IMAD UD DIN AHMED

USAGE OF PLASTIC BAGS AS SOIL STABILIZER AN ENVIRONMENTAL FRIENDLY SOLUTION

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES

OF

NEAR EAST UNIVERSITY

By

IMAD UD DIN AHMED

In Partial Fulfilment of the Requirements for the Degree of Master of Science

in

Civil Engineering

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Approval of Director of Graduate School of

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NEAR EAST UNIVERSITY GRADUATE SCHOOL OF APPLIED SCIENCES

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We certify this thesis is satisfactory for the award of the degree of Master of Science in Civil Engineering

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material.

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To my parents and siblings…

ABSTRACT

Stabilization of soil is the process which is used to improve the engineering properties of the soil such as its shear strength and bearing capacity. Soil stabilization is also involved in decreasing the permeability and structure base settlement. Sub grade soil consists of mainly native soil which has been compacted so that it can withstand the loads above it. It is required in many structures such as pavements and slabs. When sub grade soil is not adequate to support the necessary loads then it needs stabilization to make the soil suitable for construction.

Taking in consideration the harmful effects of plastic on environment and on the climate, usage of it as an additive in soil was suggested in this study. In this way, the plastic waste is used for a better purpose and the quantity of dumped plastic in landfills will get reduced.

For this purpose a clay soil sample with medium plasticity was mixed with 0.2%, 0.3% and 0.4% of plastic strips by weight of soil and the experimental results were compared to the control soil sample with 0% plastic. The tests were conducted according to American Society for Testing and Materials (ASTM) and includes Atterberg limits, Standard compaction test, Unconfined compression test (UCS) and California bearing ratio (CBR). The shrinkage behaviour of soil has been monitored via several wetting and dry cycles.

The obtained results showed that CBR values increases with addition of plastic strips. With respect to unconfined compressive strength, increasing the percentage of plastic strips from 0 to 0.4% resulted in an increase of 145% in the strength of stabilized soil. The shrinkage results also demonstrated that addition of plastic strips results in decreasing the shrinkage in soil. Therefore usage of plastic shopping bags in stabilization of subgrades is suggested as an effective and economical solution for both improving the geotechnical properties of soil and reducing the plastic pollution in the environment.

Keywords**:** Polyethylene (bags); Soil stabilization; waste reduction; environment friendly solution

ÖZET

Zemin iyilestirmesi, zemin kayma mukavemeti ve taşıma kapasitesi gibi mühendislik özelliklerini arttırmak için kullanılan işlemdir. Zemin iyilestirmesi, geçirgenliğin ve oturmasının azaltılmasını da içerir. Dolgu zeminler, üzerindeki yükler ile sıkıştırılmış doğal topraktan oluşur. Kaldırımlar ve döşeme gibi birçok yapıda gereklidir. Dolgu malzemenin gerekli yükleri desteklemek için yeterli özellileri sahip olmadığında, zemini inşaat için uygun hale getirmek için stabilizasyona ihtiyaç vardır.

Bu çalışma plastiğin, çevre ve iklim üzerindeki zararlı etkilerini göz önüne alarak, miktarını azaltmak ve çöp alanlara boşaltma yerine, zeminde iyileştirme maddesi olarak kullanılmasını önerir.

Bu çalışma için katı atık çevre sorunlarının azaltılmasına katkıda bulunmak amacıyla zemin stabilizatörü olarak plastik kullanılmıştır. Bu amaçla, orta plastisiteli bir kil numunesine ağırlıkça % 0.2,% 0.3 ve % 0.4 plastik şeritler karıştırıldı ve sonuçları plastik şeritleri içermiyen kil numunesine karşılaştırıldı. Deneysel çalışmada kıvam limitleri, standart Proktor sıkıştırma testi, Serbest basınc deneyi (UCS) ve Kaliforniya taşıma oranı (CBR) deneyleri Amerikan Test ve Malzeme kurumu (ASTM) göre yapıldı. Zeminin büzülme davranışı birkaç ıslatma ve kurutma döngü ile izlenmiştir.

Elde edilen sonuçlar CBR değerlerinin plastik şeritlerin eklenmesiyle arttığını saptadı. Serbest basınç mukavemeti ise plastik şeritlerin yüzdesi %0'dan %0.4'e yükseltildikten sonra, stabilize olan numunede %145'lik bir artış gözlenmiştir. Büzülme sonucu ayrıca daha fazla plastik şerit eklenerek zemindeki büzülmeyi azalttığını göstermiştir. Bu nedenle plastik alışveriş torbalarının dolgu zeminde kullanılması, zeminin jeoteknik özelliklerini geliştirmek için ve aynı zamanda plastik kirliliğinin azaltması için etkili ve ekonomik bir çözüm olarak önerilmiştir.

***Anahtar Kelimeler*:** Polietilen (torbalar); toprak stabilizasyonu; atık azaltma; çevre dostu çözüm

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LIST OF SYMBOLS AND ABBREVIATIONS

IGCC:	Integrated Gasification Combined Cycle
V:	Apparent fluid velocity through the medium
i:	Hydraulic gradient
k:	Coefficient of permeability
CaO:	Calcium Oxide
Ca^{+2}:	Calcium ion
OH^{-}:	Hydroxide
CSH:	Calcium – Silicate – Hydrates
CAH:	Calcium – Aluminate – Hydrates
LDPE:	Low Density Poly Ethylene
PET:	Poly Ethylene Terephthalate
PVC:	Poly Vinyl Chloride
PS:	Polystyrene
PP:	Polypropylene
CBR:	California Bearing Ratio
MDD:	Maximum Dry Density
OMC:	Optimum Moisture Content
UCS:	Unconfined Compression Strength
PI:	Plasticity Index
PL:	Plastic Limit
LL:	Liquid Limit

CHAPTER 1

INTRODUCTION

1.1 Background of study

The concept of stabilizing the soil has been ongoing for thousands of years. The need to strengthen the soil arose when it was identified that certain weak regions in the soil which were hindering the movement of man and his belongings could be improved by mixing with certain materials known as stabilizing agents like limestone. The aim of Soil stabilization is to improve the strength of the soil as well as increase aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two (Sherwood, 1993).

The basic principles of stabilization of soil include:

- Assessing the soil properties
- Determining the inadequate properties of the soil and selecting the best possible soil stabilization techniques based on economical and functional criteria
- To design how stabilized soil mix is used for intended durability and stability values.

Soil stabilization is the most common term used for any physical, chemical, biological or a merging of any of the methods applied to ensure the enhancement of particular characteristics of a natural soil to enable it meet the intended engineering requirements. The process of using cement and lime to stabilize the soil began a long time ago and has been well validated, but in recent times the use of cement is less recognized because of the expense of cement and adverse effects on the environment during its production. It can be imagined from the concept that about one ton of carbondioxiode (CO_2) is emitted while the production of a ton of cement is going on. This alongside the increasing cost of additives has given rise to the development of other stabilization additives such as plastic, wood ash, glass fiber etc. Utilization of solid wastes in soil stabilization provided one such avenue as it also provided an effective way to manage waste (White et al., 1995).

Solid waste is a term used for any unwanted, discarded or abandoned material which are generated from various activities including but not limited to domestic, industrial, commercial, agricultural, and biomedical. The texture of solid wastes may be liquid, solid, semi-solid or even containerized gaseous material (Franklin, 1997).

From the first production of synthetic polymers on an industrial scale in early 1940's, plastics and materials made with plastics have steadily served a great purpose in our regular daily activities in several areas. Plastics are regarded to this day a very significant invention by man, but its management and disposal is proving to be a major menace. The inconsiderate dumping of plastic waste in landfills leads to the emission of greenhouse gases like methane and ethylene into the atmosphere when the plastics come in contact with sunlight for a period of time. Due to the potential rise in plastic usage and dumping, its waste management is gradually becoming a top priority (Geyer et al., 2017).This research will explore how plastic waste as soil stabilizer can be used.

Climate is referred to as the general weather of a place, the integration of all climates in the world makes up the earth's climate. So, climate change can be said to be the change in the general weather of a place or the change in the earth's climate. Unlike the weather which varies daily, climate change takes at least hundreds of years to occur. The main cause of climate change is global warming; this refers to rise in the earth's temperature over a long period of time. Study suggests that the earth's temperature is increasing at an alarming rate, this increase is majorly brought about by the ascending levels of greenhouse gases emitted into the atmosphere. Some adverse effects which come about due to the increase in the earth's temperature include more frequent and intense storms, rise in sea level which will lead to flooding (Hulme, 2002).

1.2 Problem Statement

The occurrence of natural disasters can be said to be a global problem, varying only in magnitude according to different locations and its effects may be entirely disastrous to the environment and the people residing in it. Cyprus is no stranger to natural disasters, there exist vibrant neotectonics history comprising of various catastrophic historical earthquakes. Cyprus soil consists of alluvial soils, swelling clays, collapsible soils and evaporitic bedrocks. Mainly the alluvial soils are found at a topographically low and level area situated at the center of Troodos range to the south and Girne range to the north. Majority of the construction challenges like landslides experienced in North Cyprus includes silty – clayey soft soils as a result of their relatively strength level, less durability and highness in compressibility and also the swell shrink nature of the over – consolidated swelling soils. A widespread damage of buildings, highways as well as major roads has been noticed in areas where swelling clays exist (Atalar, 2002; Atalar et al., 2003; Atalar, 2004).

The major problem of solid waste management in Cyprus has to do with the disposal of the waste. Without any form of separation, all kinds of waste (municipal, construction, agricultural, hazardous) are all discarded together or land-filled. Despite the relatively low number of inhabitants, its solid waste sector is highly complicated. The estimate of the Statistical service states that the summed up municipal solid waste gotten in Cyprus as at 2017 was at 547,000 tons compared to 545,000 tons in 2016, noticing a slight increase of 0.36% (Cystat 2018). From the total amount of 521,000 tons handled in 2017, there was a disposal of 79.5% in landfills, 15.0% for recycling purposes, 2.0% for composition, and 3.2% for the purpose of back-filling and 0.3% was for recovering energy (Cystat, 2018).This amount of waste going to landfills has hazardous impacts on environment of the Island.

1.3 Objectives of Study

The objectives of this study can be sum up as:

To improve the soil engineering properties like shear strength and bearing capacity.

To provide alternate remedy for plastic waste disposal

Decreasing cost of soil stabilization by using cheaper material

Making the waste materials and environmental hazardous material into the useful material

1.4 Research Questions

The questions that could be asked regarding this research

1. How can the engineering properties of the soil be improved?
2. What alternative solution can be used to dispose waste?
3. How can cheaper materials help to decrease cost of soil stabilization?
4. Can waste materials as well as hazardous materials transform into useful materials?

1.5 Research Significance

As previously stated, the need for less costly stabilization additives and also as a means to reduce adverse effects on the environment brought about from the production of cement has led to the search of more desirable additives. Also, the alarming rates at which plastic wastes is increasing has generated awareness in the fact that more effective waste management procedures are greatly needed.

So, in order to manage the waste and also reduce pollution to the environment, the focus of waste management has shifted to recycling rather than incineration. One of such methods is to convert such wastes to stabilizing agents, the use of such materials is very reasonable as it is cost effective and also steadily available.

This research was undertaken to explore the potential increase in soil shearing strength when it is reinforced with plastic waste. It was contemplated that productive results in the laboratory will lead to testing in the field and if successful would eventually lead to the reduction of plastic wastes and also be greatly beneficial to the environment and economic sector.

1.6 Structure of the Thesis

This thesis consists of five chapters. The first chapter begins with the background of the study, explains the problem statement that this thesis poses to solve, it goes further to explain the objectives of this study as well as the research questions to be answered through the findings of this work. This chapter explains the significance of this work, the methodology used, and definition of terms and the structure of the thesis.

The chapter two goes deeper by giving the literature review which consists of soil stabilization, mechanical stabilization, chemical stabilization as well as the advantages of soil stabilization. It also goes further to explain the components of soil stabilization. The chapter three of this work dissect the materials and methodology used in details.

In chapter four all the results obtained from the experiments were discussed and in chapter five recommendations were made in order to get benefits from the study and how to reduce plastic waste.

CHAPTER 2

LITERATURE REVIEW

2.1 Stabilization of Soil

Soil stabilization is usually explained as the physical or chemical treatments given to a soil to maintain or increase its stabilization as well as improve the engineering properties of the soil. There is addition of IGCC (Integrated Gasification Combined Cycle) residues to a soil to give a construction sub-base aimed at improving the strength and durability of the soil, controlling volume changes and providing a temporary wearing surface. Stabilization of soil is basically the improvement of soil quality and softening water by increasing the resistance through soil particles bonding. There are various alternatives provided by technology but the basic solutions are composition and drainage. Other methods include development of particle size gradation and addition of binders to expansive soil. The procedure can be divided into chemical and mechanical stabilization (Choudhry et al., 1986; Agüero et al., 1996).

2.1.1 Mechanical stabilization

Stabilization of soil can be achieved via physically altering the native soil nature by either induced vibration, compacting or through incorporation of alternate physical properties like barriers and nailing. The characteristics of the soil material are dependent on the soil stability. There is a mixture of two or more types of natural soils in order to get a mixture which surpasses any of its components (Tiwari and Tiwari, 2016).

2.1.2 Chemical Stabilization

The stabilization here is dependent on the chemical reaction that exists between the stabilizer and soil minerals to accomplish expected result. Some stabilizers include: Portland cement, lime cement – fly ash, plastic, bitumen, lime etc. This would be the elaborated on more as it is the main focus of this research. (Tiwari and Tiwari, 2016).

2.1.3 Soil stabilization advantages

This enhances the engineering characteristics of the soil, thereby improving the soil fertility capacity. Soils in which stabilization has been carried out on are much stronger compared to soils with no stabilization because the properties have been strengthened through the reaction between the soil and the stabilizer. It saves time and cost. Site preparation time is reduced due to the soil already undergoing stabilization as it would not require the tradition 'dig and dump' method. Also, it reduces drying and strengthening of wet soil. This stability can also be utilized in preventing erosion of soil or dust formations, this is important during dry season. It enhances the workability and the durability of the soil-aggregate. Stabilization in slope areas can be achieved using this procedure. It also reduces the soil volume change due to a change in temperature or water content (Fauzi, et al., 2016).

2.2 Properties of Soil Stabilization

Soil stabilization (chemical stabilization) involves using stabilizing agents to alter the geotechnical characteristics of a weak soil like the strength, durability, compressibility, strength and permeability. The components comprise of the soil and a stabilizing agent that is additives (Bowles, 1992).

2.2.1 Soil

Soil Stabilization is mostly done on soils with soft texture (clayey, peat, silty and organic soils) to attain preferable engineering properties. Sherwood (1993) says that using fine – grained granular materials is the easiest way to ensure stability because of their large surface area and particle diameter. In comparison to other types of soil, clay soil has a larger surface area due to its elongated and flat particle shape nature. While, silty soil is mostly sensitive to little moisture change and so may be difficult during stabilization. Organic soils contain high exchange capacity that may tamper with the hydration process by keeping the calcium ions constantly liberated throughout the period calcium silicate and calcium aluminate is hydrated in the cement to maintain satisfaction in exchange capacity. The success of soil stabilization depends on the proper binder selection as well as the amount of binder added (Hebib and Farrell, 1999; Lahtinen and Jyrävä, 1999, Åhnberg et al., 2003). Organic soil and also peat soil have high water content, high porosity as well as high organic content.

2.2.2 Soil Properties

Various geotechnical properties of soils have different influence on the civil engineering structures (Roy and Bhalia, 2017). In order to determine the suitability of a soil as a foundation and as construction materials, details about its geotechnical properties are required and to evaluate these properties its physical and engineering properties are very important (Laskar and Pal, 2012). For the planning and designing of structures, information on the surface and sub – surface is vital as it would be advantageous to invest some amount on sub – surface exploration involving construction of heavy structures than to overdesign and make it costlier (Roy and Bhalia, 2017).

2.2.3 Specific Gravity

This is calculation of equal ratio of a mass of solid soil and water. It is a crucial indicating characteristic when considering the behavior of the soil and also in classification of soil minerals as it can be used in determining porosity, saturation degree, and void ratio among others. It is also used in determining the compatibility of a soil to be used for construction a high specific gravity indicates more strength for foundations and roads. A study shows that an increase in specific gravity leads to an increase in shear strength parameters (cohesion and angle of shearing resistance) (Roy and Dass, 2014). Specific gravity also leads to an increased strength in sub grade materials for road construction thereby increasing the California bearing ratio (Roy, 2016).

Table 2.1: Typical values of specific gravity (Bowles, 2012)

Soil type	**Specific gravity**
Sand	2.65 – 2.67
Silty sand	2.67 – 2.70
Inorganic clay	2.70 – 2.80
Soil with mica or iron	2.75 – 3.00
Organic soil	1.0 – 2.60

2.2.4 Particle size analysis

This is one of the compatibility indicators of soils used for construction of roads, dams etc. There are two methods used in determining the particle size of various soils; Sieve analysis which is used for determining particle sizes coarser than 75µ and Hydrometer analysis used for determining sizes less than 75µ. After conduction of the analysis, a particle size distribution curve is plotted using the data, this constitutes the distribution of the various sized particles in the soil mass. This curve, also called a gradation curve can be used to get a general concept on the gradation of the soil. This procedure can also be used to estimate soil – water movement Chebet and Kalumba (2014)

2.2.5 Permeability

The degree of permeability of a soil refers to the ability of the soil to allow the passage, transmission or movement of fluids (air and water) through it. The permeability of a soil has a significant effect on its use as a construction material for dams, reservoirs and other embankment constructions. According to Darcy's law there is a linear relationship that exists between flow velocity (**v**) and hydraulic gradient (**i**) for any given saturated soil under steady laminar flow conditions. It is denoted by the permeability coefficient (k) in Darcy's equation:

$$V = k.i$$

Where;

V = the apparent fluid velocity through the medium

k = coefficient of permeability

i = hydraulic gradient

Some of the factors which affect the permeability of a soil include: grain size, particle size, impurities, void ratio, pore size distribution, degree of saturation among others (Chandel and Kumar, 2016)

Table 1.2: Various classes of permeability (Chandel and Kumar, 2016).

Type of Soil	Hydraulic Conductivity, k (cm/sec)	Remarks
Gravel	$k > 1.00 * 10^{-01}$	Very High
Coarse Sand, Fine Sand	$1.00 * 10^{-03} < k < 1.00 * 10^{-01}$	High to Medium
Silty Sand	$1.00 * 10^{-05} < k < 1.00 * 10^{-03}$	Low
Silt, Silty Clay	$1.00 * 10^{-07} < k < 1.00 * 10^{-05}$	Very Low
Clay	$k < 1.00 * 10^{-07}$	Tends to be Impermeable

The table above shows various types of soil and their rate of permeability (k). In descending order, the values of ‘k’ indicate the rate (cm/sec) at which fluids flow through the different types of soil, with gravel being the most permeable and clay as the least permeable.

2.2.6 Shear strength

This is defined as the internal resistance per unit area where the soil has resistance to failure and sliding occurrences on a plane (Das, 2014). It occurs through the effect of friction and the interconnection of soil particles or bonding as the particle contacts. Soils possessing high angular particles have a high likelihood of withstanding displacement, thus have a higher shearing strength than soils containing particles with lower angular particles. This soil property is of utmost importance in the consideration of various constructions including: airfields and highways, foundation design, embankment constructions etc. The shearing strength of a soil originates from the following:

i. Resistance due to interlocking of particles
ii. Adhesion between soil particles or cohesion.
iii. Frictional resistance between the individual soil grains.

Clayey soil is seen to have a lower friction angle compared to its cohesion and vice versa for sandy soil. The addition of clay into sandy soil leads to the filling of void spaces in the sand particles by the clay particles and this generates interlocking properties within the sand material. Therefore, clay induced sand soil tends to have low cohesion but a high clay content leads to an increase in cohesion. Some factors affecting shear strength include shape of the particles, mineralogy, initial void ratio, density of the particles among others. Some of the various methods used to calculate shear strength include: (a) Direct shear test, (b) Triaxial compression test, (c) Unconfined compression test, (d) Vane shear test (Chen, 2012).

2.2.7 Atterberg limits

These are limits which originated from Albert Atterberg, a Swedish soil scientist whose aim was to observe and measure the various significant changes in fine – grained soils situated on the water content. There are four kinds of fine – grained soils consistency developed by the Atterberg system as regards to water content: (i) Solid, (ii) Semi – solid, (iii) Plastic, (iv) Liquid. Three major Atterberg limits are:

Shrinkage limit: This is the point of limitation attained when there is no reduction in soil volume due to increase in loss of water from the soil. It can be explained as the least water quantity a soil can have and still be 100% saturated.

Plastic limit: This can be defined as the lowest water content attained by which a thread of soil of approximately one – eighth in diameter, begins to crumble, when rolled out on a surface that is nonporous. This limit exists between the plastic and semi – solid state of a soil.

Liquid limit: This is defined as the lowest water content by which a soil exhibits minute shearing strength opposing flowing, even though in liquid state. This limit lies between the liquid state and plastic state (Holtz and Kovac, 1981).

2.2.8 Determinants of soil stabilization strength

Organic Matter: A vast quantity of organic matter can be found at the surface of most soils, although, it may extend deeper in well drained soils. When hydration products come in contact with organic matters found in the soil, this leads to a reduction in pH level. This pH reduction may impede the hardening of the stabilized soil, resulting in difficulties in its solidification. Temperature: Temperature plays a vital role in soil stabilization as pozzolanic reactions between soil particles and binders have specific requirements. At low temperatures, these reactions tend to decelerate resulting in a reduction in strength of the stabilized soil.Moisture content: This is an important factor to consider before the commencement of the stabilization process since it not only is crucial for the process of hydration but also for competent compaction. For the desired result to be generated, various stabilization additives require different levels of moisture as insufficient moisture content may lead to inadequate results because of incomplete reactions between the additives and the soil to be stabilized.

Sulphides: The use of an additive containing calcium in a sulphate rich soil may prove detrimental to the stabilization process as a reaction between the two can bring about the formation of hydrated sulphate, which if combined with water can attack the stabilized soil (Kaushal and Guleria, 2015).

2.2.9 Stabilizing agents

Soil stabilizing agents are used to improve the disadvantageous properties of the soil. These stabilizing agents can be used to increase the soil particle cohesion, alter and maintain the soil moisture content and also act as cementing agents (Jonathan et. al., 2004). Generally, the purpose of the stabilizing agent is either the reinforcement of the bonds between the particles or filling up of the pore spaces. The type of stabilizing agent used relies on the type of soil and the desired property to be improved.

a) Cement

Cement stabilization also known as soil – cement stabilization is the bonding together of soil particles and cement brought about by the hydration of cement particles which join together to form a sturdy material. As the cement fills the vacuum within in the soil particles, water is then added to the soil which leads to the hardening of the cement. So, the unit weight of the soil and also shear strength and bearing capacity increases. It assists to modify the mechanical and engineering characteristics of the soil. Cement has been used as a soil stabilizing agent since the beginning of soil stabilization in the 1960’s. Soil cement is a very dense combination of soil, cement and water. Cement is considered as primary stabilizing agent or hydraulic bonder since it can be applied by itself for stabilizing action. (Sherwood, 1993; EuroSoilStab, 2002). The major benefit of using cement is that the reaction is not based on the soil minerals but on its reaction with water which is basically present in any soil. There are various types of cements obtainable today like Portland cement, blast furnace cement, sulfate resistant cement and high alumina cement etc. The type of cement to be used is selected based on the type of soil and the desired final strength. The hardening (setting) of cement will enclose soil as glue, but it will not change the structure of soil (EuroSoilStab, 2002). Factors which affect the hydration of cement include: water to cement ratio, curing temperature, presence of foreign matters or impurities, specific surface of the mixture. The final effect on the hardening and the strength of a cement stabilized soil may vary depending on the factors involved.

b) Lime

This method of soil stabilization involves the addition of lime to the soil to enhance its properties. Lime is the oldest traditional chemical stabilizer used for soil stabilization (Mallela et al., 2004). The various types of lime used include monohydrated dolomite lime, dolomite lime, calcium lime, calcite quick lime. There are two main phases involved in lime stabilization, the first phase, which is known as immediate or short-term treatment, occurs within a few hours or days after lime is added (Locat et al., 1990; Abdi and Wild, 1993). In this phase, there are three main chemical reactions, namely, flocculation – agglomeration, cation exchange and carbonation. This phase involves the drying of the wet soil and also, increases in workability of the soil.

The second phase is regarded as a long-term treatment due to the fact that for it to be complete it needs a long period of time usually several months or years. In this phase, the primary reaction is Pozzolanic reaction which is closely related with the increase in soil strength and durability. Pozzolanic reactions are time dependent and require long periods of time (years) because such reactions are functions of temperature, calcium quantity, pH value and the percentage of silica and alumina in the soil minerals (Eades and Grim, 1960; Kassim et al., 2005).

The first action which occurs as lime (mainly quick lime) is introduced into the soil is water absorption. The introduction of lime into the soil water system generates calcium ion (Ca^{+2}) and hydroxide (OH^{-}). Quicklime is the most frequently used lime; it can be used to react with pozzolana materials to bring about cementitious compounds in the presence of water. CaO and hydrated lime can also be used for this process. Some reasons why quicklime is preferred over hydrated lime include the fact that it is denser than hydrated lime, it has higher available free lime content per mass, it produces heat which causes a large decrease in moisture content and speeds up strength gain of the soil, it also contains less dust.

After the beginning mixing stage is completed, flocculation and agglomeration occurs. In this process, the Plasticity Index of the soil drastically reduces as the soil becomes crumbly and better to handle due to the hydrated lime formed when quicklime combines with water, releasing calcium ions which resettle at the surface of the clay and water and other ions are replaced. The breaking down of clay particles is brought about by the addition of a sufficient amount of lime and water, which causes a rapid rise in the pH of the soil. Cementitious products like calcium – silicate – hydrates (CSH) and calcium – aluminate – hydrates (CAH) are formed as the silica and alumina released comes in contact with the calcium in the lime. These products help structure the matrix which enables the alteration of the soil from a sandy, powdery substance to a hard, water resistant material with a high load bearing capacity having a structural layer which is both durable and flexible.

The effects of lime on the geo – technical properties of the soil include: increase in fatigue strength, decreased swell in potential and volume change, increase in durability, increased soil strength, decreased plasticity index. Also, some disadvantages to using lime involve carbonation, sulphate attack among others. (Singh et al, 2008).

c) Fly Ash

Fly ash is regarded as the waste material generated from the burning of coal, usually from coal furnaces or from heat power plants which burns coal as a fuel. The remnant mineral after the coal is burnt is known as fly ash. This ash is very similar to the volcanic ashes of long ago which were presumed to be one of the foremost pozzolans applied during that era. Two vital aspects which arise from the production of fly ash are the management of the fly ash and also an effective and proper disposal of the fly ash. In other to avoid any disruption in the ecological system and also prevent any form of environmental pollutions which may generate from the extracted waste due to its hazardous nature, proper pre – treatment is required before its disposal or storage (Singhi et al., 2016).

This type of stabilization has been getting more recognition in current times, this is mainly due to its available wide spread, low cost and is also less time consuming than the rest methods. In current situation, it is seen that the production of fly ash is more than its utilization rates. Fly ash can be classified into four categories based on a lime reactivity test, these are, non – pozzolanic fly ash and pozzolanic fly ash, cementitious and pozzolanic fly ash, Cementitious fly ash. Also, on the basis of its chemical composition, it can also be divided into dual categories namely: Class F fly ash and Class C fly ash. Some limitations accompanied with this type of stabilization include:

I. Sulphur contents found in soil – fly ash mixture can lead to the formation of expansive minerals, which in the long run will result in reduction in strength and durability.
II. Dewatering may be required due to the soil to be stabilized having less moisture content.
III. The slacking and strength loss of soil is mainly linked to Soil-fly ash mixture cured below zero and then soaked in water (Makusa, 2012).

d) Plastic

As earlier discussed, plastic waste has become a menace to the environment. A common problem associated with the recycling of plastics is the fact that they are usually composed of more than one kind of polymer or have been affixed with fibers for added strength. This problem is helpful when considering the use of the plastic waste to improve the geotechnical properties of the soil (Vasudeva et al., 2006). A major way of controlling plastic wastes is by using it for construction of roads and pavements consideration its effects in transmitting stability and durability to the roads and also providing a solution to the environmental hazard due to the abundance of plastic wastes. To have a better understanding of the responsibility of plastics in construction, one must be informed about the specific material characteristics and methods involved in road laying.

The two major types of plastic wastes involved are:

(i) Thermoplastics and

(ii) Thermosetting plastics.

Thermoplastics include Low Density Poly Ethylene (LDPE), Polyethylene Terephthalate (PET), High Density Poly Ethylene (HDPE), Poly Vinyl Chloride (PVC), Polystyrene (PS), Polypropylene (PP) etc. and this class of plastics are recyclable. Thermosetting plastics are constituted of alkyd, ester, epoxy, phenolic formaldehyde, urea formaldehyde, metallised and multilayer plastics, melamine formaldehyde etc. Various ways which plastics are being mismanaged include: (Patil et al., 2016).

The emission of polluting gases brought about by the burning of garbage containing plastics which causes air pollution. The blocking of drainage and littering of plastic waste in the environment. The hindering of waste processing facilities due to municipal waste containing plastic which may cause problems during landfill operations. The operation of recycling industries in non – conforming areas which may lead to hazards to the environment.

Table 2.3: Plastic wastes and its sources (Hulme, 2002)

Plastic waste	Origin
Low density polyethylene	Carry bags, sacks, milk pouches, detergent bottles etc.
High density polyethylene (HDPE)	Carry bags, bottle caps, house – hold articles etc.
Polyethylene Terephthalate (PET)	Drinking water bottles etc.
Polypropylene (PP)	Bottle caps, detergent wrappers, biscuit packets etc.
Polyvinyl chloride (PVC)	Mineral water bottles, credit cards, toys, electrical fittings etc.
Polystyrene (PS)	Yoghurt pots, food trays, egg boxes, disposable cups etc.

Thorough examination and adherence to the guidelines (IRC: SP: 98: 2013) is mandatory to ensure the right quality of plastic waste is being utilized. The use of Poly Vinyl Chloride (PVC) and Flux sheets should be prohibited.

The types of plastic waste which are applicable in the rural road construction include:

a) Hard foams (PS) of any thickness.
b) Soft foams (PE and PP) of any thickness
c) Films (carry bags) of thickness ranging to 60 microns (PE, PP and PS)
d) Laminated Plastics of thickness ranging up to 60 microns (biscuit wrappers, detergent wrappers).

There are two ways by which plastic can be used to improve the properties of bituminous aggregate, which are Dry and Wet process. This technology was developed and explained by Dr. R. Vasudevan of Thiagaraja College of Engineering and also by Dr. Sangita, Sr. scientists, Flexible Pavement Division. For isolated works, the dry process is recommended. In this process, the optimum percentage of plastic waste to be added as per tests should be 8% of the bitumen used. So, considering a 1 km road of width 3.75m which uses approximately 21.3 tones of bitumen for a new road and 12 tones for an upgrade, this would require approximately1.7 tonnes of plastic waste for a new road and 1 tone of plastic waste for an upgrade.

Advantages of using plastic in construction of roads

There is an increase in strength of the road. Better resistance to water and water stagnation. There is little to no stripping and has no bumps. The Dry process can be examined in all climatic conditions. It is less expensive since about 8 – 15% less bitumen is used and plastic waste is used. The percentage of plastic can be changed to better alter the method to suit climatic and topographical conditions. Higher durability: A normal 'highway quality' road may last up to 4 – 5 years but a plastic – bitumen road may last up to 10 years. Maintenance cost is significantly lower compared to conventional roads (Tejeswini, 2013)

2.2.10 Why Plastic?

Its abundant availability, pollution of the environment and the need of a competent disposal method are some of the reasons why plastic is being used for this research. Studies have shown that instead of the continuous dumping of unwanted plastics, it can be blended properly with the soil to stabilize it by increasing its durability and strength like shear strength, tensile strength and California bearing ratio.It can greatly improve the properties of the soil used in the construction of road infrastructure (Arora, 2004). Plastics have various characteristics which make them a viable choice when considering soil stabilization. Some of its properties include: flexibility, elasticity, resistance to water, corrosion and chemical resistance, high strength – to – weight ratio, low electrical and thermal conductivity, good durability etc.

Plastic waste statistics in Cyprus

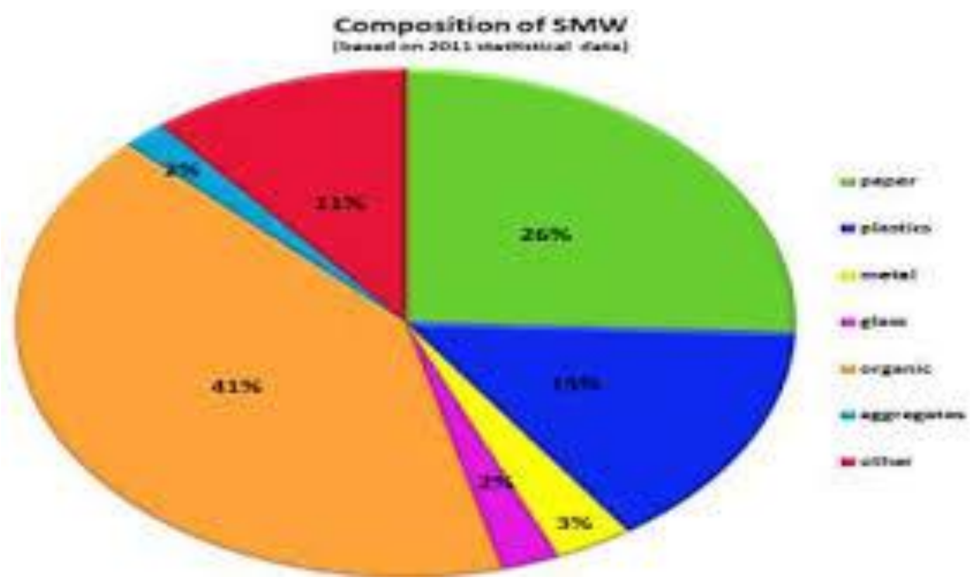

Figure 1.1: Composition of SMW in Cyprus (Cystat 2018)

According to report by Athena Papanastasiou (Environment officer) the figure above shows the composition of solid municipal waste in Cyprus in 2011. In increasing order, the analysis consists of 2% aggregates, 2% glass, 3% metal, 11% other wastes, 15% plastic, 26% paper and

41% organic waste. The overall compositional analysis can be seen in the table below which shows the total amount of waste generated. Going by this data, it can be said that plastic generation was approximately 85,000 tonnesin 2011 (Cystat, 2018).

Figure1.2: Total waste generated in Cyprus (Cystat, 2018)

GENERATION AND TREATMENT OF MUNICIPAL SOLID WASTE

Indicator	Unit	2009	2010	2011	2012	2013	2014	2015	2016 p	2017 p
Total waste generated (1+2+4+6+11-10)	**000's tonnes**	**589.06**	**571.44**	**571.87**	**567.61**	**532.98**	**523.22**	**541.20**	**545.39**	**547.36**
Per capita generation of waste	**kg/person**	**730**	**690**	**674**	**657**	**618**	**613**	**642**	**642**	**636**
Total waste treated, including backfilling (1+3+4+7+8+11-5)	**000's tonnes**	**589.06**	**558.95**	**548.13**	**543.91**	**512.22**	**498.85**	**512.33**	**520.88**	**521.12**
Amount of waste sorted for recycling (1)	**000's tonnes**	**49.39**	**61.09**	**72.22**	**69.65**	**69.78**	**70.05**	**72.12**	**73.25**	**78.21**
- by type of waste										
Paper, paperboard and cardboard	"	35.09	38.38	44.55	40.86	42.87	44.21	46.06	47.46	49.56
Plastics	"	2.86	5.96	9.42	10.86	9.77	8.55	11.05	10.28	9.85
Glass	"	4.02	5.13	6.47	5.86	6.68	6.36	6.59	6.11	6.71
Metal	"	5.55	10.03	9.42	9.53	8.49	8.86	6.48	7.06	9.20
Wood	"	1.86	0.65	0.37	0.48	0.87	0.70	0.74	0.50	0.60
Textiles	"	…	0.85	1.05	1.11	1.00	1.30	1.00	1.78	2.19
Mixed recyclable materials	"	0.01	0.09	0.94	0.95	0.10	0.07	0.20	0.06	0.10
Amount of biodegradable waste from sorting (6) of which, after biological treatment:	**000's tonnes**	**0.00**	**26.31**	**47.92**	**50.99**	**41.15**	**42.76**	**46.16**	**48.63**	**51.19**
Compost for backfilling (7)	"	0.00	7.89	14.95	16.20	11.67	8.72	12.05	16.77	16.62
Partly stabilised waste incinerated for energy recovery (8)	"	0.00	0.00	0.00	0.00	0.00	4.45	0.00	0.00	0.00
Water losses (9)	"	0.00	12.49	23.74	23.70	20.76	21.29	22.22	16.77	20.02
By-products landfilled (10)	"	0.00	5.93	9.23	11.09	8.72	8.30	11.89	15.09	14.55
Amount of waste disposed to landfills (11)	**000's tonnes**	**539.67**	**489.97**	**460.96**	**451.28**	**422.82**	**397.85**	**403.00**	**409.96**	**414.33**

... = data not available
*** = provisional data**

(Last Updated 21/11/2018)

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The estimate of the Statistical service states that the summed up municipal solid waste gotten in Cyprus as at 2017 was at 547,000 tons compared to 545,000 tons in 2016, noticing a slight increase of 0.36% (Cystat 2018). From the total amount of 521,000 tons handled in 2017, there was a disposal of 79.5% in landfills, 15.0% for recycling purposes, 2.0% for composition, and 3.2% for the purpose of back-filling and 0.3% was for recovering energy (Cystat, 2018).

2.2.11 Plastic Pollution

Plastic pollution is referred to as the amassing of plastic materials in the environment which have a negative effect on the surroundings and also the living organisms. Plastic pollution majorly impacts land and aquatic habitats alike. The fact that they are cheap and long – lasting has led to the increase in pollution.

Plastic pollution can be grouped into macro-plastics which refer to large plastics which can be seen clearly that do not have a direct impact on the food chain in their current form, micro-plastics which are generally macro – plastics that have been degraded through various processes breaking it down into smaller particles. In this form it is very hazardous as it can directly affect the food chain and cannot be easily managed due to its minute size. Despite the multiple benefits that the material offers, plastics are associated with high levels of waste and leakage to the environment. This is the result of single-use plastics applications, inadequate end of-life treatment, low recyclability and re-usability rates and high potential of disintegration into microplastics (Geyer et al., 2017).

Although more research is critically needed in the subject, it is evident that very little percentage of disposed plastic is actually recycled or converted to energy through incineration. Study also shows that microplastic pollution is much higher on land than in marine or freshwater. Though the long – term effects of microplastic pollution are yet to be fully determined, some of the effects include the fact that most plastics are non-biodegradable and majority end up in the sewers. Sewage sludge is commonly used as fertilizers for the soil, thereby transferring the microplastics to the soil and this has adverse effects on living organisms which we depend on like earthworms.

Also chlorinated plastics (PVC) which is very commonly used contains toxic chemicals which is then released into the soil, this not only affects the soil stability and its organisms but also flows into nearby water sources thereby leading to contamination.

2.3 Previous Studies

It has been ascertained through several studies that the qualification of plastic waste in regards to its use as a soil stabilizer. Studies include:

Gill et al. and Choudhary in 2010 through a research conducted, proved the potential possibilities of HDPE (high density polyethylene) to act as a soil reinforcer by enhancing the properties of sub grade soil. Various percentage of HDPE strips length and proportions were obtained from plastic waste and mixed with the soil, on which a series of CBR tests were conducted on the reinforced soil. The CBR test conducted shows that the addition of HDPE strips in soil to reinforce it is beneficial in highway application.

Nsaif (2013) through a research to study the manner in which soil strengthened is by plastic waste materials concluded that by mixing pieces of plastic waste with both clayey and sandy soil at varying mixing ratios (0, 2, 4, 6, 8)% respectively by weight, there was a relevant increment in the cohesion for both soil types. It was also concluded that was a reduction in MDD and OMC of the soil as a result of the low specific gravities of the plastic pieces.

In 2014, Chebet et al conducted experiments in the laboratory to ascertain the shear strength increase and yielding capacity of found sand locally brought about by the random infusion of HDPE strips obtained from plastic shopping bags. Through visual inspection of the plastic material after the conduction of the tests and analysis, implication was the increased strength for the reinforced soil is as a result of tensile stresses mobilized in the reinforcements. Plastic properties (concentration, length and width of the strips) and soil properties (gradation, shape, particle size) were some of the factors indicated to have an effect on the proficiency of the reinforcement material.

Dhatrak et al. (2015) conducted a research to calculate the technical properties of soil by bringing it together with plastic waste. The result detected showing that the use of plastic waste bottle chips is an alternative method to enhance the sub grade soil when considering the construction of flexible pavements. Plastic waste was mixed with various proportions (0.5%, 1%, 1.5%, 2% and 2.5%) containing dry soil to calculate value of CBR. It was concluded that the mixture of plastic strip waste with the soil will enhance its strength and also, provide an economical and eco – friendly method to dispose of the plastic waste.

Hansaraj Dikkar (2017) conducted a research to improve the properties of soil by adding plastic shopping bags with different measurements as 10mm and 15mm lengths and 20mm,40mm and 60mm widths.The the percentages of plastic content used was 0.15%,0.30%,0.45% and 0.60%.It was concluded from the research that 0.30% of plastic content is optimum percentage to be used as a stabilizing agent for sizes 10mm x 40mm and 15mm x 40mm.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Materials

The materials used in this case study were locally acquired. The soil used was collected from around the university. The soil sample was prepared according to ASTM standards and basic routine tests were carried out in order to classify the soil sample. Figure 3.1 show the material used for this study.

Figure. 3.1: Material used for the study.

3.1.1 Expansive soil

Expansive soils are made up of montmorillonite, which brings about the excessive swelling and shrinkage characteristics of the soil and are formed from basalt or trap (Shah and Shroff, 2003). These soils contain expansive clay minerals such as smecite which leads to the absorption of water. Expansive soils basically consist of varying proportions of minerals which include: Smectite, Nontronite, Montmorllionite, Kaolinite, Illite (Masoumeh and Masoud, 2012). Due to the presence of montmorillonite, the soil possesses unwanted plasticity properties as well as high optimum moisture content and high swelling and shrinkage characteristics. These undesirable properties bring about volume changes which result in damages to structures constructed on the soil. Presence of organic matter in the form of humus enables the soil to be more compressible and plastic.

3.1.2 Plastic waste strips

In the process of conducting this study, shopping bags were collected from the students in university Campus. The material has an average density of average 798kg/m^3, with a tensile strength range of 14 to 20 MPa, with a thickness of 40 micron (Dikkar, 2017). In order to conduct the experiment a batch of plastic strips of known dimensions and weight were combined to dry soil and then thoroughly mixed. The shopping bags were cut into strips of width 10mm and length 15mm and were added to the soil at concentrations of 0.20%, 0.30% and 0.40% by weight of soil.The percentages and measurements were selected keeping in notice the previous study done by Hansaraj Dikkar in 2017 in which he uses different measurements as 10mm and 15mm lengths and 20mm,40mm and 60mm widths. The percentages of plastic content that he used was 0.15%,0.30%,0.45% and 0.60%. It was concluded from the research that 0.30% of plastic content is optimum percentage to be used as a stabilizing agent for sizes 10mm x 40mm and 15mm x 40mm.

Figure. 3.2: Plastic strips

3.2 Experimental Procedures

In the conduction of this experimental study, the following steps were taken:

- Evaluation of specific gravity of the soil sample according to ASTM D 854 method.
- To find out different limits of soil according to (Atterberg Limits)
    a. Liquid limit by Casagrande's apparatus as per ASTM D4318.
    b. Plastic limit as per ASTMD4318method.
- Particle size distribution using sieve analysis according to ASTM D 422M method.
- Evaluation of the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the soil sample using Proctor compaction test as per ASTM D 698.

- Evaluation of shear strength using:

    a. Unconfined Compression Test (UCS) according to ASTM D2166 method.

- A shrinkage test as per IS: 2720 (Part 6) – 1972 to evaluate significant volume change.

- The California Bearing Ratio test as per ASTM D1883 to determine the optimum amount of plastic strips in the soil by mixing the soil with percentages of 0.2%, 0.3% and 0.4% by weight.The mixing of soil with plastic strips and it compacted form in mould can be seen in Figure 3.3 and Figure 3.4.

Figure. 3.3: Plastic strips with soil

Figure 3.4: Plastic strips with soil

3.2.1 Specific gravity of soil

The soil specific gravity is simply the ratio of the soil solid weight versus equal volume of water weight. This test conducted is in order to determine specific gravity in the soil sample based on ASTM D 854. It is ascertained with the use of a volumetric flask in a basic experimental procedure.

3.2.2 Liquid limit

It can be defined as the water content at which the soil loses its strength and behave as viscous material. This test is carried out according to ASTM D 4318.The groove is made in the soil and then it is get closed in just 25 blows in liquid limit device shown in Figure 3.6.To ensure better accuracy, the test is performed several times and number of blows (N) are recorded. The liquid limit is plotted at 25 no of blows and water content (w %) on a graph. (Murthy, 2002).

Figure 3.5: Liquid limit test apparatus

3.2.3 Plastic limit

The plastic limit of soil is determined as per ASTM D 4318.when the soil has too much water content it loses it shape which is called plastic limit of soil. This test is performed by rolling out the fine – grained soil till it reaches 3mm in diameter and then measuring the content of water for the soil as it crushes on getting this diameter.

Figure 3.6: Determination of plastic limit by crumbling

3.2.4 Plasticity index

The plasticity index is the range of water contents where the soil shows plastic behavior. It is the difference between the liquid limit and the plastic limit (PI = LL-PL). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 tend to have little or no silt or clay. (Das and Sobhan, 2013). Figure 3.7 shows Casagrande’s plasticity chart.

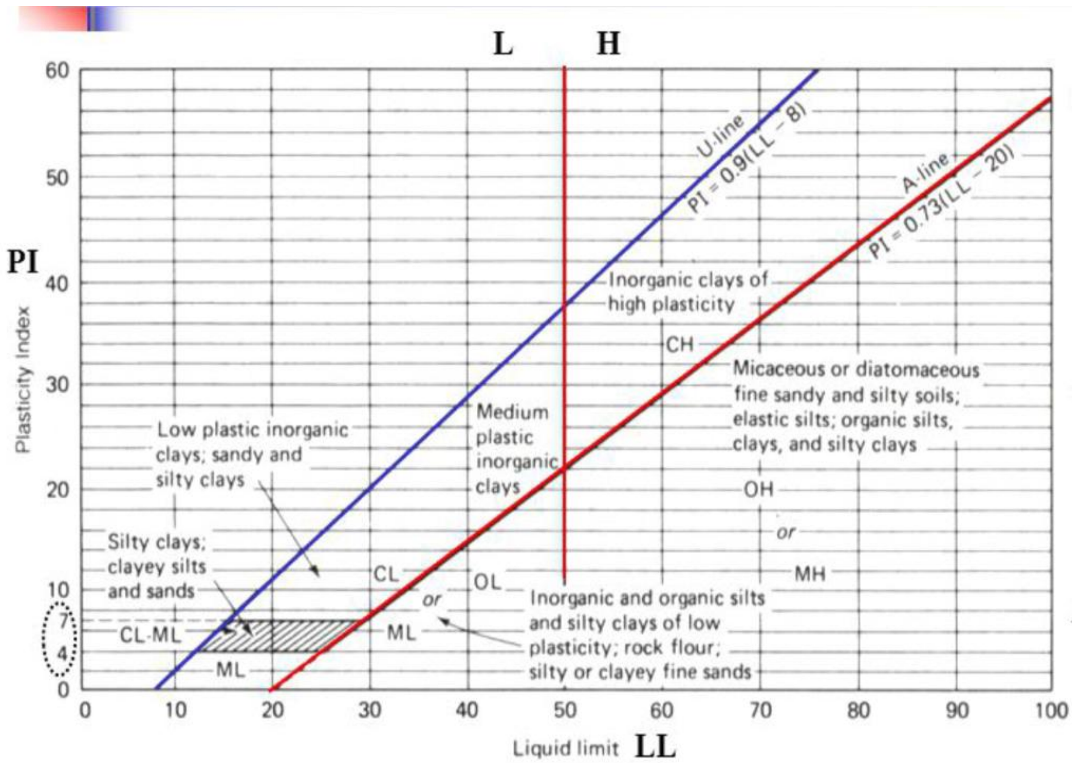

Figure. 3.7: Casagrande's plasticity chart (Howard, 1977)

3.2.5 Particle size distribution

This test is done to find the particle size distribution of soil as per ASTM D 422M. The test is carried out using the sieve analysis. The soil sample was passed through various meshes sizes and the retained weight was determined at each level. The total mass percentage represents the mass fraction within that particular size of particle range of distribution. The outcome from analysis is then sketched on semi-logarithmic graph with diameter of particle or the size of sieve with axis of logarithm and the passing percentage as the ordinate release a pure idea about the distribution of the size of particle (Soltani et al., 2017). Figure 3.9 is showing various sizes of sieves.

Figure 3.8: various sizes of sieves

3.2.6 Standard Proctor Compaction Test

The test shows a distinct correlation between the moisture content of the sample soil with the dry density of the sample soil. A sequence of tests is done on the reinforced plastic soil sample as per ASTM D698. The setup comprises of (a) a cylindrical metal mould of 10.15cm internal diameter and 11.7cm internal height, (b) a detachable base plate, (c) a collar of 5cm effective height, (d) a 2.5 kg rammer. The process of compaction aids the enhancement of the density in bulk by releasing air of the void spaces. The soil is added in three layers of the moulds, with each one undergoing blows of about 25 (Pradhan, 2012).

The dry density of a soil mass differs with moisture content for various types of soil and compactive effort. Adhesion and internal friction between soil particles aid in limiting compaction at low moisture content. With the increase in moisture content, moisture films are developed around the particles, thus lubricating them and increasing soil mass workability. This increase in moisture content does not exceed a certain value, as the soil particles are then replaced by the water at this stage and as the soil particles are more than the unit weight of water the density begins to decrease.

The mass of the compacted soil and volume of the mold gives the bulk density, and from water content we can find the Dry Density. The same procedure is repeated by increasing the water content. Each test produces a different set of values for the dry density and water content and from these values the compaction curve is drawn. The maximum point of the soil compaction curve is its maximum dry density (MDD) and the water content aligning with this point is the moisture content optimum which moisture content optimum (OMC) (Rajput et al., 2015)

Figure 3.9: Proctor compaction test apparatus

3.2.7 Unconfined compression test

This experiment is to find the unconfined compressive strength as per ASTM D2166, which would be used to evaluate the shear strength of the soil sample. The UCS of a soil is the pressured stress at which soil sample will fail under a compression test. The test comprises of the compression device and dial gauges for load and deformation. Prepared compacted soil is placed in the loading machine between the lower and upper plates. In beginning of the test a constant axial strain of 0.5% to 2% per minute is applied on sample. The loading is continued until the load values reached to 15% or 20% axial strain. The unconfined compressive strength is taken as the maximum load per unit area or the load per unit area at 15% axial strain. From the sample the water content is measured (Kate, 2005).The unconfined compression machine is shown in Figure 3.11.

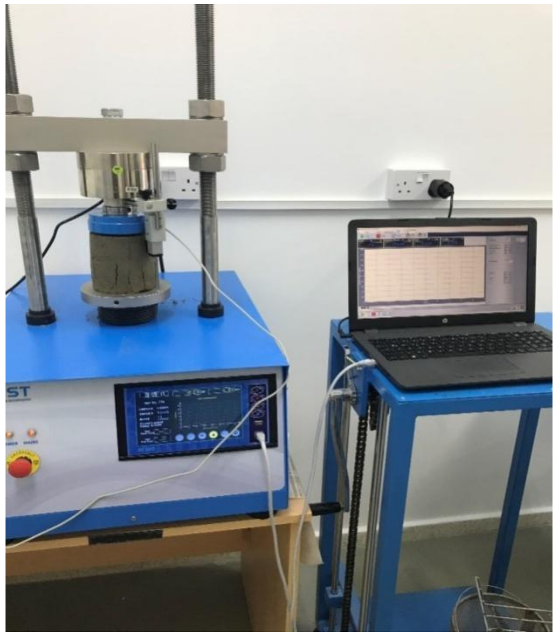

Figure.3.10: Unconfined compression test apparatus

3.2.8 California bearing ratio

The CBR test is laboratory experiment that measures the bearing value and the mechanical strength of highway sub – bases and sub grades. The test was developed by the California Division of Highways to find soil bearing capacity. The experiment is done in accordance with ASTM D 1883. The test is performed on remolded soil samples. It consists of a CBR machine which calculates readings at a constant rate of 1.25mm/min. A cylindrical mould of (150x175mm) diameter and height respectively. A collar of 50mm in length and detachable perforated base, compaction rammer, surcharge weight – annular weights each of 2.5kg and 147mm in diameter and a sieve 4.25mm as per American standards, coarse filter paper, balance (Choudhary, 2010).The CBR apparatus is shown in figure 3.1.2

Figure 3.11: CBR test apparatus

The soil sample is sieved through the ASTM sieve 4.25, water was then added to different soil sample having different weights. The optimum water content is attained. Sample is then prepared in the moulds and placed in the machine. The needle is brought in contact with the soil and a load is applied for the establishment of contact between plunger and soil sample. The dial readings are then adjusted to zero. Loads at penetration rates of 12.5mm, 12.7 and 12.9 mm were noted.

3.2.9 Volume shrinkage behavior of soil

This experiment is conducted according to IS:2720 (Part 6) – 1972 to ascertain the volume shrinkage behavior of a soil sample. For the purpose of this study, the soil sample has been compacted with zero and then with three different percentages of plastic content as 0.2%, 0.3% and 0.4% respectively. With this method, the volume of soil sample can be measured. After samples were prepared the initial volume of prepared samples has been measured and they were put to series of wetting and drying cycles. In each cycle 200 grams/ml of water was added in each sample to notice the crack and shrinkage behavior. As the water content of a soil increases or decreases, the soil will either shrink or swell. This can result in soil damages such as cracks (Atique and Sanchez, 2011). The volume (length x breadth x height) is also measured with the use of a scale. This measure in volume is calculated until stability in volume is achieved.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter is going to concentrate on the analysis and discussion of the experimental laboratory work in order to achieve the general objectives of the thesis. As such, this chapter is going address the following discussion.

1. Atterberg Limits analysis
2. Compaction analysis
3. Unconfined compression test (UCS)
4. California bearing ratio test (CBR)
5. Shrinkage test analysis

4.1 Atterberg Limits analysis

The Atterberg limit analysis is the analysis that comprises the comparison of liquid limit and plastic limit test. These are limits which originated from Albert Atterberg, a Swedish soil scientist in 1911 whose aim was to observe and measure the various significant changes in fine – grained soils based on its water content. Figure 4.1 shows the result of liquid limit which is 49 and Figure 4.2 shows the comparison of Atterberg limits having plastic limit of 32 and plasticity index is 17.Seeing the results from liquid limit it can be seen from plasticity chart that the soil has medium plasticity (Holtz & kovacs, 1981).

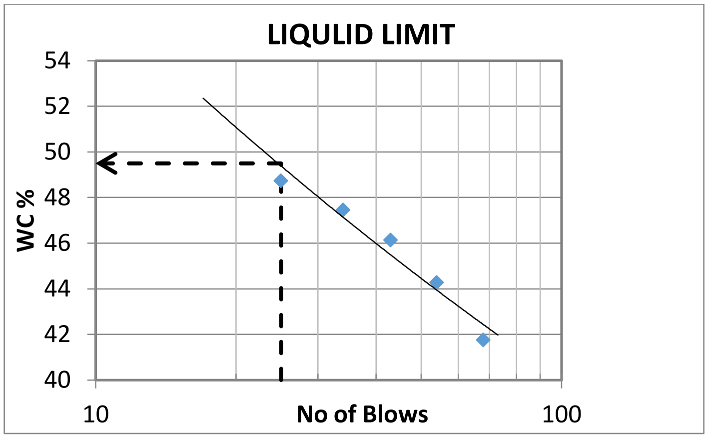

Figure. 4. 1: LL test with respect to No. of stroke and WC (%)

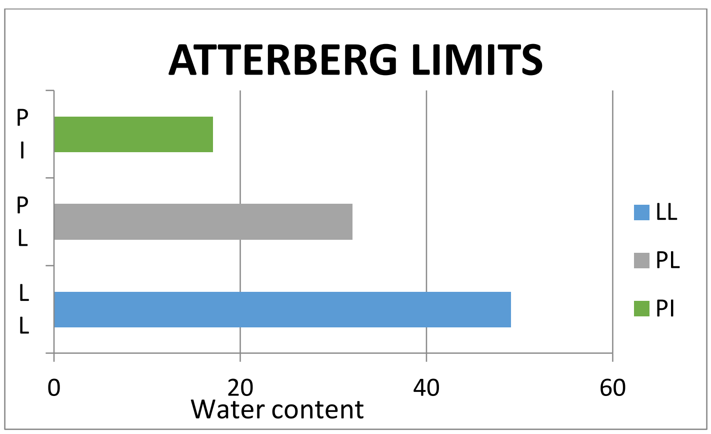

Figure 4.2: Atterberg limit comparison showing PL, LL and PI

4.2 Compaction Test Analysis

Compaction is a process that brings about an increase in soil density or unit weight, accompanied by a decrease in air volume. There is usually no change in water content. The degree of compaction is measured by dry unit weight and depends on the water content and compactive effort e.g weight of hammer, number of impacts, weight of roller, and number of passes. For a given compaction effort, the maximum dry unit weight occurs at optimum water content. Compaction can be applied to improve the properties of an existing soil or in the process of placing fill. The main objectives are to: increase shear strength and therefore bearing capacity, increase stiffness and therefore reduce future settlement and decrease voids ratio and so permeability, thus reducing potential frost heave. It has been reported that a number of factors will affect the degree of compaction that can be achieved: Nature and type of soil, i.e. sand or clay, grading, plasticity, water content at the time of compaction, site conditions, e.g. weather, type of site, layer thickness, compactive effort: weight, vibration, number of passes (Elsharief and Sufian, 2018).

In compaction test firstly, we used 5%, 10%, 15%, 20% and 25% of water content to find the optimum moisture content (OMC) and maximum dry density (MDD). The obtained results show that the OMC can be reached and found at 20.11% and MDD is 1.62 (g/cm^3) (see, Table 4.1), this result can be demonstrated with 0% plastic content.

Table 4.1: Compaction results for WC% and DD with 0% plastic content

W (%)	9.8	15	20.11	27.64	30.36
γd (g/cm3)	1.4943	1.5662	1.6152	1.4100	1.3491

From the Figure 4.3 it can be seen that the water content and dry density have direct relationship between 5%-15% this is to say the higher the moisture content the higher the dry density (DD). But when the percentage water content increased to 20% then the DD decreases with the increases of water content values. Based on the Table 4.1 it can also be observed that, the water content is increasing with the increase in dry density. This is clear that after 15% the DD is reducing even with the increased of water content. Figure 4.3 demonstrated the compaction results showing compaction with 0% plastic contents together with Saturation of 100%, 90% and 80%.

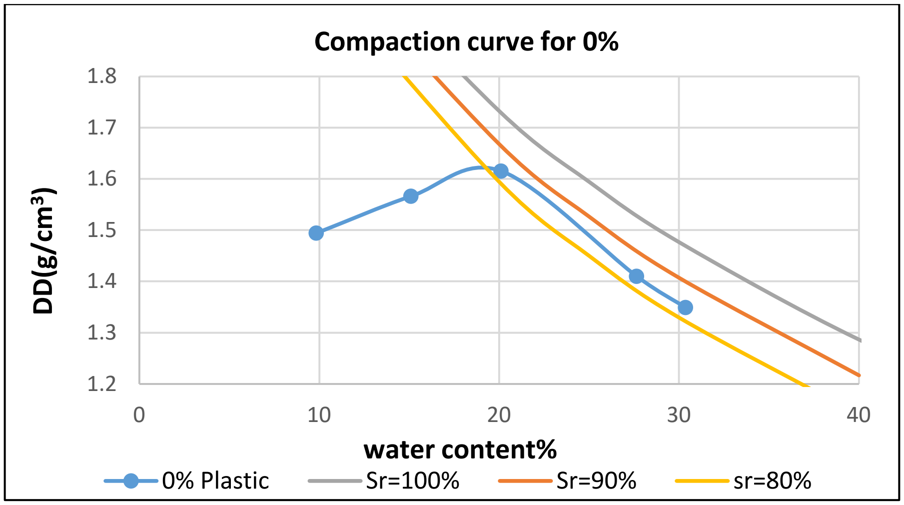

Figure 4.3: Compaction for WC% and DD with 0% plastic

Secondly the compaction was carried out with 0.2% plastic contents by the weight of the soil.This were carried out with the same percentage of water contents (5%, 10%, 15%, 20 %and 25%). Table 4.2 shows the summary of the obtained WC% and DD. As it can be seen the water contents were found to be higher than the aimed water contents at the end of measurements. It could be related to the internal water around the clay particles. The samples were dried at 60 degree centigrade, so their properties will not alter during the drying process. This has resulted in starting with 2% water content.

Table 4.2: Compaction results for water content and DD with 0.2% plastic content

W (%)	7.8	13	16.77	22.31	27.55
γd (g/cm3)	1.4314	1.3814	1.5042	1.5307	1.4120

From the Table 4.2 it can be seen that the WC percent and DD have direct relationship between 5%-20% this is to say the higher the moisture content the higher the DD, the DD was attained to be 1.5307(g/cm^3) at 20% with the corresponding w% as 27.55%. But when the percentage water content increased to 25% then the DD decrease to 1.412 (g/cm^3) with the increase in water content values. This is clear that after 20% the DD is reducing even with the increased of water content. Figure 4.4 demonstrated the compaction results showing WC and DD with 0.2% plastic contents. Together with the saturation curves. As it can be seen that 80% saturation line cross the compaction curve at the optimum water content. Moreover it has shown that the obtained DD is highly significant and can be used reliably in this type of soil.

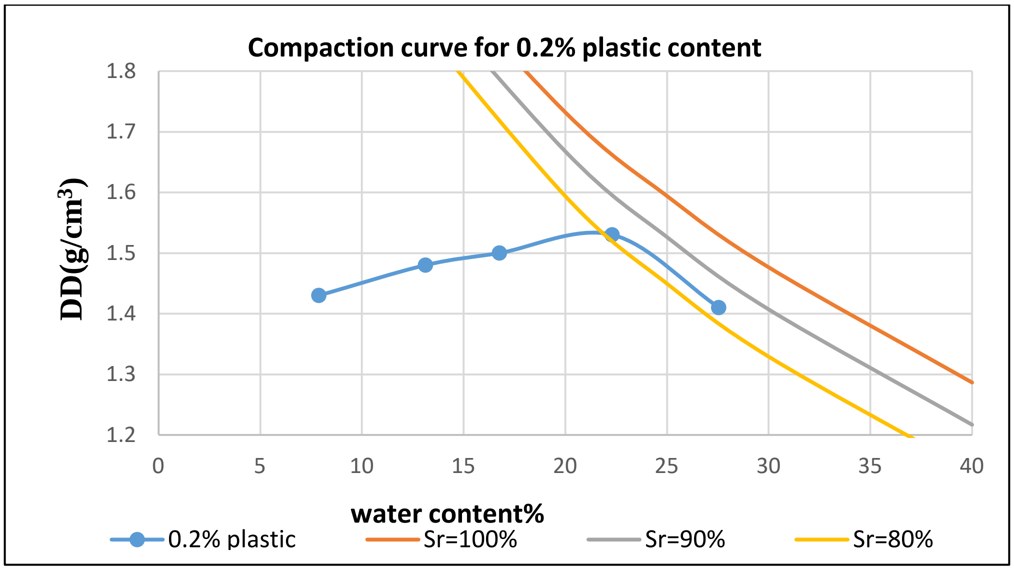

Figure 4.4: Compaction for WC% and DD with 0.2% plastic

Thirdly the compaction was again implemented with 0.3% plastic contents by the weight of the soil. This was carried out with the same percentage of water contents (5%, 10%, 15%, 20 % and 25%). Table 4.3 shows the summary of the obtained WC% and DD.

It can be observed from the Table 4.3 that the WC% and DD have direct relationship between 5%-15% with the range of 1.4, 1.5 to 1.6 this is to say the higher the moisture content the higher the DD, the DD was attained to be 1.624(g/cm^3) at 15% with the corresponding w% as 18.07(g/cm^3). But when the percentage water content increased to 20, 25% then the DD decreases to 1.47(g/cm^3) and 1.411(g/cm^3) respectively, with the increases of water content values. This is clear that after 20% and 25% the DD is reducing even with the increased of water content. Figure 4.5 demonstrated the compaction results showing WC% and DD with 0.3% plastic contents.

Table 4.3: Compaction results for WC% and DD with 0.3% plastic content

W (%)	9.6	13.13	18.07	25.55	28.13
γd (g/cm3)	1.4126	1.5291	1.6240	1.4700	1.4113

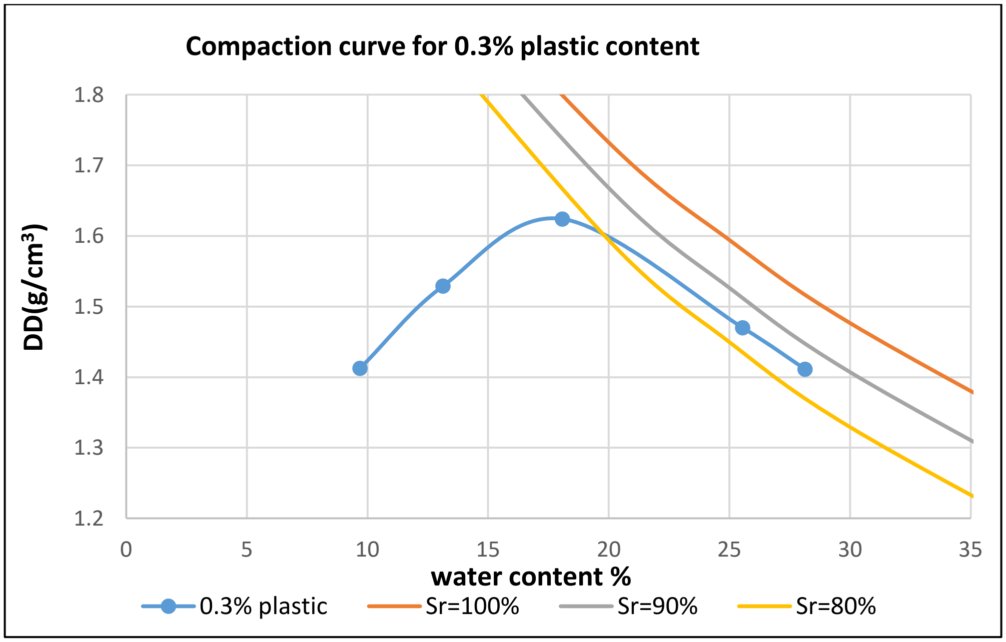

Figure 4.5: Compaction for WC% and DD with 0.3% plastic

Finally, the compaction was applied with 0.4% plastic contents by the weight of the soil. This was supported out with the same percentage of water contents (5%, 10%, 15%, 20 % and 25%). Table 4.4 shows the summary of the obtained WC% and DD (see, Table. 4.4 and Figure 4.6)

Table 4.4: Compaction results for WC% and DD with 0.4% plastic content

W (%)	7.9154	12.8784	18.0093	21.9797	28.2010
γd(g/cm3)	1.4800	1.5400	1.5900	1.5400	1.3884

From the Figure 4.6 and Table 4.4 it can be seen that the WC% and DD have direct relationship between 5%-15% this is to say the higher the moisture content the higher the DD. But when the percentage water content increased between the range of 20% to 25% then the DD decreases with the increases of water content values. This is clear that after 20% the DD is reducing even with the increased of water content. Figure 4.6 demonstrated the compaction results showing WC% and DD with 0.4% plastic contents together with saturation curve.

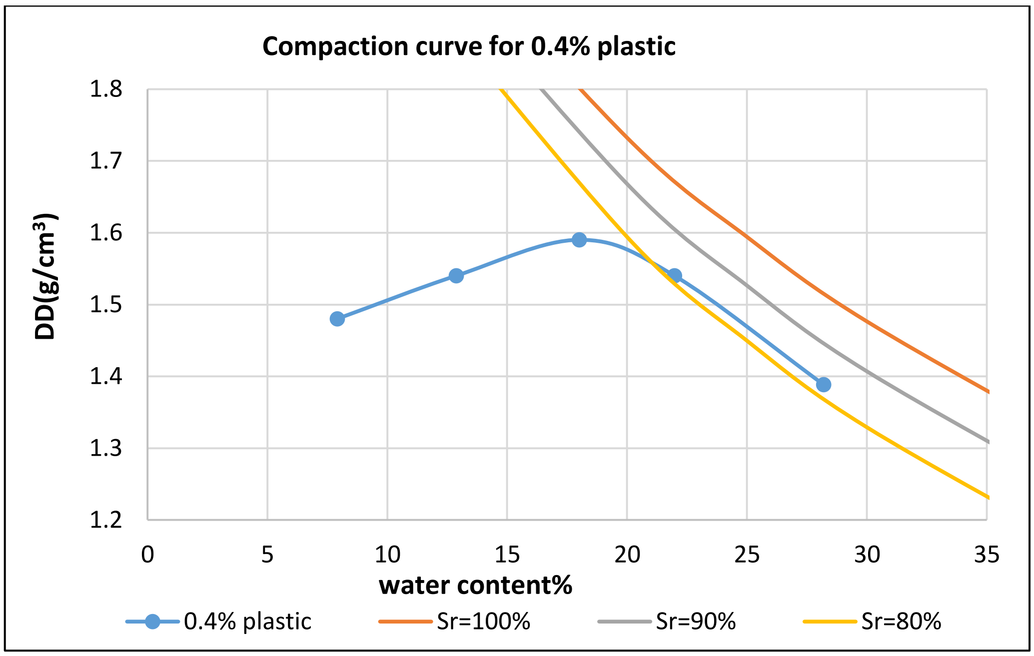

Figure 4.6: Compaction for WC% and DD with 0.4% plastic

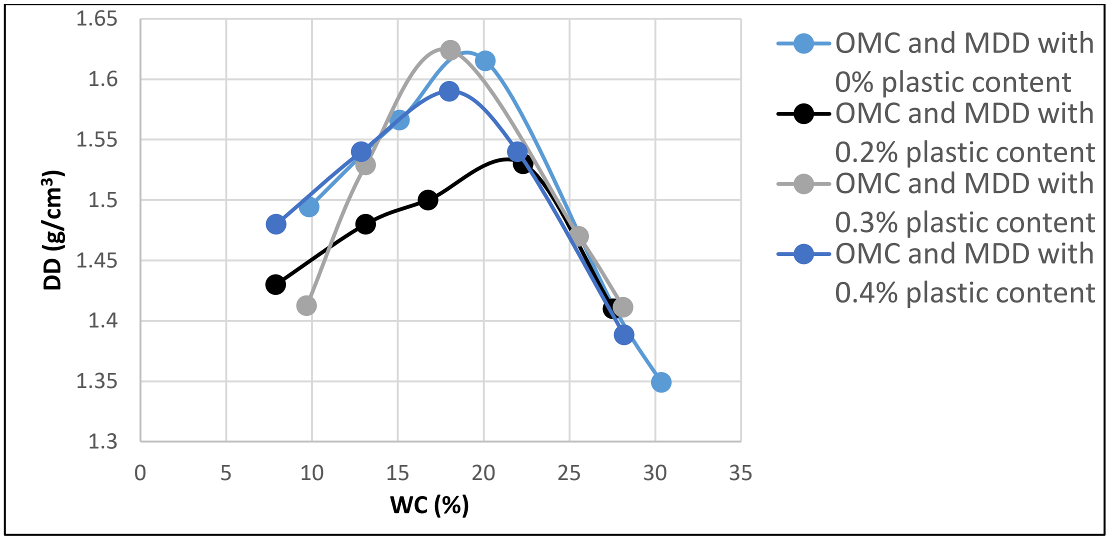

Figure 4.7: Comparison of DD with WC%

Table 4.5: The Comparison of MDD and OWC

Plastic %	**OWC%**	**MDD(g/cm^3)**
0%	15	1.56
0.2%	16.77	1.5
0.3%	18.07	1.62
0.4%	16.77	1.5

In table 4.5 the comparison of MDD and OWC are given with different percentages of plastic. It can be seen that increase in plastic bag content to 0.2% reduced the MDD however by addition of plastic it increased again to the atmost same value of 0% MDD. More addition of plastic bags to 0.4% resulted in reduction of MDD. This could be explained by mixing the plastic bags shreds disturb the original orientation of grains and therefore reduce the degree of compaction. The optimum compaction degree was achieved at 0.3% plastic bag.

4.3 California bearing ratio (CBR)

The California Bearing Ratio (CBR) is the most utilized parameter for dimensioning flexible pavements.

The analysis was also carried using the same content of plastic (0, 0.2, 0.3 and 0.4%). The samples were compacted at their previously obtained OWC and MDD in CBR mould, and the test was conducted till 12.9mm penetration. Table 4.5 shows the water content percentage measured at the end of test with the corresponding plastic values.

Table 4.6: WC (%) with corresponding plastic content 0-0.4%

Plastic	0%	0.20%	0.30%	0.40%
Water content (WC) %	20.11%	22.31%	18.08%	18.01%

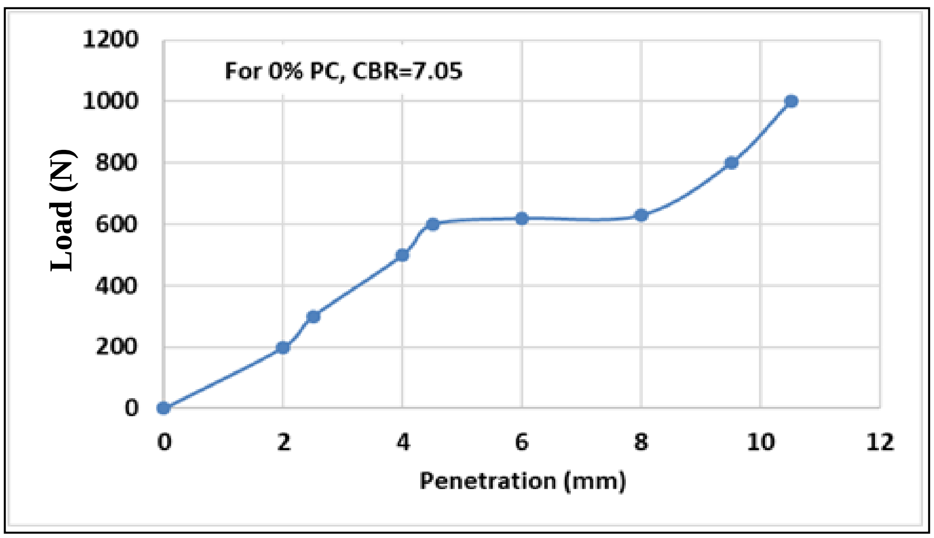

Figure 4.8: CBR with Load vs. Penetration for 0% plastic

In figure 4.8 shows CBR load verses penetration. The load was given in ratio of 1.25mm till 12.9mm penetration was reached. Figure 4.9, 4.10 and 4.11 are showing results for 0.2%, 0.3% and 0.4% plastic bag addition respectively.

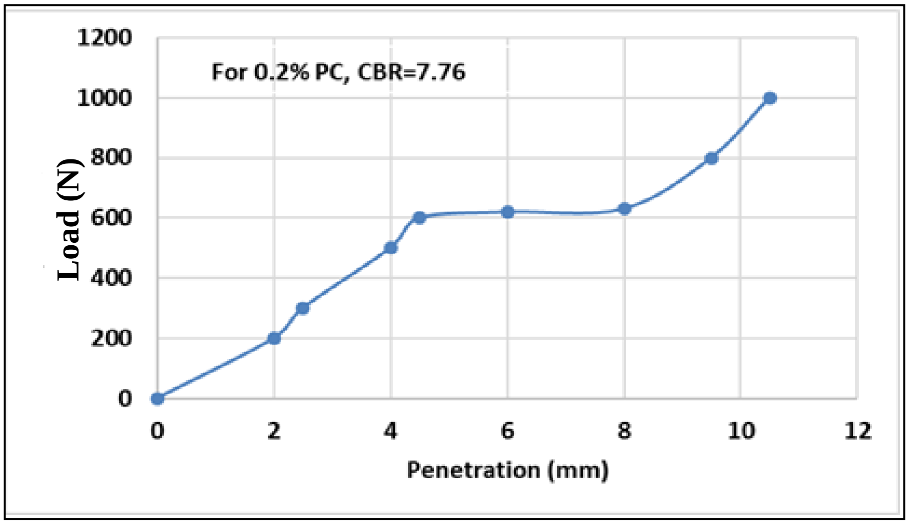

Figure 4.9: CBR with Load vs Penetration with 0.2% plastic

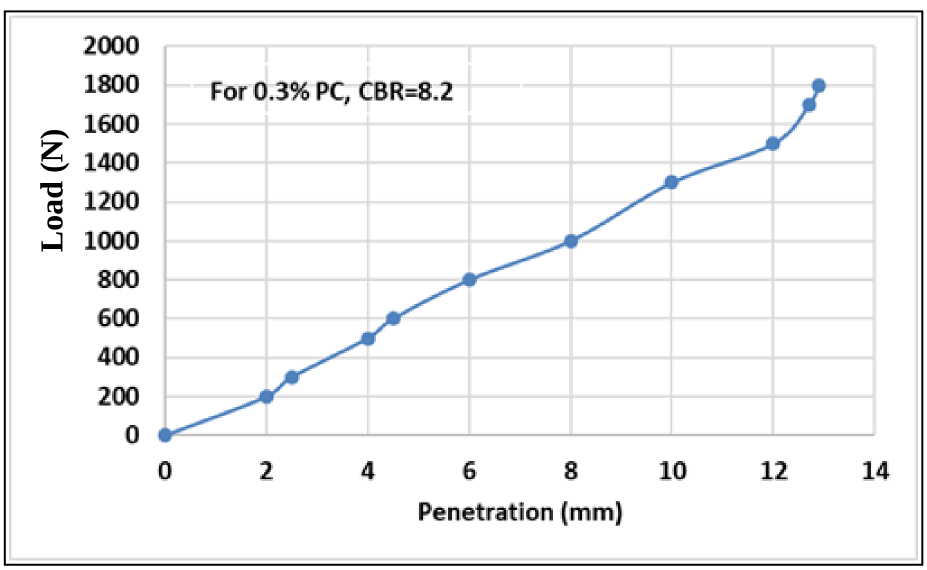

Fig 4.10: CBR with Load vs. Penetration with 0.3% plastic

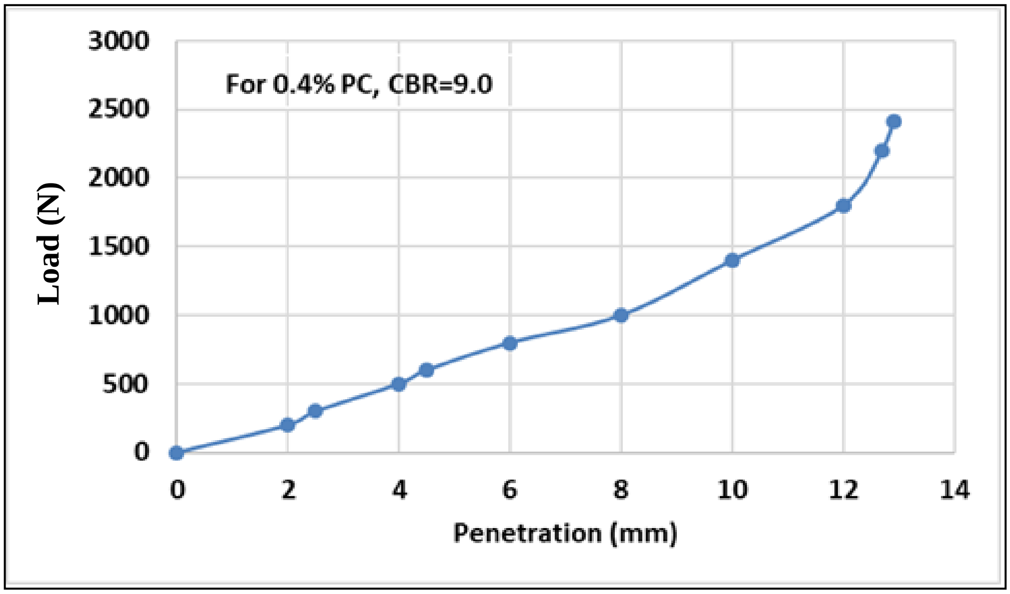

Figure 4. 11: CBR with Load vs. Penetration with 0.4% plastic

Table 4.7: Plastic content with CBR Value and load penetration

Plastic content	CBR%	LOAD(N)
0	7.05	1594
0.2%	7.76	1695
0.3%	8.2	1795
0.4%	9.0	2415

As it can be seen from the table 4.7 the increase in resistance to penetration is increased as percentage of plastic is increased which also causes increase in CBR ratio. At 0.4% the sample required more load which is 2.415kn to penetrate the soil specimen. And harder the material the higher will be the CBR value. So CBR is also found to be maximum at 0.4% inclusion of plastic content .The CBR value for clay should be from(3 – 10%) according to (American Association of State Highway and Transportation Officials). As we achieve more CBR at 0.4% plastic content but we are losing maximum dry density. Hence recommended is soil sample with 0.3% plastic content because it has better soil packing with a good CBR value of 8.2%.

4.4 Unconfined Compression Strength (UCS)

The UCS is done to find compression strength in an unconfined condition of the soil, for this purpose four samples were compacted at their obtained MDD and OWC with 0, 0.2, 0.3 and 0.4% of plastic bag addition. The height and diameter of sample were (120.7) mm and (102) mm respectively. The samples are then placed in UCS testing machine and readings were observed until the cracks were observed in the samples.

After getting the results it is noticed that the strength of soil is increased as plastic bag percentage is increased. Therefore at 0.4% addition of plastic bags unconfined compressive strength was reached. But same is the scenario with UCS as with CBR we loses our maximum dry density at 0.4%. So UCS at 0.3% can be accepted as the optimum amount of stabilizer addition.

Table 4.8: UCS Results with different percentages of plastic/percentage difference

Plastic content	UCS (kPa)	IncreaseinUCS%	Cohesion
0% plastic content	88	-----	44
0.2% plastic content	154	75%	77
0.3% plastic content	195	121%	97.5
0.4% plastic content	216	145%	108

By addition of 0.4% of plastic bags an increase of 145% is observed in compressive strength of soil sample. As undrained cohesion of clay soil can be measured by equation

$$C_u = q_{u/2}$$

Where C_u is cohesion

and q_u is Unconfined compression strength

So it can be concluded that increasing the plastic bags content increases the cohesion of the samples and therefore shear strength increases.

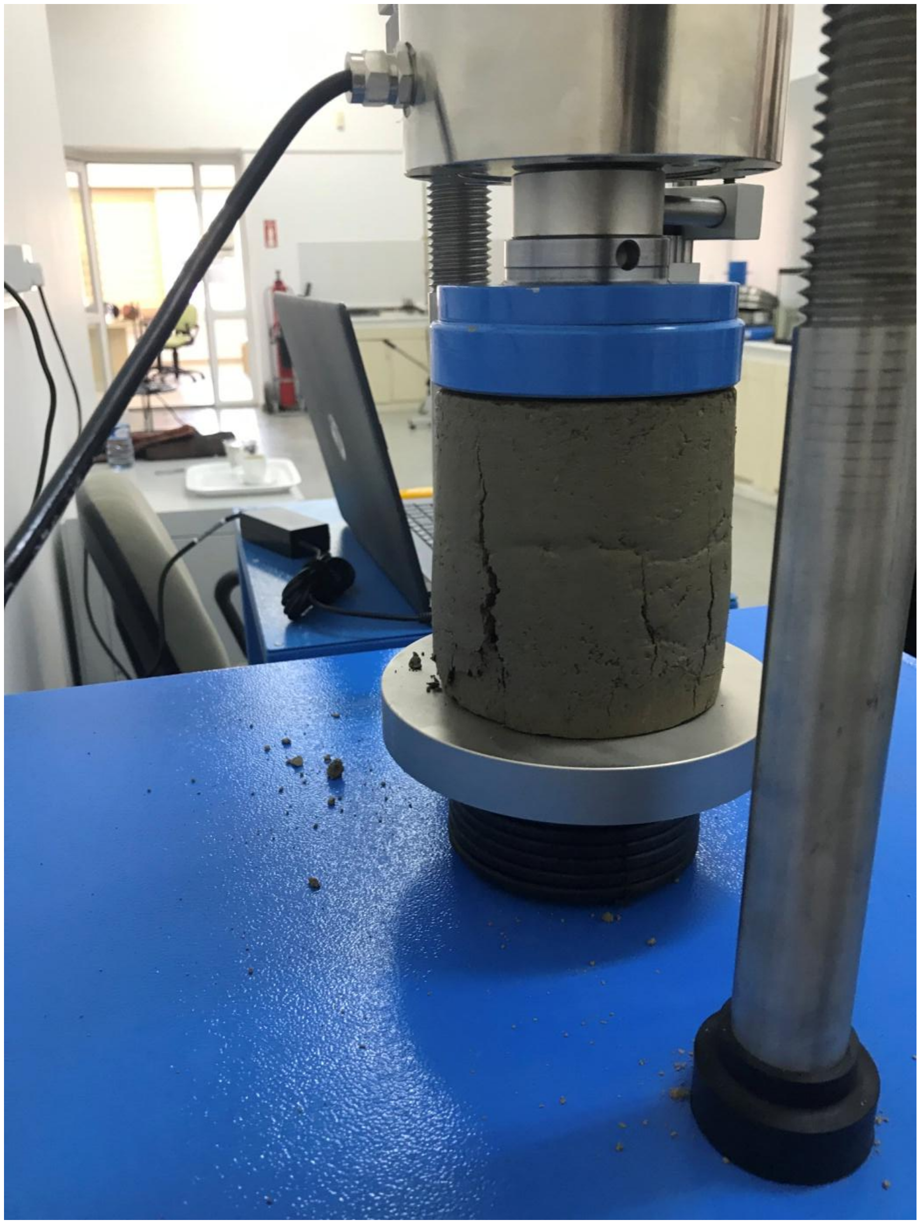

Figure 4.12: UCS result showing the failure under stress for 0% plastic content

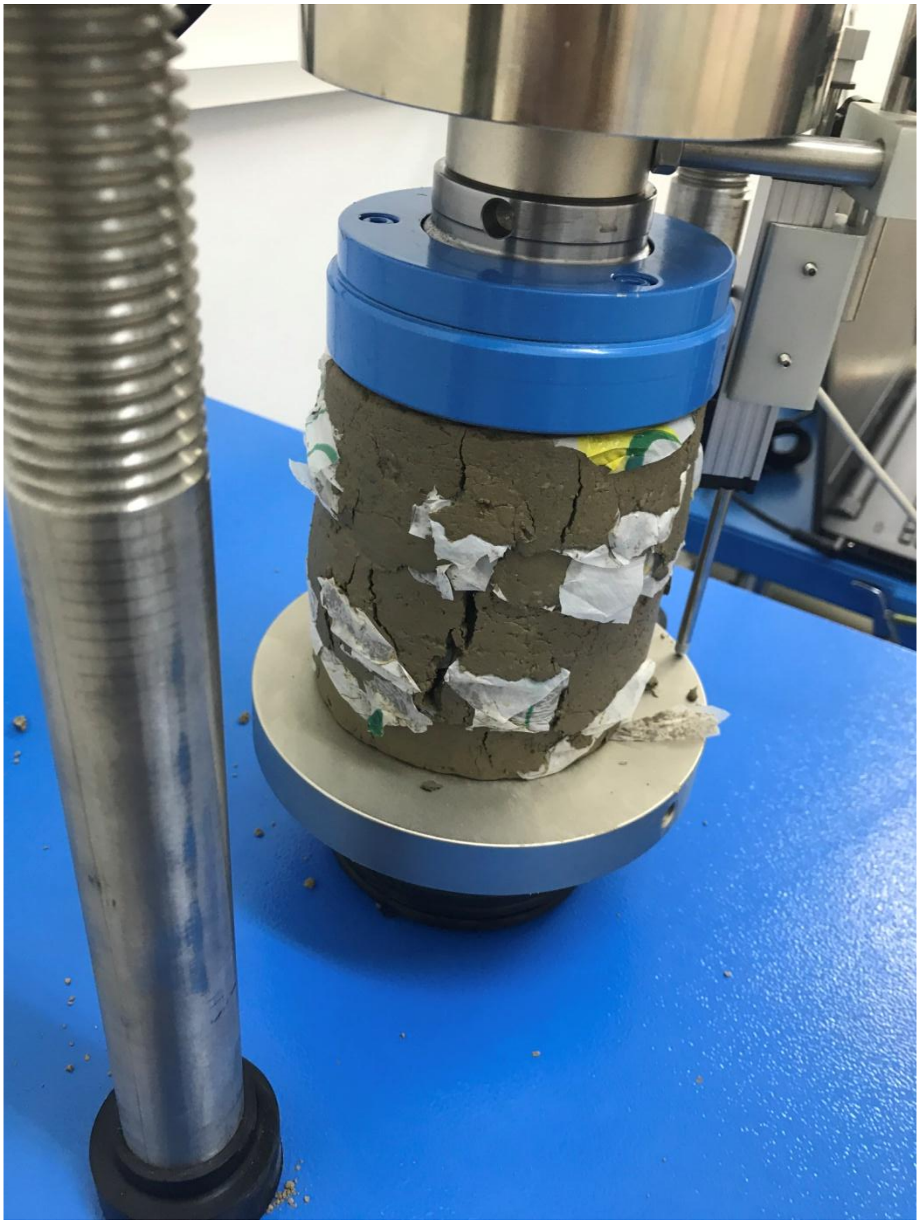

Figure 4.13: UCS result showing the failure under stress for 0.2% plastic content

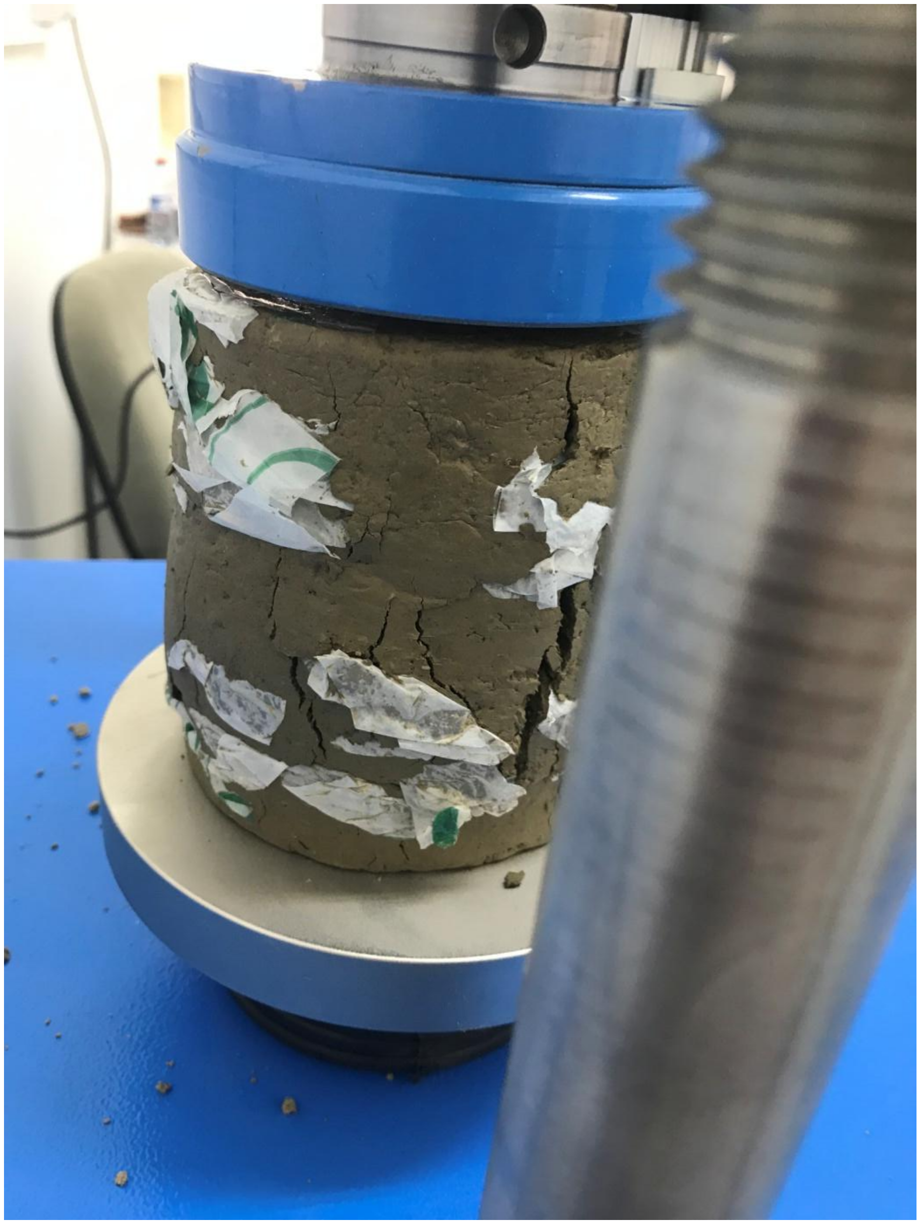

Figure 4.14: UCS result showing the failure under stress for 0.3% plastic content

Figure 4.15: UCS result showing the failure under stress for 0.4% plastic content

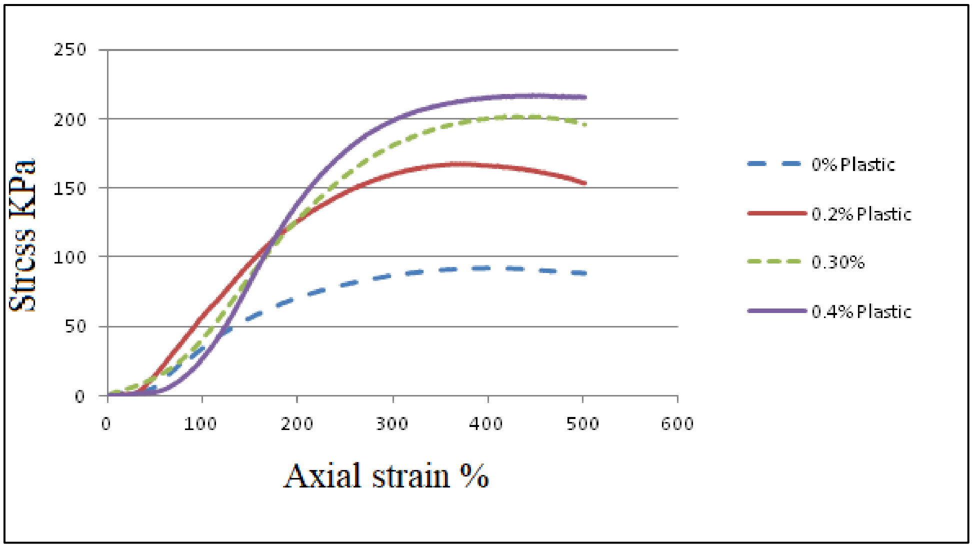

Figure 4.16: Comparison of UCS with different percentages of plastic content

Figure 4.16 shows the UCS comparison of soil samples with 0.2%, 0.3% and 0.4% of plastic bags strips stress (kpa) vs Axial stain(%). As it can be seen that all the samples show plastic behavior while failure as it is expected from cohesive samples which means that samples continue to carry some stress even after failure in response to its residual strength.

4.6 Shrinkage Behavior of Soil Analysis

This experiment is conducted according to IS:2720 (Part 6) – 1972 to ascertain the volume shrinkage behavior of a soil sample. For the purpose of this study, the soil sample has been compacted at his optimum water content with zero and then with three different percentages of plastic content as 0.2%, 0.3% and 0.4% respectively. With this method, the volume of the soil is measured. After they were put to series of wetting and drying cycles. In each cycle 200 gram/ml of water was added in each sample to notice the crack and shrinkage behavior.

(a) With 0% plastic

(b) With 0.2% plastic

(c) With 0.3% plastic

(d) With 0.4% plastic

Figure 4.17 : Showing samples with (a)0%, (b)0.2%, (c)0.3% and (d)0.4%after drying/shrinkage

Table 4.9: Showing different volumes calculted at different intervals

Plastic percentage	Days1	Day2	Day4	Day6	Day8	%Difference
	0	24	48	96	144	
0%	$2000cm^3$	$2000cm^3$	$1000cm^3$	$725cm^3$	$621cm^3$	68%
0.2%	$2000cm^3$	$1600cm^3$	$1450cm^3$	$1050cm^3$	$869cm^3$	56%
0.3%	$2000cm^3$	$1875cm^3$	$1772cm^3$	$1345cm^3$	$910cm^3$	54%
0.4%	$2000cm^3$	$1750cm^3$	$1654cm^3$	$1280cm^3$	$828cm^3$	58%

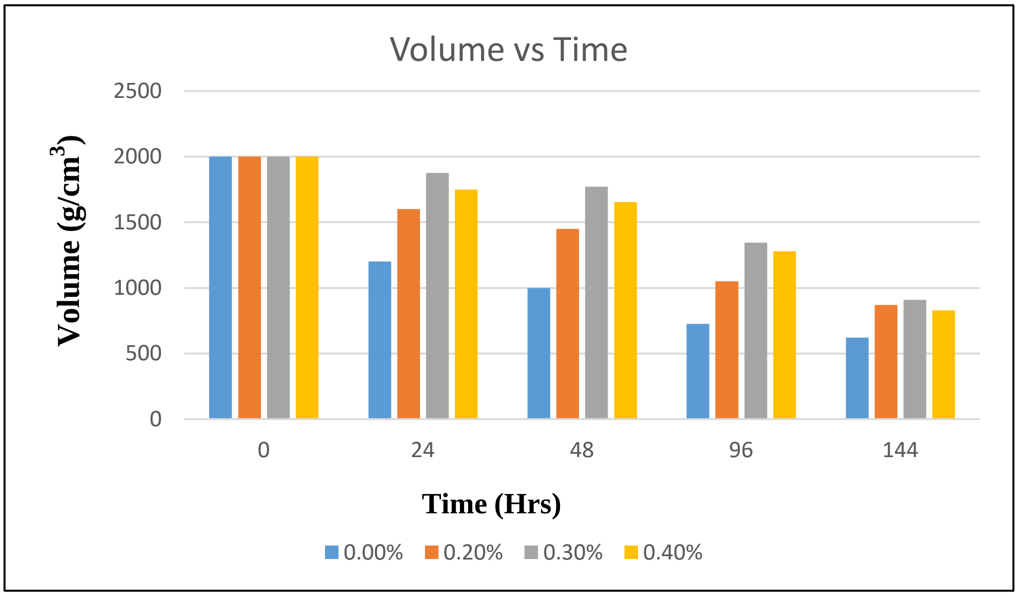

Figure 4.18: Showing volume comparison of samples

As it can been seen from the table 4.6 there is significance volume change after adding water to the sample and leaving it to several wetting drying cycles. The initial volume noted after the samples were made was 2000Cm^3 for each sample and it was left till it totally dried, that normally took about 24 hours in temperature of 30 to 40 degree centigrade for one day to dry and the measurement done after drying shows that the sample with 0% plastic content has shrinked more than sample with 0.4% plastic content because the shrinkage was less as compared to other samples. It can be explained as plastic bags shreds act as fibers within the soil, keeping the grains together and therefore resisting the shrinkage. After the second measurement 200 g/ml of water was added in all the sample and the readings were noted after full drying. The sample with 0% plastic shows more shrinkage as compared to the samples containing more amount of plastic content. The samples were further more left for wetting/Drying cycles by adding 400 g/ml in total on water with 2 days interval of wetting and drying. The results noted after 4 cycles shows that the sample with higher shrinkage contains no plastic. At 0.4% less cracks were observed as it can be seen in figure 4.18. Maximum volume change after the fourth cycle was observed in the sample with no plastic content by 68%.volume reduction. This volume reduced to 54% in addition of 0.3% plastic bags shreds. 0.2% and 0.4% reduced the volume shrinkage to 56% and 58% respectively. The starting stage of drying was from OWC but after first drying cycle 200g/ml of water was added to sample with area of 500(cm^2) resembling 4mm of rain per square meter. After second cycle of drying ,400 gram/ml water resembling 8mm of rain was added to the sample, showing a heavy rain condition 4 to 8mm per hour (USGS.gov).

As Cyprus is considered as a semi arid climate therefore soil is often dry or partly saturated. The test was operated to monitor the behavior of dry soil after a heavy rain and then the shrinkage of it during drying process.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The plastic waste is deteriorating our environment and proper care or methods need to be obtained in order to get rid of plastic pollution and to use it in to something more beneficial. So as geotechnical engineering our major goals is to use this waste material in to recyclable material, therefore this thesis employed the used of plastic waste as the stabilization of the soil.

As stated above the following are the main objective of the thesis:

- To improve the engineering characteristics of the soil such as shear strength and bearing capacity
- To find a good way for dumping of plastic wastes.
- Decreasing cost of soil stabilization by using cheaper material
- Making the waste materials and environmental hazardous material into the useful material.

For this purpose, the soil from near east university campus has been collected and different test such as compaction, compression, CBR and shrinkage behavior of the soil has been implemented with and without plastic percentage content as the stabilizer. Optimum moisture content and maximum dry density of the soil were found out and then soil with plastic content as 0.2%, 0.3% and 0.4% were considered and it was noted that the optimum was reached and attained at 0.3%.

It was observed that CBR value goes on increasing from 7.05% at 0% to 9.0% at 4.0% plastic bag contents. Major difference has been noted in soil for 0% and 0.4%.

While performing UCS test the percentage difference of samples with no plastic and with 0.2%,0.3% and 0.4% were calculated which goes on increasing from 0 to 145% showing that the samples with 0.4% plastic fibers has much compression strength as compared to other samples.

Shrinkage analysis were also done on samples with same amount of plastic bags content and results shows that shrinkage were reduced and cracks were visibly improved.

Soil stabilization is a process of increasing different engineering properties of soil such as its strength and its bearing capacity. The main purpose is to make the soil good enough to be used for different construction purposes such as road construction and pavements.

The demand of plastic and its usage is increasing every day and it is effecting our environment. It is very important to find a good way for its disposal instead of dumping which has some harmful effects. So using it to stabilize the soil is a cheap and better way. Like many countries Cyprus has also issues of dumping the waste so this will help to reduce the amount of plastic waste and will provide us a soil which has better engineering properties. These plastic wastes have much harmful effect even on climate. If we dumped these waste we are having ground pollution. The latchet flowing from these plastic bags percolate into ground and destroying our ground water resources. Burning these wastes causes emission of methane gases which is destroying our ozone layer.

Adding plastic to soil will improve its engineering properties. The demand of plastic is increasing and we need to find a cheap and better solution for its disposal. According to this research and comparing it with previous studies done it is observed that using this waste in soil stabilization give good engineering properties to the soil. Many countries are now focusing on using soil in plastic. India has started it in construction of roads and pavements.

5.1 Recommendation

1. Different sizes of plastic strips should be used in order to compare the result with different length and percentages.

2. Different types of soils like sand, clay and silt can be used.

3. Compressibility and permeability of samples can be found out via further tests.

4. Other products for solid waste can be used as soil stabilizer like bottles, tires, plastic glass fiber etc.

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