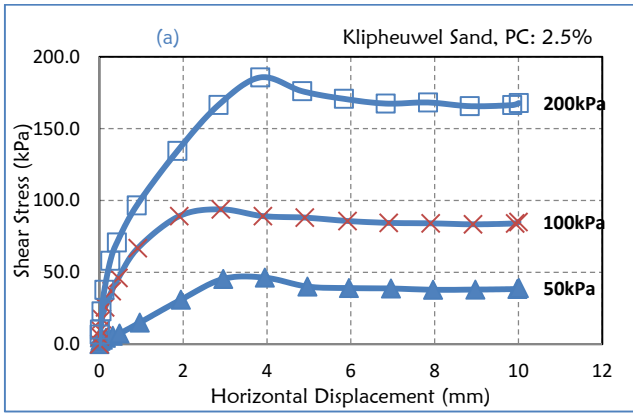
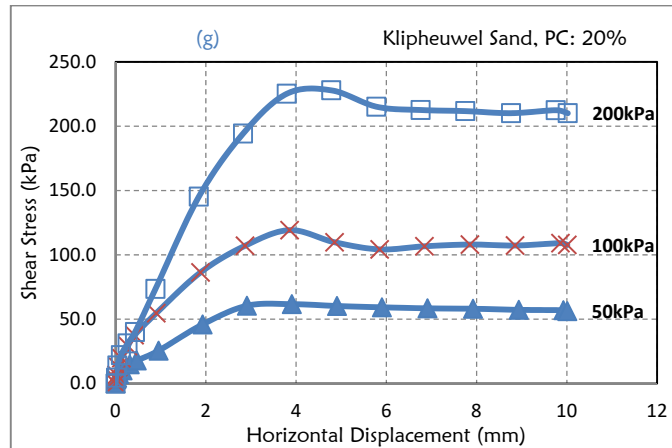


Figure 4-5: Shear stress versus horizontal displacement and vertical displacement against horizontal displacement for Cape Flats sand mixed with Plastic shreds of the size 4.75 mm at Plastic shreds content of (a) 2.5, (b) 5, (c) 7.5, (d) 10, (e) 12.5, (f) 15, (g) 20 and (h) 100% by dry weight.

### KLIPHEUWEL SAND 4.75mm





**Figure 4-6:** Shear stress versus horizontal displacement and vertical displacement against horizontal displacement for Klipheuwel sand mixed with Plastic shreds of the size 4.75 mm at Plastic shreds content of (a) 2.5 , (b) 5, (c) 7.5, (d) 10, (e) 12.5 (f) 15, and (g) 20% by dry weight.

**Table 4-3:** Peak shear stresses for 4.75mm Plastic Shreds

4.75mm						
Plastic % Content	Peak shear stresses (kPa)					
	Cape Flats Sand			Klipheuwel Sand		
	50kPa	100kPa	200kPa	50kPa	100kPa	200kPa
0.0	36.1	72.5	139.7	38.2	77.2	151.2
2.5	44.4	85.0	169.8	46.3	93.9	185.7
5.0	47.9	97.8	177.5	49.9	106.8	193.5
7.5	62.7	103.7	199.0	64.8	112.8	215.1
10.0	65.7	122.8	218.0	67.9	132.0	234.2
12.5	64.1	120.8	215.9	71.1	137.8	241.9
15.0	61.5	113.0	213.2	63.6	122.1	229.4
20.0	59.7	110.2	211.9	61.7	119.2	227.9
100.0	39.8	63.1	138.4	39.8	63.1	138.4

As observed in plastic shred-sand composite containing 2.0mm plastic shred, the addition of plastic shreds to sand enhanced its shear stress. The peak stress increasing up to a maximum value as the amount of plastic shred increased. These maximum shear stresses and optimum shred dosages for each applied normal pressures are presented in Table 4-3.

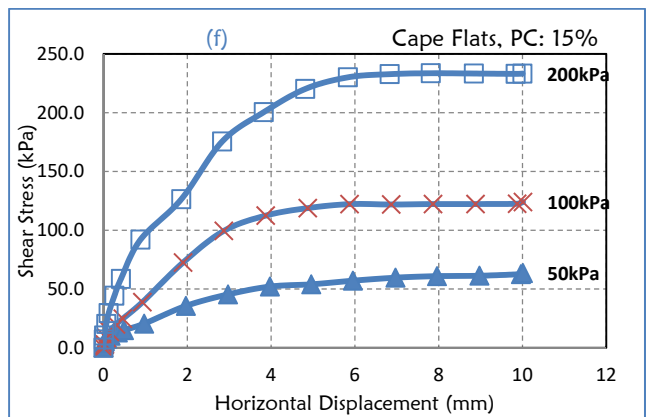
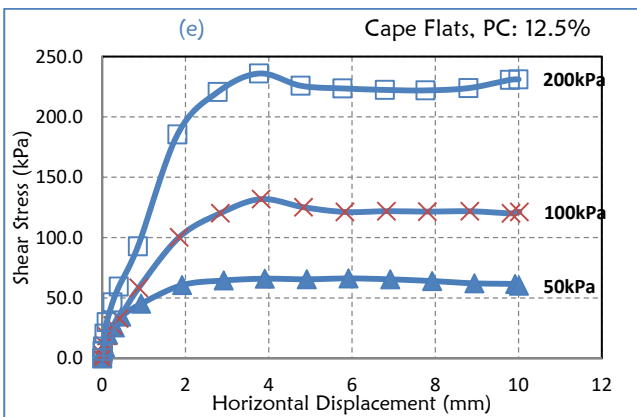
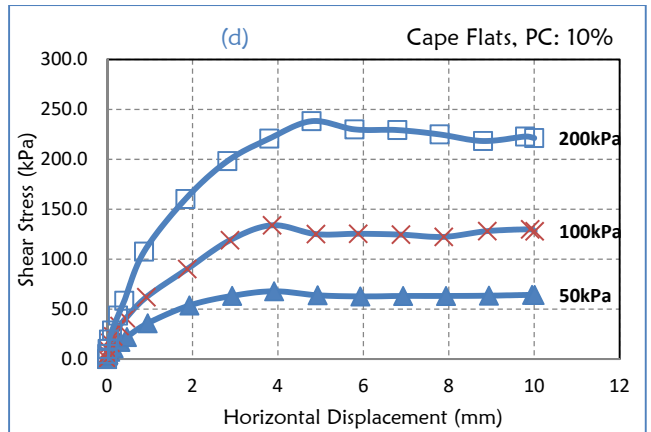
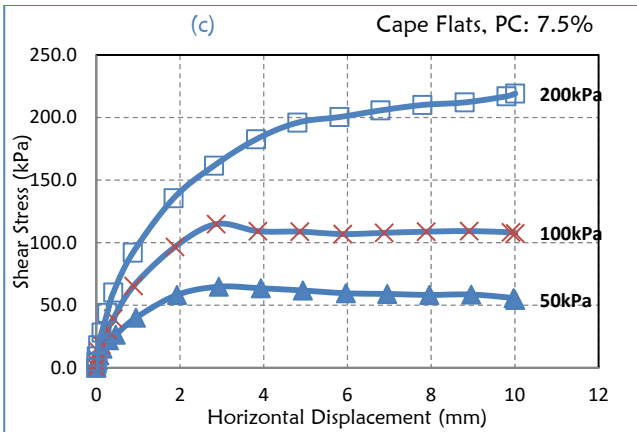
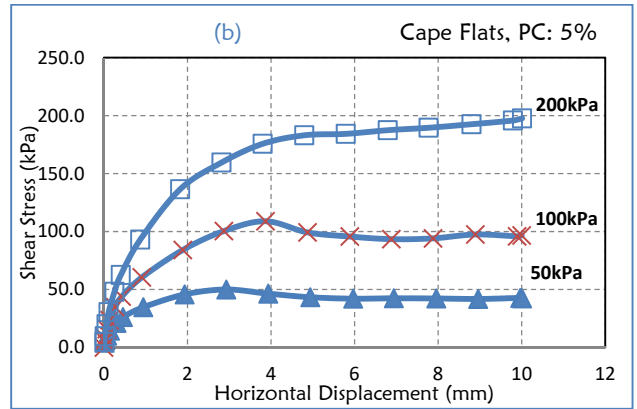
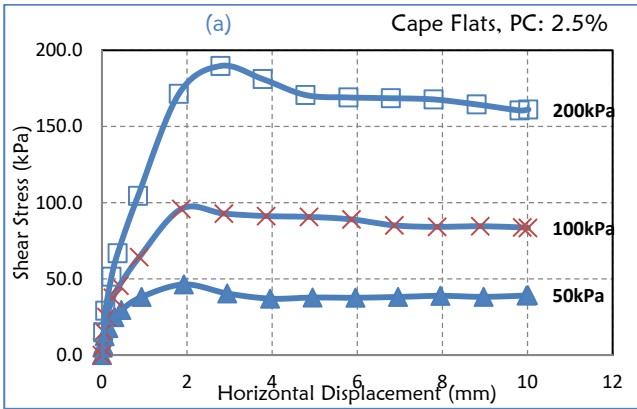
The normal shear stress development for 2.0 mm plastic shred was analyzed in comparison to that observed in 4.75 mm plastic shreds composite. Table 4-2 & 4-3 shows the shear stress development from 4.75mm plastic shred-sand mixture is higher compared to that observed from 2.0mm plastic shred-sand samples for the two types of sand. The difference in improvement may be attributed to the long plastic shreds which had the larger contact area with sand. These long randomly distributed plastic shreds in sand acted as anchors in the shear zone and thus increased the shear resistance compared to the smaller plastic shreds.

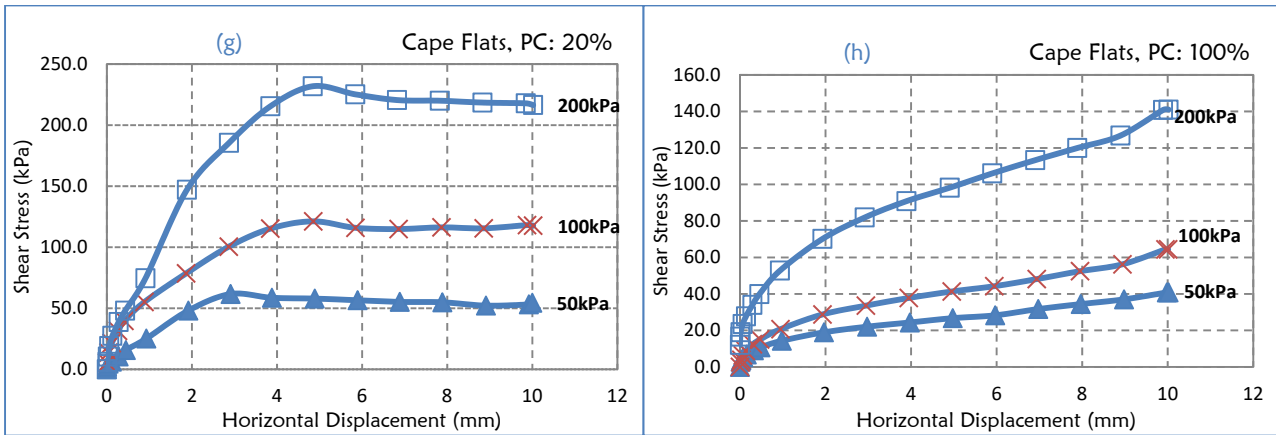
The shear stress improvement from unreinforced sand and shreds dosage of 2.5, 5, 7.5, 10, 12.5, 15 and 20% in Cape Flats sand at a vertical pressure of 50 kPa were 36.1 kPa, 44.4 kPa, 47.9 kPa, 62.7, 65.7, 64.1, 61.5 and 59.7 kPa respectively. The same trend was observed in plastic shred-Klipheuwel sand composite. The values of peak shear stresses obtained from this particular size of plastic shreds are given in Table 4-3.

#### **4.4.3 Shear stress-displacement response for 5.6 mm plastic shreds**

As the plastic shred increased in size, the peak shear stress and residual shear stress for both sands increased with a similar response as from 2.0mm and 4.75mm plastic shreds. Again, at low normal pressures, the effect of varying size of the shreds was not significant. However, at high normal pressures and reinforcement with plastic content of 2.5%, Klipheuwel composite was observed to have an improvement of 26.3% in peak shear stress while that for Cape Flats composite was up to 28.4%.

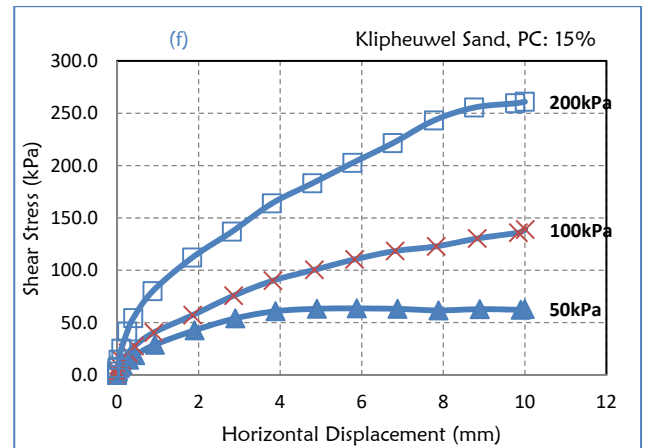
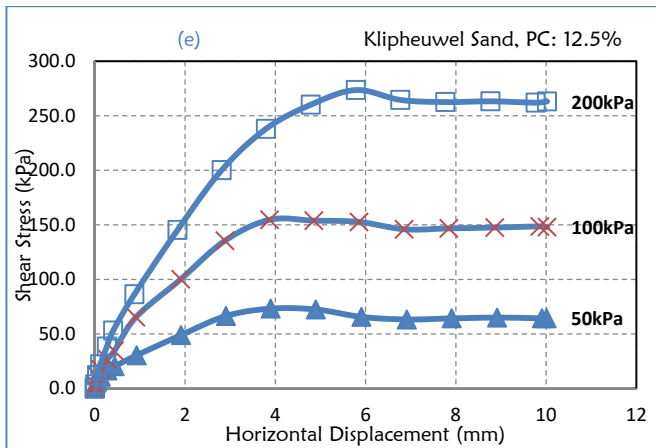
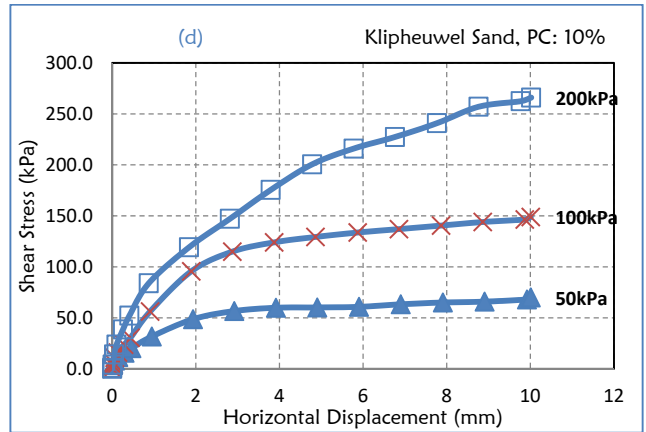
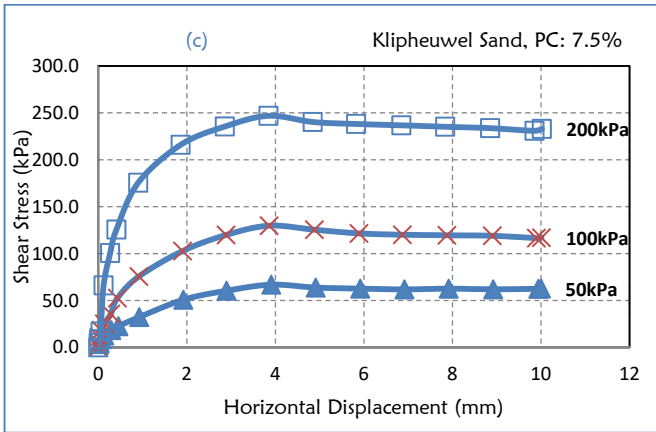
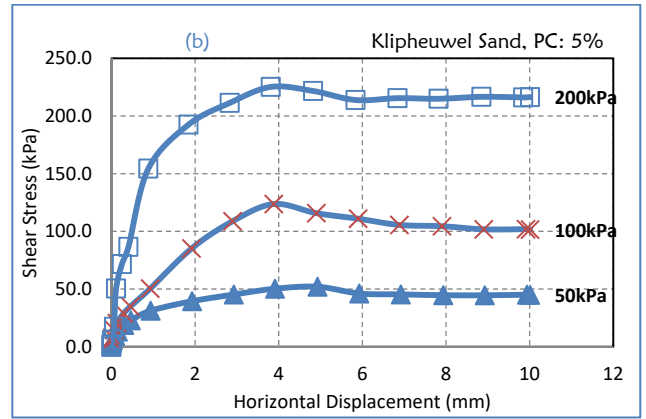
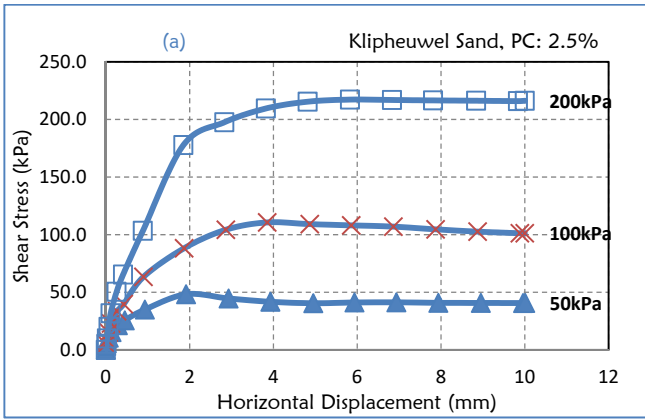
CAPE FLATS SAND 5.6mm

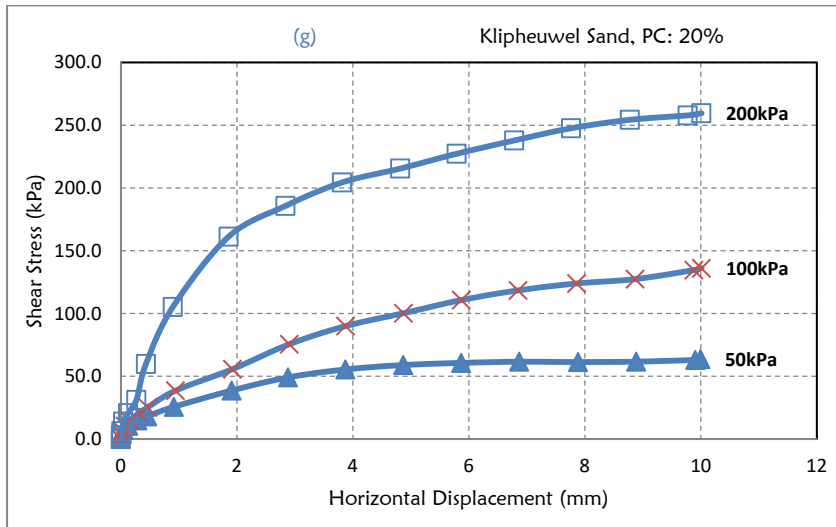




**Figure 4-7:** Shear stress versus horizontal displacement and vertical displacement against horizontal displacement for Cape Flats sand mixed with Plastic shreds of the size 5.6 mm at Plastic shreds content of (a) 2.5, (b) 5, (c) 7.5, (d) 10, (e) 12.5, (f) 15, (g) 20 and (h) 100% by dry weight.

### KLIPHEUWEL SAND 5.6mm





**Figure 4-8:** Shear stress versus horizontal displacement and vertical displacement against horizontal displacement for Cape Flats sand mixed with Plastic shreds of the size 5.6 mm at Plastic shreds content of (a) 2.5, (b) 5, (c) 7.5, (d) 10, (e) 12.5, (f) 15 and (g) 20% by dry weight.

**Table 4-4:** Peak shear stresses for 5.6mm Plastic Shreds

5.6mm						
Plastic % Content	Peak shear stresses (kPa)					
	Cape Flats Sand			Klipheuwel Sand		
	50kPa	100kPa	200kPa	50kPa	100kPa	200kPa
0.00	36.11	72.52	139.72	38.22	77.22	151.20
2.50	46.38	95.92	189.71	48.28	110.62	217.21
5.00	49.99	108.88	197.62	51.99	123.68	225.22
7.50	64.80	114.86	219.15	66.90	129.76	246.85
10.00	67.90	133.98	238.22	70.05	148.93	265.97
12.50	66.21	131.90	235.98	73.21	154.70	273.58
15.00	63.47	124.01	233.56	63.59	138.93	260.97
20.00	61.65	121.18	231.85	63.70	136.03	259.50
100.00	40.84	64.47	141.02	40.84	64.47	141.02

## **4.5 Coulomb failure envelope for PET chips sand mixtures**

The relationship between maximum shear stress and applied normal pressure which is the Mohr-Coulomb failure envelope from the test result data is discussed in this subsection.

The maximum shear stresses samples were tested at three different normal pressures such as 50, 100 and 200 kPa which were used to plot Coulomb failure envelope line. The inclination of the failure envelope to the horizontal axis represents the slope which gives the internal angle of friction ( $\phi'$ ) while the intercept on the vertical axis gives the apparent cohesion ( $c'$ ).

### **4.5.1 Shear Strength response for 2.0mm plastic shred.**

Figure 4-9 presents the Mohr-Coulomb failure envelope of Cape Flats sand and Klipheuwel sand at reinforced with 0% to 20% of plastic shreds by dry weight soil. The angle of internal friction obtained from unreinforced sand (0%) was  $34.53^\circ$  and  $36.92^\circ$  for Cape Flats sand and Klipheuwel sand, respectively. The results showed that Klipheuwel sand had higher angle of internal friction than that of Cape Flats sand. This difference was attributed to high degree of interlocking within Klipheuwel sand particles because of high coefficient of uniformity of ( $C_u=4.21$ ) compared to that of Cape Flats sand ( $C_u=2.37$ ).

At various concentrations of plastic shreds, the friction angle obtained increased up to maximum concentrations of plastic for both sandy soils and then reduced. At 2.5% plastic shred content, the angle of internal friction of Cape Flats and Klipheuwel sand was  $34.53^\circ$  and  $36.92^\circ$  respectively.

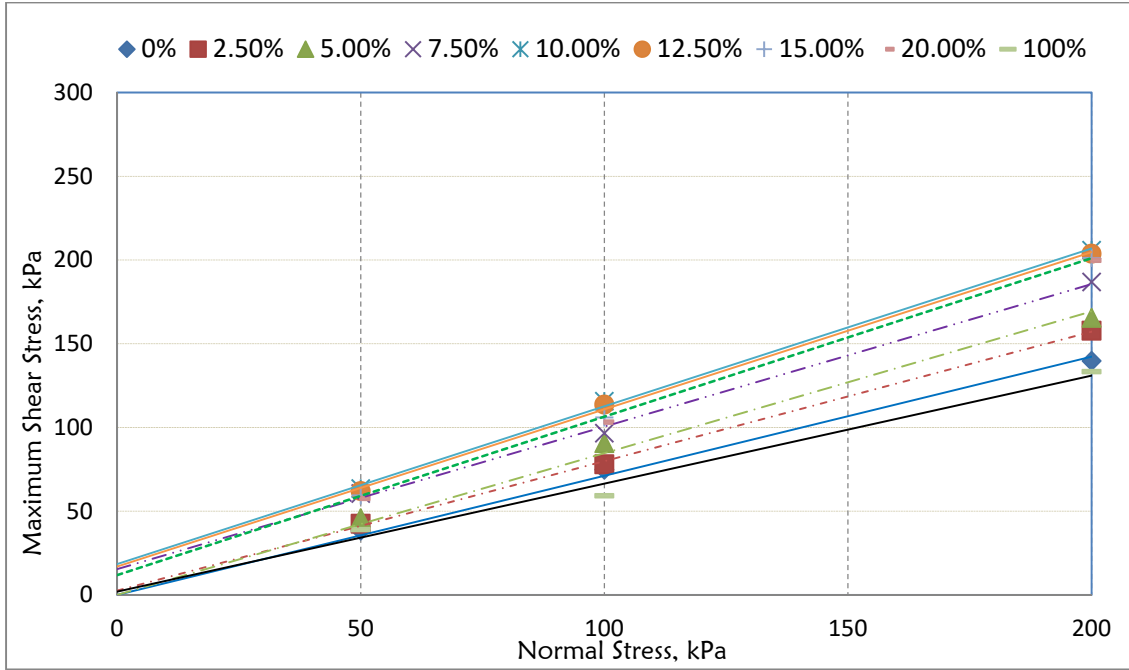


Figure 4-9: Relationship between the maximum shear stress and normal applied pressure for 2.0 mm plastic shred inclusion in Cape Flats sand

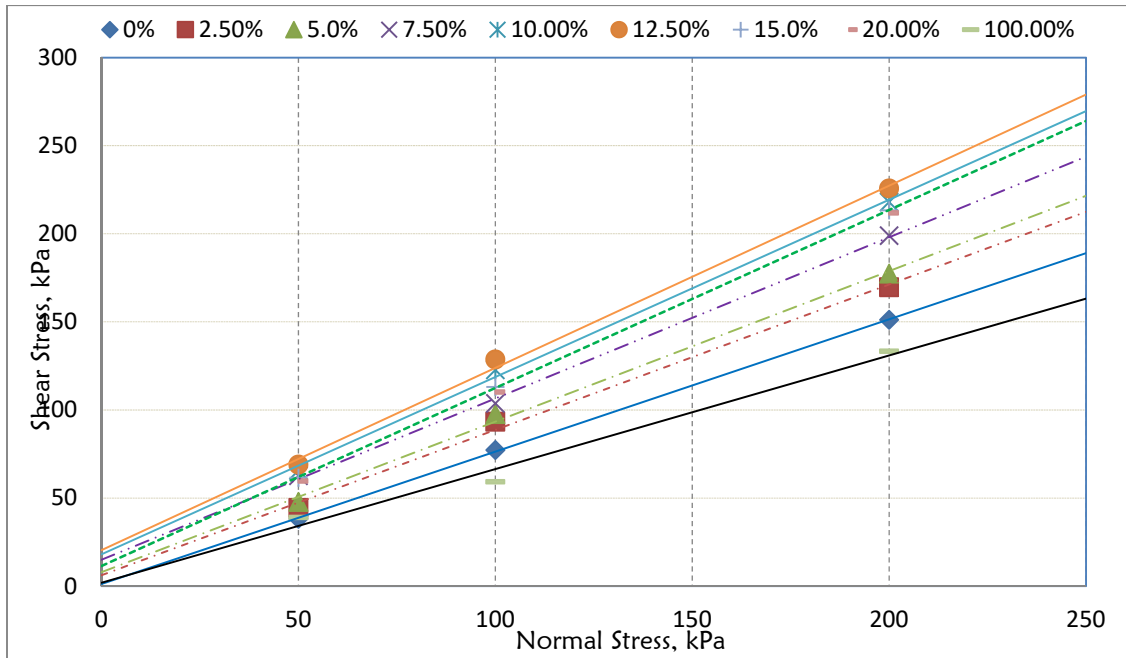


Figure 4-10: Relationship between the maximum shear stress and normal applied pressure for 2.0 mm plastic shred inclusion in Klipheuwel sand.

**Table 4-5:** Shear strength parameters (friction angle and cohesion) obtained from plastic shreds unreinforced sand and plastic shred sand composites for 2.0mm shreds.

Plastic Sherds (%)	2.0mm					
	Cape Flats			Klipheuwel Sand		
	C	$\phi$	% Increase	C	$\phi$	% Increase
0.0	2.50	34.53		1.22	36.92	
2.50	2.56	37.71	9.20	1.96	39.94	8.17
5.00	8.42	38.32	10.98	7.92	40.52	9.75
7.50	15.40	40.40	16.99	14.99	42.46	15.01
10.00	18.42	43.30	25.38	18.07	45.19	22.38
12.50	16.93	43.19	25.09	20.43	45.97	24.51
15.00	11.84	43.42	25.74	11.46	45.30	22.69
20.00	9.32	43.55	26.12	8.87	45.42	23.03
100.00	1.91	32.84	-4.90	1.91	32.84	-11.05

#### 4.5.2 Shear strength response for 4.75 mm plastic shred

The relationship between shear stress and normal stress was also plotted and analyzed for 4.75mm plastic shreds in Cape Flats and Klipheuwel sands. The lines of the best fit were drawn to show the Coulomb failure envelopes.

In Figure 4-11 and Figure 4-12 the shear stress and normal applied pressure are presented and summarized in Table 4-6. Using the same concentrations used with 2.0mm plastic shreds, the shear strength increased.

All dosages considered in the cohesionless sands showed improvement of apparent cohesion. The maximum values of 45.19 kPa and 48.35 kPa were reached at shred content of 10 and 12.5% respectively for Cape Flats sand and Klipheuwel sands.

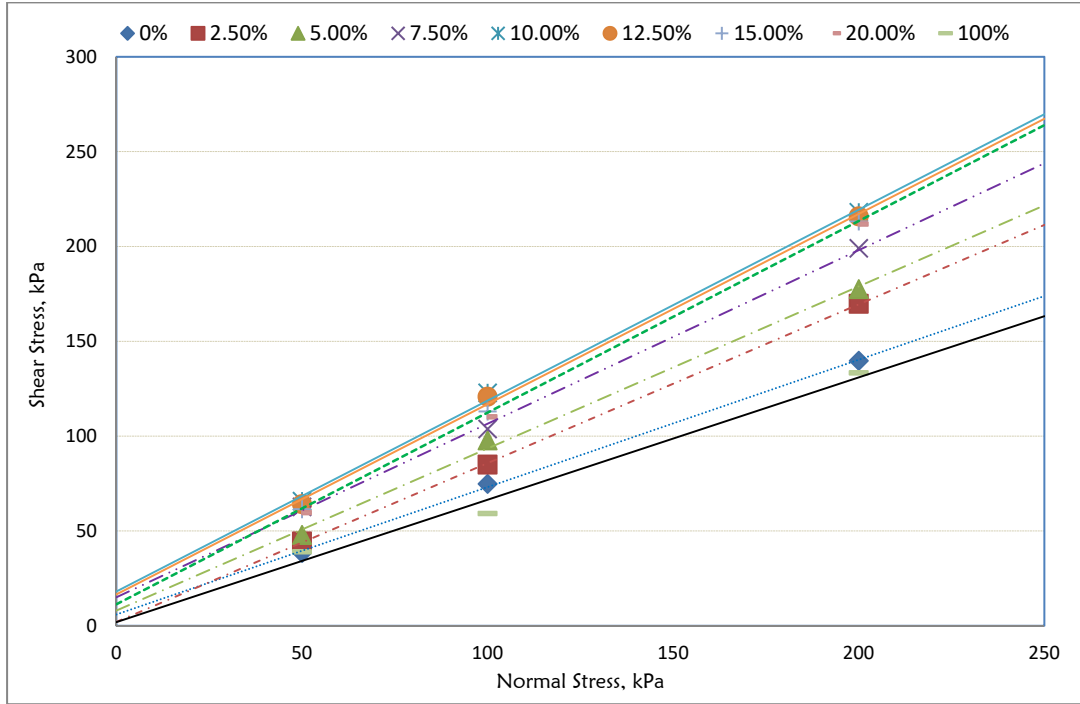


Figure 4-11: Relationship between the maximum shear stress and normal applied pressure for 4.75 mm plastic shred inclusion in Cape Flats sand

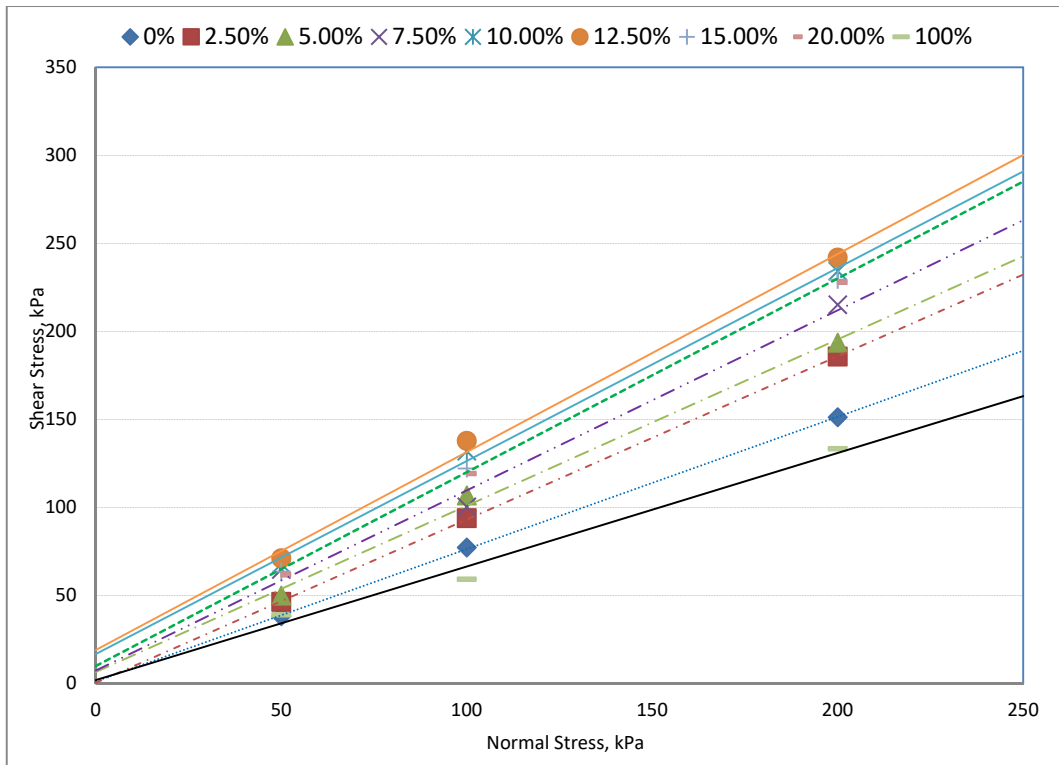


Figure 4-12: Relationship between the maximum shear stress and normal applied pressure for 4.75 mm plastic shred inclusion in Klipheuwel sand.

**Table 4-6:** Shear strength parameters (friction angle and cohesion) obtained from plastic shreds unreinforced sand and plastic shred sand composites for 4.75mm shreds.

Plastic Shreds (%)	4.75mm					
	Cape Flats			Klipheuwel Sand		
	C	$\phi$	% Increase	C	$\phi$	% Increase
0.00	2.50	34.53		1.23	36.92	
2.50	2.00	39.94	15.7	0.42	42.84	16.03
5.00	8.02	40.52	17.3	6.52	43.37	17.47
7.50	15.03	42.46	23.0	13.63	45.01	21.93
10.00	18.10	45.19	30.9	16.75	47.64	29.02
12.50	16.55	45.09	30.6	19.05	48.35	30.97
15.00	11.35	45.30	31.2	9.97	47.74	29.30
20.00	8.82	45.42	31.5	7.37	47.85	29.61
100.00	1.91	32.84	-4.9	1.91	32.84	-11.05

#### 4.5.3 Shear strength response for 5.6 mm plastic shred

Similar results as those from 2.0mm and 4.75mm plastic chips showed that Klipheuwel sand had higher angle of internal friction also with 5.6mm chips sizes.

The friction angle obtained from pure plastic chips tyre shreds was  $34.53^\circ$  and the cohesion was 2.57 kPa. The addition of plastic chips to sand influenced its cohesion and friction angle. The friction angle was increased from  $36.92^\circ$  for pure Klipheuwel sand to  $48.18^\circ$  for PET chips-sand mixture at 2.5% plastic chips shreds content then decreased for further increase of chips content.

Both cohesion and friction angles from 5.6 mm chips size are presented in Table 4-7. As the plastic chips increased in size, the peak shear stress and residual shear stress for both sands increased. Again, at low normal pressures, the effect of varying diameter was considered as negligible.

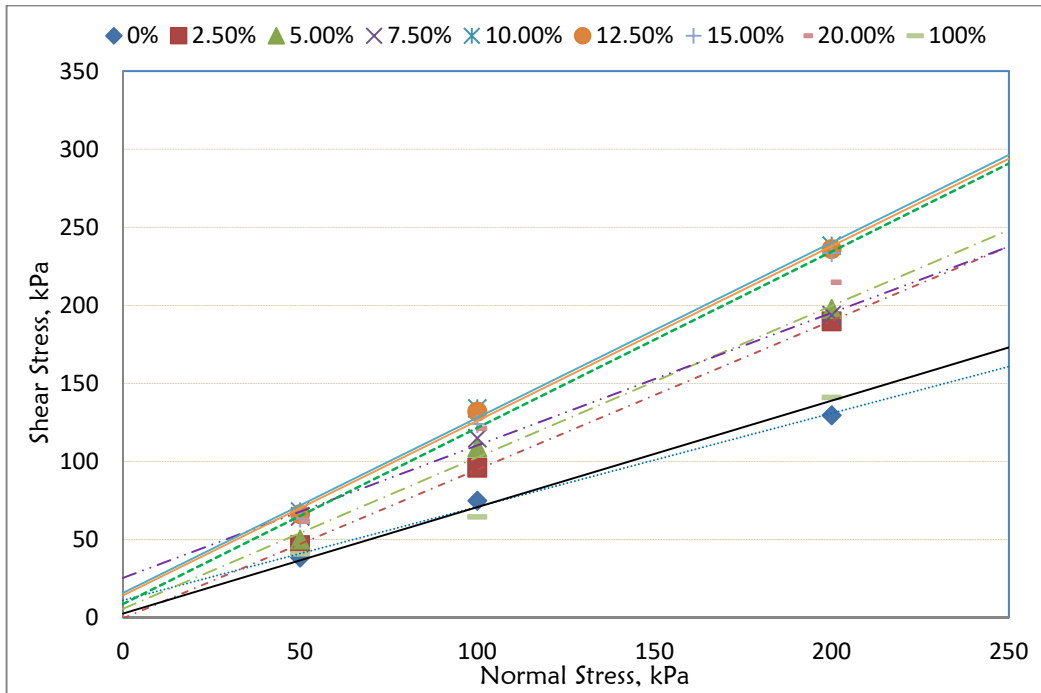


Figure 4-13: Relationship between the maximum shear stress and normal applied pressure for 5.6 mm plastic shred inclusion in Cape Flats sand

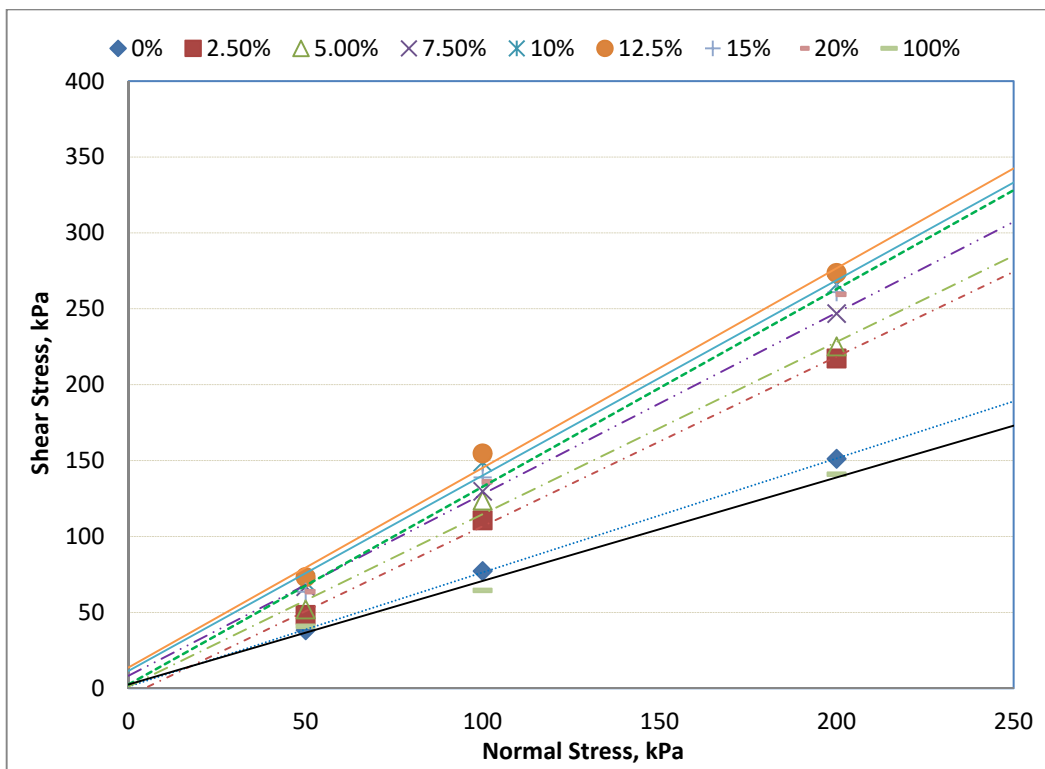


Figure 4-14: Relationship between the maximum shear stress and normal applied pressure for 5.6 mm plastic shred inclusion in Klipheuwel sand.

**Table 4-7:** Shear strength parameters (friction angle and cohesion) obtained from plastic shreds unreinforced sand and plastic shred sand composites for 5.6 mm shreds.

Plastic Sherds (%)	5.6mm					
	Cape Flats			Klipheuwel Sand		
	C	$\phi$	% Increase	C	$\phi^\circ$	% Increase
0.00	2.50	34.53		1.23	36.92	
2.50	0.52	43.62	26.3	0.00	48.18	30.49
5.00	5.62	44.14	27.8	1.22	48.62	31.68
7.50	12.66	45.87	32.9	8.36	50.09	35.67
10.00	15.78	48.30	39.9	11.53	52.15	41.24
12.50	14.17	48.21	39.6	13.77	52.74	42.86
15.00	8.86	48.40	40.2	4.58	52.23	41.48
20.00	6.32	48.51	40.5	1.97	52.33	41.74
100.00	2.57	34.28	-0.7	2.57	34.28	-7.15

#### 4.6 Effects on friction angle ( $\Phi$ ) and cohesion (c) for 2.0mm, 4.75 and 5.6mm PET plastic shreds.

##### 4.6.1 2.0 mm plastic shreds size

Figure 4-15 shows the change of cohesion and friction angles for the different plastic shreds dosages. Generally mixing plastic shreds with Cape Flats and Klipheuwel sands in various proportions increased both their cohesion and internal angle of friction.

As presented in Figure 4-15 (a), the addition of 2.0mm plastic shreds to Cape Flats sand improved its cohesion. This enhancement was obtained for all concentrations of plastic shreds in comparison to that of unreinforced sand. A concentration of 10% and 12.5% in the mixture gave a maximum value of 18.42KPa and 20.43KPa for Cape Flats and Klipheuwel sands respectively.

In Figure 4-15 (a) the dosages of 5, 7.5, 10 and 12.5% presented a significant improvement compared to 2.5% PET shred content. By looking at the shape of the curve in Figure 4-15 (a), it is clear that the maximum cohesion was achieved at a dosage of 12.5%. And dropped for plastic shreds added to Cape Flats sand in 12.5% concentration.

The variation of friction angle for different dosages in Klipheuwel sand is given in Figure 4-15(b). It can be seen that other plastic shred contents, such as 10% and 12.5%, provided an improvement

based on friction angle from unreinforced sand which was  $36.92^\circ$ . Beyond these dosages the friction angle was lower than that of the sand only control test (0% shreds). 10-12.5% was identified as an optimum which maximized the friction angle.

As presented in Figure 4-15 (a), the Klipheuwel sand-plastic shred composite showed the better improvement in cohesion compared to that of Cape flats sand-plastic shred mixtures. This was same for the friction angle which was increased for Klipheuwel sand-plastic shred composite and decreased for plastic shred mixed with Cape Flat sand as shown. The relationship between friction angle and plastic shred contents is shown in Figure 4-15 (b).

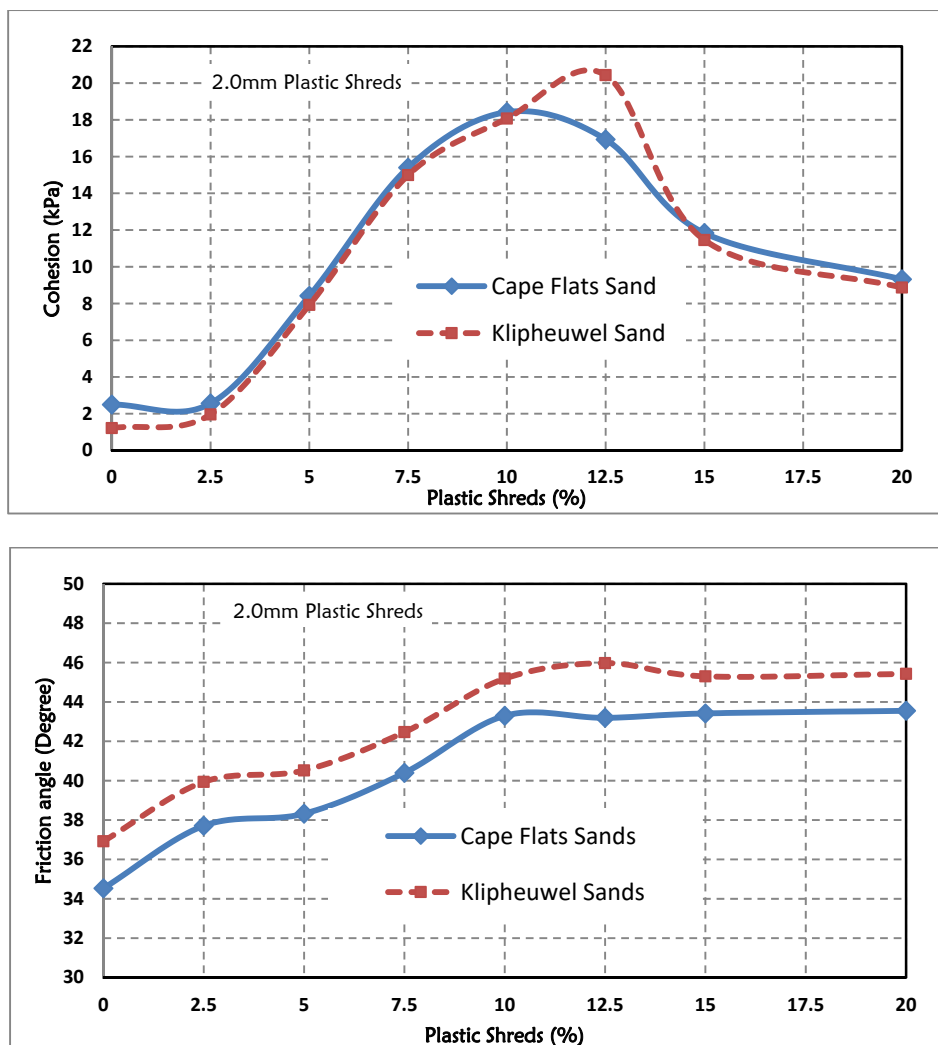


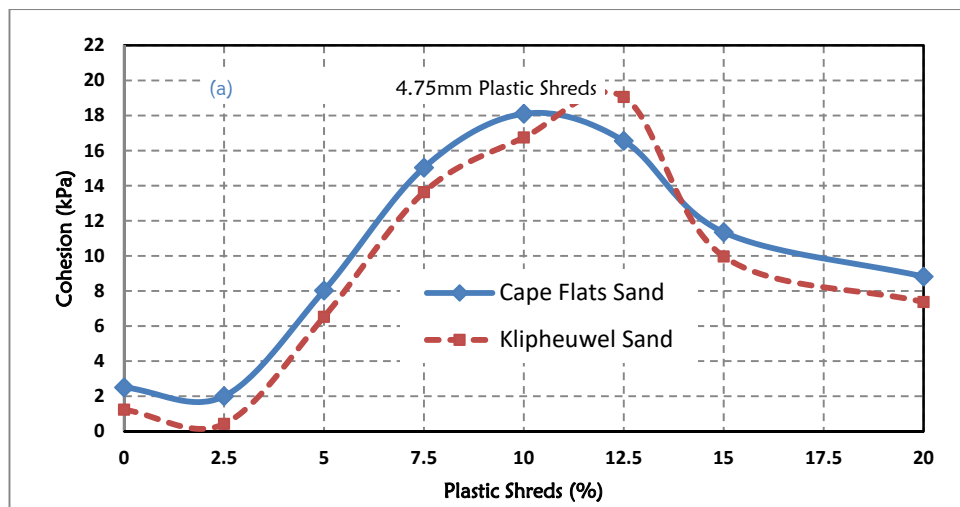
Figure 4-15: Comparison of (a) cohesion and (b) friction angle from 2.0 mm shreds Cape Flats Sand and Klipheuwel Sand

#### 4.6.2 4.75 mm plastic shreds size

The comparison of internal angle of friction and cohesion for the sand mixed with 2.0mm, 4.75mm and 5.6mm is given in Figures 4-15 (a & b), Figure 4-16 (a & b) and Figure 4-17 (a & b) for Cape Flats and Klipheuwel sands.

It is clear from Figure 4-16 (a) that the friction angle from Klipheuwel sand containing 4.75 mm plastic shreds kept above that of Cape flats sand up to maximum 12.5%.

It can be said that the addition of larger average diameter shreds to this type of sand enhanced its friction angle and that the smaller shred pieces reduced it. Contrary to friction angle, improved cohesion was obtained for all shred sizes at all shred dosages, but the degree of improvement was different. The maximum value of angle of internal friction obtained from the mixture that contained 4.75 mm plastic shreds on Cape flats sand was  $45.42^\circ$  at a concentration of around 20% compared to that of 2.0 mm and 5.6mm plastic shreds, which was  $43.55^\circ$  and  $48.51^\circ$  respectively at the different plastic shred content.



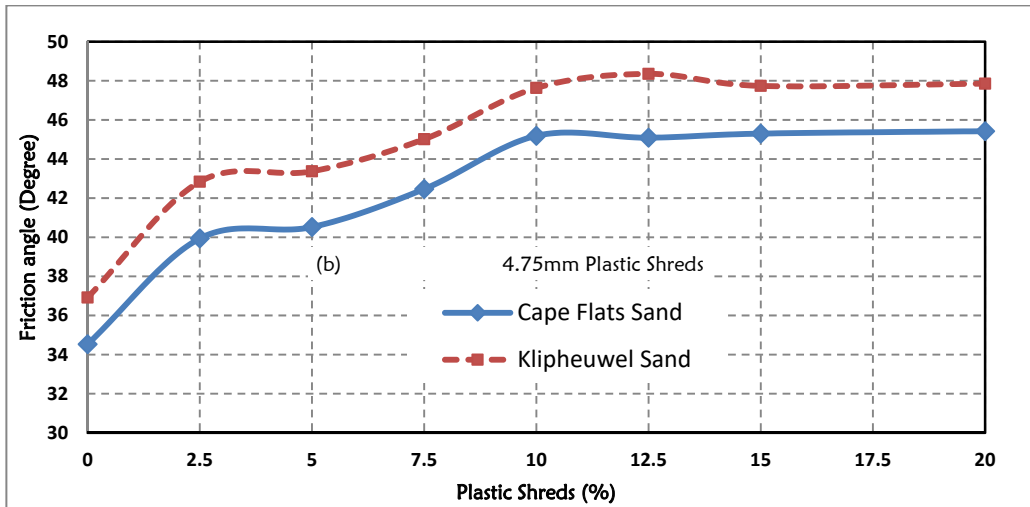
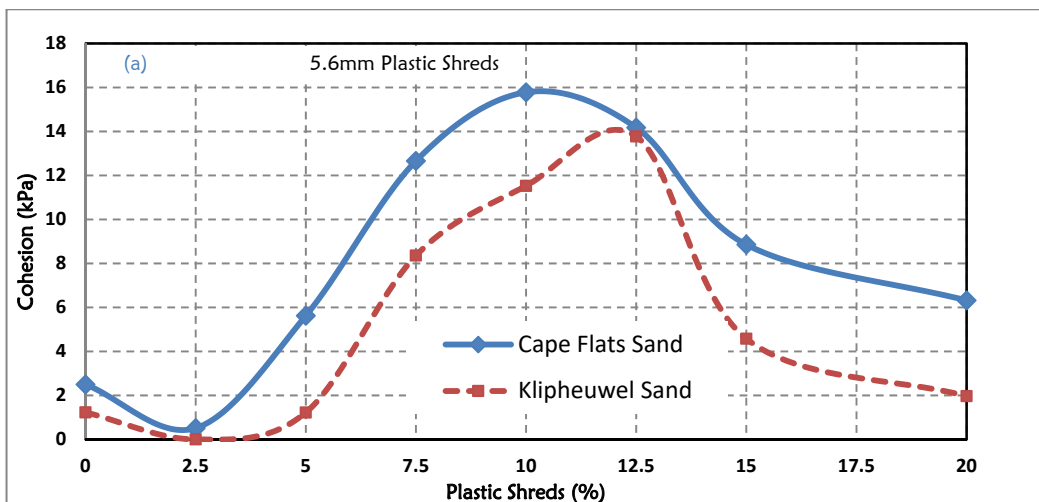


Figure 4-16: Comparison of (a) cohesion and (b) friction angle from 4.75 mm shreds Cape Flats Sand and Klipheuwel Sand

#### 4.6.3 5.6 mm plastic shreds size

The effect of 5.6mm plastic shred on dry selected soil is as shown in Figure 4-17(a) and (b). Similar to the results in 2.0mm and 4.75mm plastic shreds, there seemed to be linear relationship between 5.6mm plastic shreds concentration and angle of internal friction up to a maximum plastic shred content.

As plastic shred concentration increased,  $\Phi$  gradually improved up to an optimum concentration of 10% and 12.5% for Cape Flats and Klipheuwel sands, respectively. The relationship between cohesion and plastic shreds content showed linear relationship with slight decline at 15% plastic shred content for both soils as shown in figure 4-17 (a).



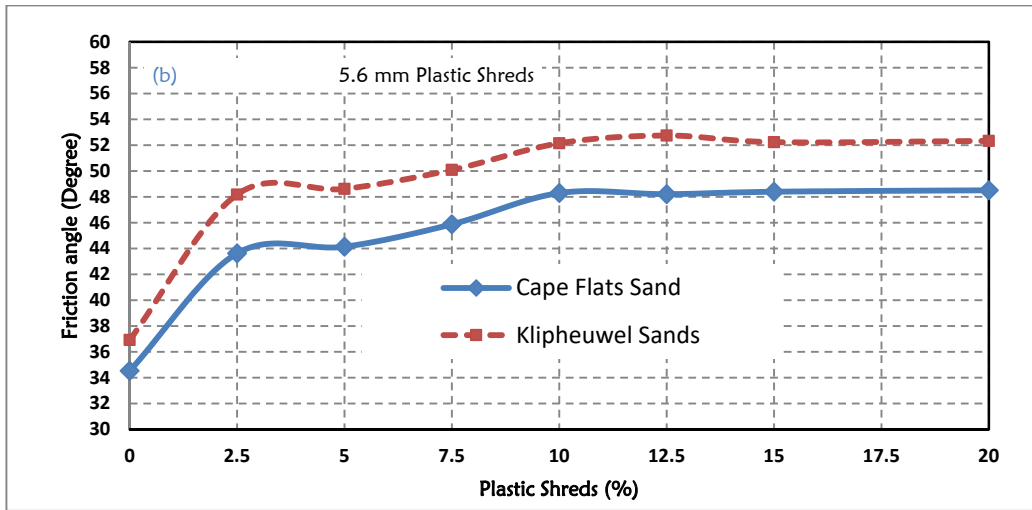


Figure 4-17: Comparison of (a) cohesion and (b) friction angle from 5.6 mm shreds Cape Flats Sand and Klipheuwel Sand.

#### 4.7 Comparison of results for the various plastic shred sizes

Figures 4-18 (a) and (b) compares the angle of internal friction results obtained from each plastic shred sizes (2.0, 4.75 and 5.6mm) mixed with soils in dry condition. It is evident that 5.6mm plastic shred has the greatest effect on the angle of internal friction at peak shear strength across all the plastic shred concentration investigated. This observation is evident in both sands (Cape Flats and Klipheuwel sands).

This effect of plastic shreds on angle of internal friction linearly increased with addition of PET plastic content up to a maximum content of 12.5% for both 4.75mm and 5.6mm in Klipheuwel, but seemed to remain constant from 2.5% of 2.0mm shred content.

Similarly, plastic shreds content improved the angle of internal friction of Cape Flats sand compared to the Klipheuwel sand as shown in figure 4-18 (a).

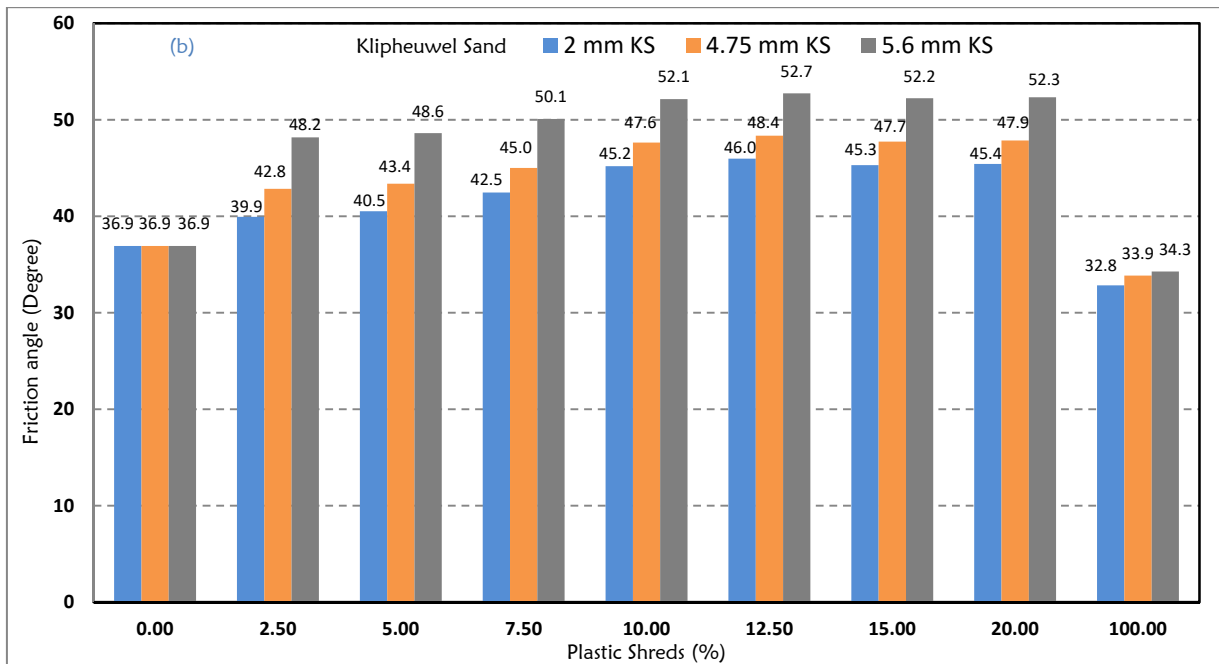
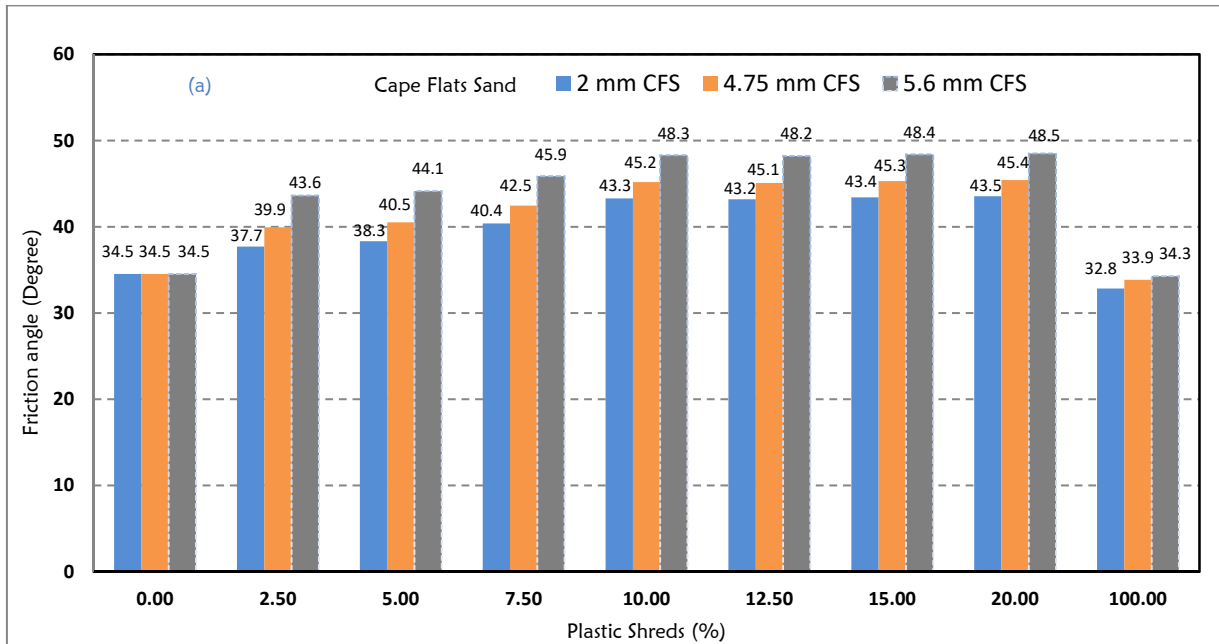


Figure 4-18: Comparison of the effect of the various plastic shred size on (a) Cape Flats sand, (b) Klipheuwel sand

## CHAPTER 5

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### 5 PRACTICAL APPLICATION

#### 5.1 Introduction

Soil reinforcement has been used for many years and has often proved to be successful (Peterson, M. (2009). South Africa produces a high volume of PET plastic waste and therefore the need for the reuse and recycling of a great quantity of these wastes is essential. Some of these include slope stabilization, widening of highway embankments, repair of landslides and reinforcing soil for low cost housing development. This study investigates the use of PET plastic waste for ground improvement purposes in geotechnical applications.

The objective of this chapter was to propose the application of plastic chips and granular soils of South Africa based on the experimental results, and the guidelines which can be followed during the execution of the project. A design example of an embankment fill and the slope stability analysis of the designed embankment with Cape Flats sand are presented. The analysis is also applicable to other soil types.

#### 5.2 Quality guidelines

The presented guidelines are based on laboratory experimental results

- Selection of the best plastic chips size.

The major source of plastic chips shreds would be the plastics recycling companies and the plastic chips obtained from the companies should be:

1. Dry and free of contaminants such as gasoline, oil, grease, diesel, etc., that can create a fire hazard.
2. of 4.75 mm to 5.6 mm size which resulted in higher strength parameters and are therefore preferable to reinforce cohesionless soil compared to 2.0mm plastic chips.

### 5.3 Highway embankment application

The proposed application uses PET chips in granular soils as lightweight fill material in the construction of road embankments. When mixed with soil, PET chips reduce its weight in a given volume and improve its shear strength, which in turn stabilizes the embankment in terms of settlement reduction and the improvement of slope stability when used as fill materials. The results obtained from the current study suggest that the larger PET chips could be mixed with sandy soils of South Africa, i.e. Cape Flats sand or Klipheuwel sand and used as lightweight fill material in construction of road embankments in this country. These results can be seen in Chapter 4. Section 5.3.1 and 5.3.2 present the design and construction procedures to be followed.

#### 5.3.1 Design Consideration

A 6 m high embankment with 12 m horizontal crest is to be constructed over soft clay to accommodate low volume vehicular use. Cape Flats sand reinforced with PET plastic chips is proposed as an embankment fill with slope of 1:2. The underlying foundation and embankment fill soil properties are summarized in table 5-1. The vertical and horizontal displacement, and factor of safety against slope failure will be analyzed using both reinforced and unreinforced fill.

Table 5-1: Geoslope input parameters

Material model	Unreinforced Cape Flats Sand	Reinforced Cape Flats Sand	Soft Clay	Units
Type of behaviour	Drained	Drained	Undrained	-
Dry unit weight Sand( $\gamma_d$ )	17.1	16.6	16	kN/m
Cohesion Sand (C)	9.4	18.10	30	kPa
Friction angle ( $\phi$ )	33.9	43.55	40	°
Dilatancy angle ( $\Psi$ )	4.875	4.875	0	°

#### 5.3.2 Structural design

The principal design consideration for a chips shreds-sand composite in embankment construction comprises the composite mixture confinement, the particle size distribution of plastic chips shreds and sand, type of belts and the required compacted density of the mixture. The following should be taken into account during the design of the embankment constructed from plastic chips shred.

- The mixture should be enclosed in geotextiles fabric to ensure the necessary containment.
- 1:2 embankment side slope (Vertical: Horizontal) is recommended.
- At least 0.9 mm thickness of soil cover should be placed between the top of enclosed plastic shred-soil fill and the base of pavement to minimize differential settlement.

The analysis was divided into stages, starting with material model, defining initial and boundary condition, application of initial stresses, setting out the calculation and finally viewing the output. It should be noted that this prototype design problem only simulated the displacements obtained in reinforced fill compared to unreinforced soil mass. Therefore, several inherent assumptions were incorporated for simplicity, such as:

- A surcharge of 10kPa and 30kPa was considered to simulate the loading expected on the embankment analysed in the drained conditions. Figures 5-1, 5-2, 5-3 and 5-4 present the analysis of the slope stability with 2 m and 3 m thickness of clay for both reinforced and unreinforced slope.

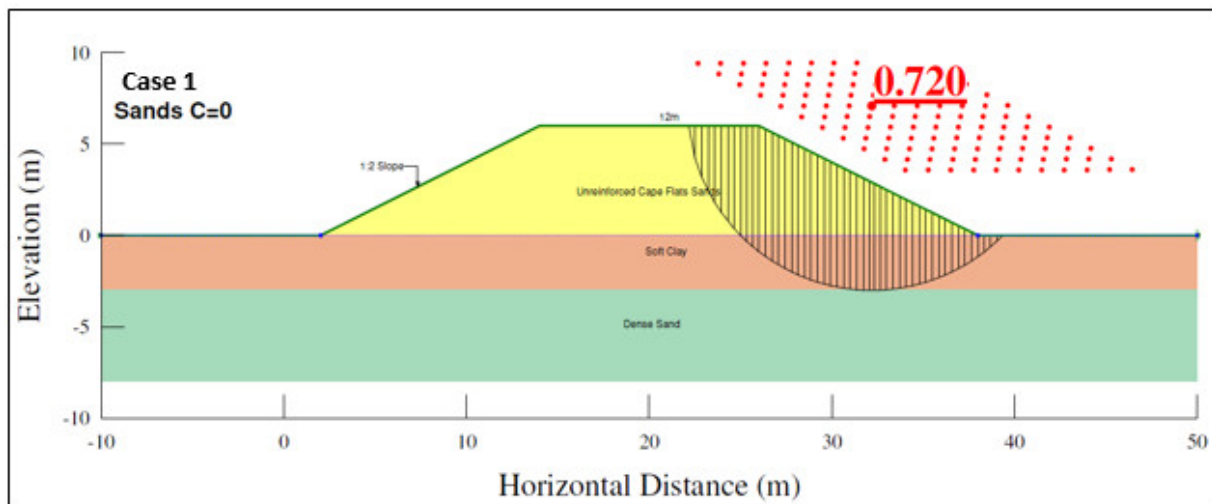


Figure 5-1: Case 1: Unreinforced Cape Flat Sands (3m Soft Clay)

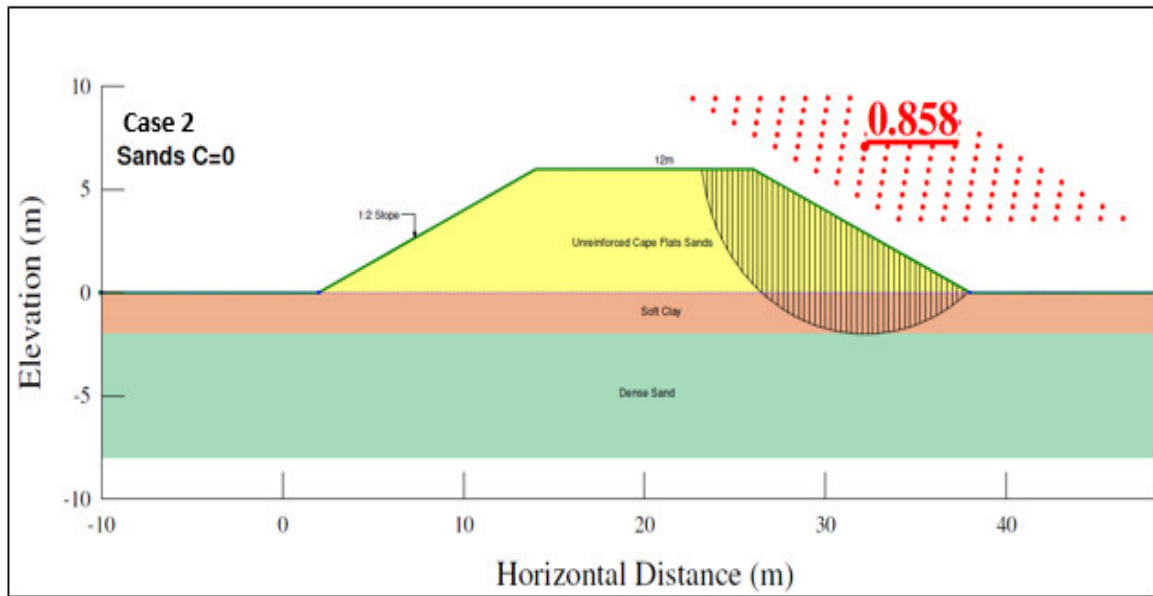


Figure 5-2: Case 2: Unreinforced Cape Flat Sands (2m Soft Clay)

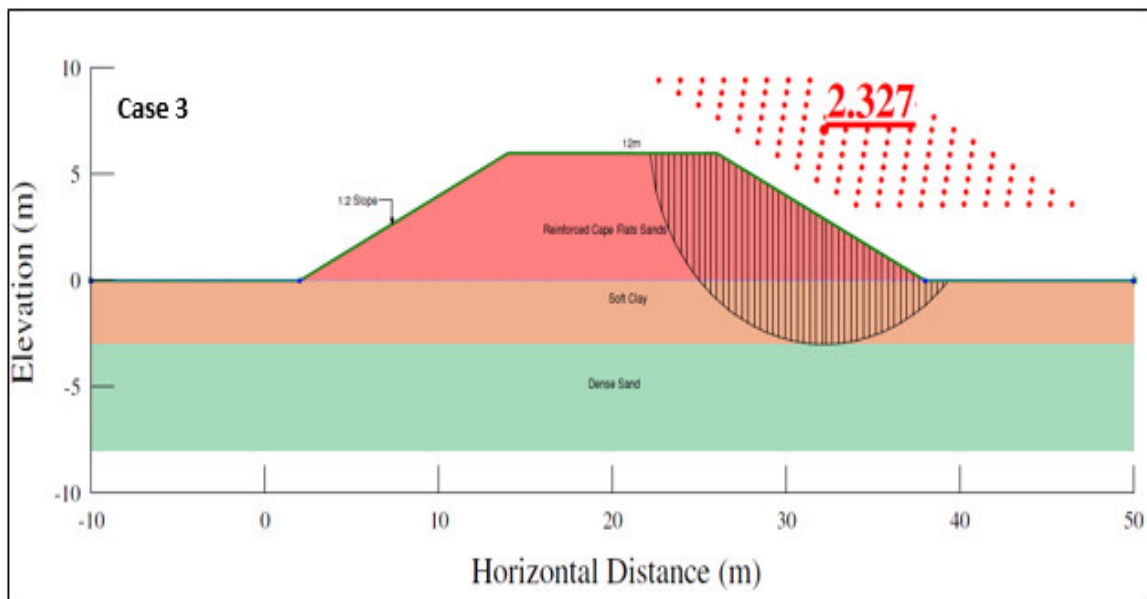


Figure 5-3: Case 3: Reinforced Cape Flat Sands (3m Soft Clay)

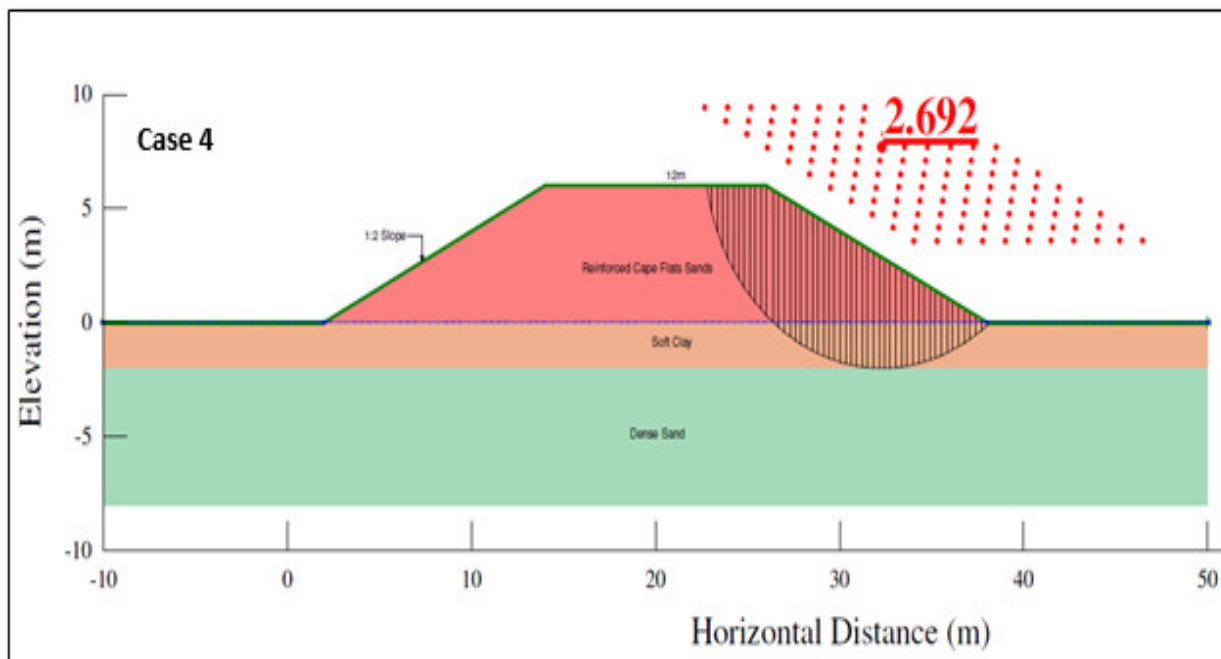


Figure 5-4: Case 3: Reinforced Cape Flat Sands (2m Soft Clay)

The results of factor of safety obtained using Bishop simplified method of slicing using GeoSlope software are given in Table 5-2. From the results, it is evident that reinforcing the embankment fill reduces the total vertical settlement .

Table 5-2: Summary of Factor of Safety

Summary Factor of Safety			
		Reinforced Cape Flats Sand	Unreinforced Cape Flats Sand
3m thick Clay Cu=10kPa	Case 1		0.72
2m thick Clay Cu=10kPa	Case 2		0.858
3m thick Clay Cu=30kPa	Case 3	2.327	
2m thick Clay Cu=30kPa	Case 4	2.692	

It is concluded that long plastic chips mixed with granular soil could be used in the preparation of embankment fill materials in South Africa because of their good performance and relatively low

cost. The smaller plastic chips require too much energy like cutting, mixing and compacting as well as low level of improvement of soil properties compared to long plastic chips.

As a great quantity of plastic chips-soil is used in embankment, if the demolition or level of the road embankments or other plastic chip-soil structures is likely to happen for other purposes, the disposal of these materials may be a big challenge to environmentalists. They should not be used in any other structures (temporary road embankment for example), the choice should be permanent structures (road embankment, retaining walls, etc.) which last longer and not temporary ones as PET plastic materials are non-biodegradable. In this research, a suggestion is to use plastic chips-sand mixtures in motor ways and national road embankments in South Africa which last longer. If levelling is to be done for the purpose of extending the structure (road embankment) either increasing its height or the number of lanes, other fill materials should be placed following the proposed guidelines.

## CHAPTER 6

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### 6 CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Introduction

This study investigated the shear strength behavior of PET plastic shreds when mixed with selected granular soil composites; Direct shear tests were conducted on reinforced Cape Flats sand and Klipheuvel sand which were selected based on their availability locally. These soils are predominant in Cape Town and are used in the construction of roads embankments. The PET was mixed together with selected soil at plastic shred sizes 2-4.75mm, 4.75-5.6mm and >5.6mm content by dry weight of soil. This section presents the summary of the findings and the recommendations for further research.

#### 6.2 Summary of the findings

The shear strength test results from the 3 different PET plastic shreds sizes mixed with sand generally showed that the shear strength parameters of sand soils were improved for the increased plastic shreds dosage.

The results showed that the addition of plastic shreds of 2.0, 4.75 and 5.6mm sizes to Cape Flats and Klipheuvel sands improved their shear strength for optimum plastic contents of 10% and 12.5% by dry mass. A significant increase in cohesion was observed as plastic chips were added as obtained from Mohr-Coulomb shear strength envelopes. The cohesion reached its maximum value for both sands at a shred dosage of 30% by dry mass of the soil. The same trend was observed for small plastic chips Shreds 2.0 mm incorporation in the selected granular soils and the respective shred contents. The exception was the slight reduction in internal angle of friction for all plastic shred Cape Flats sand composites.

### **6.3 Recommendations**

The investigation suggests the possibility of using this type of reinforcement to improve strength properties of soils in geotechnical works. Further studies into this potential reinforcement material will provide more information on the behavior of sand-plastic composites including;

- Chemical tests on plastic chips for potential leaching into the ground.
- The effect of plastic chips longer than 5.6 mm to observe the maximum friction angle that can be achieved with the inclusions.
- Larger scale tests on a wider range of coarse grained soils to broaden the understanding on the engineering properties of the composite material.

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**University of Cape Town**  
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**Certificate of Corrections**


<b>CANDIDATE</b>	Décio Jose Pinto Chim Jin
<b>STUDENT NUMBER</b>	JMXDER001
<b>THESIS TITLE</b>	LABORATORY INVESTIGATION OF SOIL REINFORCEMENT USING SHREDDED WASTE PLASTIC BOTTLES
<b>DEPARTMENT</b>	Civil Engineering
<b>SIGNATURE</b>	

I/We, the undersigned supervisor/s, hereby certify that the above-mentioned candidate has completed the corrections to the Masters dissertation to my/our satisfaction in accordance with the recommendations of examiners.

A schedule of the completed corrections is attached. Where any corrections have not been made, an explanation is given.

The copy of the corrected dissertation has been uploaded on PeopleSoft for OpenUCT purposes.

All the above is subject to the Dean's approval.

	<b>Name</b>	<b>Signature</b>	<b>Date</b>
<b>Supervisor 1</b>	Assoc Prof. D Kalumba		19 Oct 2018
<b>Supervisor 2</b>			
<b>Head of Department</b>			
<b>Approved by the Dean</b>			



**LABORATORY INVESTIGATION OF SOIL REINFORCEMENT USING SHREDDED WASTE PLASTIC  
BOTTLES**

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**BY**

**DÉRCIO JOSÉ PINTO CHIM JIN**

**SUPERVISED BY DR DENIS KALUMBA**



**REPORT OF REVISIONS**

**University of Cape Town  
Department of Civil Engineering  
October 2018**



### Report Corrections

Section/Chapter	Page	Action taken
Dedication	ii	...and enabled <u>me</u> to...
Abstract	iv	The sentence flow changed to..." It was found that presence of plastic shreds improved the shear strength parameters of the sand soil and they tend to improve further with increasing in plastic shred dosage. The cohesion reached its maximum value for both sands at a shred dosage of 30% by dry mass of the soil".
Table of content	90	Added: 5.3.2 Structural design
List of Figures/Tables	ix, x	All the list of figures and tables are updated with colons
	1	Research gaps added.
1.1 Background	1	Initials removed, Citation updated to read as...Babu, Sivakumar (2011).
	1	Added "a" ...the plastic bottles waste as <b>a</b> geotechnical...
1.2 Problem Statement	2	Magnitude of the problem stated on 1.2
	3	Last sentence rewritten as requested.
1.3 Justification	3	...has been <del>for used</del> in several studies...
1.4 Aim and objectives	4	The first specific objective removed: <del>Effect of shredded plastic bottles specifically on Klipheuwel and Cape Flats sands.</del>
1.5 Scope and limitations of the study	4	Will be removed and replaced with was: ...Direct shear method <del>will be was</del> performed to evaluate...
	6	They stand for "Soil Reinforcement"
	10	Full stop removed after the citation: ...major advantages of soil reinforcement: (Priyadarshree et al., 2014).
2 LITERATURE REVIEW	10	Citations updated accordingly to read as, According to Christopher et al., (1990). And According to Jones, 2007, on page 12. And Zornberg et al. 2004 and Foose et al. 1996 on page 19.
	10	Label added to the statement "Table": ...Table <b>2-1</b> below provides a general summary...



	10	The sentence flow changed to... There are many types of geosynthetics, which are commonly used for soil reinforcement. These include but not limited to geotextiles, geogrids, geonets, geocell and geocomposites as shown in Figure 2-5.
	19	Added <b>in</b> : ... Using direct shear with 64 x 64mm shear box, Foose et al. (1996) performed tests <b>in</b> order to establish...
	19	The sentence flow changed to: ... The addition of shredded tyres to sand has significant influence on variation of cohesion. The graph below shows that as the concentration of threads increase so does the shear strength as was deduced by Zornberg et al.
2 LITERATURE REVIEW	22	Full stop removed before the citation: ... as they are not biodegradable- (Muntean Radu et al.2011).
	27	The figure on page 27 caption added: Figure 2-22: PET beverage bottle wasting and recycling.
	28	Comma added and word <b>it</b> and <b>by</b> to the statement: ... To prevent this, <b>it</b> is necessary to reduce the quantity of PET bottles waste <b>by</b> eliminating unnecessary use of this material or minimize the use and substitute with more environmental alternatives...
	32, 52, 53, 57, 58	All equations were labelled
4 RESULTS, ANALYSIS AND DISCUSSIONS.	67	Discussion of Table 4-2 were added.
	82,84	The heading of Table 4-6 and 4-7 were added
	91	For soft clay undrained, the angle of internal friction was changed to be 40



### Figure and Tables

The external examiner's reports raised an important general query pertaining to the captions on Figures and Tables. Every table and figure have been reviewed by the author and all necessary formatting were added and updated with colons.

Signed:.....*Décio Jose Pinto Chim Jin*.....

Date:.....*19/10/2018*.....