Investigation on the combined effect of Marble dust and Waste paper sludge to improve the geotechnical properties of Black cotton soil (The case of Gelan Area)

Dereje Kebede Getachew

A Thesis Submitted to

Department of Civil Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Civil Engineering (Specialization in Geotechnical Engineering)

Office of Graduate Studies
Adama Science and Technology University

July 2021

Adama, Ethiopia

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Declaration

I hereby declare that this Master’s thesis entitled ” Investigation on the combined effect of marble dust and waste paper sludge to improve the geotechnical properties of black cotton soil (The case of Gelan Area)” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

Dereje Kebede	______________________	______________
Name of the student	Signature	Date

Recommendation

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Investigation on the combined effect of marble dust and waste paper sludge to improve the geotechnical properties of black cotton soil (The case of Gelan Area)**" prepared under my guidance by **Dereje Kebede** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Civil Engineering (Specialization in Geotechnical Engineering). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Afzal Khan(PhD)	____________________	______________________.
Advisor	Signature	Date

Approval Page of M.Sc. Thesis

I, the advisor of the thesis entitled "**Investigation on the combined effect of marble dust and waste paper sludge to improve the geotechnical properties of black cotton soil (The case of Gelan Area)**" and developed by **Dereje Kebede** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

<u>Afzal Khan(PhD)</u>	____________________	____________________.
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Dereje Kebede** have read and evaluated the thesis entitled "**Investigation on the combined effect of marble dust and waste paper sludge to improve the geotechnical properties of black cotton soil (The case of Gelan Area)**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Mater's of Science in Civil Engineering (Specialization in Geotechnical Engineering).

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List of Abbreviations and Symbols

AASHTO	American Association of states high ways and transport Official
USCS	Unified Soil Classification System
ASTM	American Society for testing material
BCS	Black Cotton Soil
WPS	Waste Paper sludge
MD	Marble dust
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
UCS	Unconfined Compressive Strength
$\mathbf{e_o}$	Void Ratio
Cc	Compression index
Cv	Coefficient of vertical consolidation (Cv)
Mv	Coefficient of volume compressibility (mv)
$\mathbf{{}^{KN}/_{m2}}$	Kilo newton per Meter Square
$\mathbf{{}^{g}/_{cm3}}$	Gram per centimeter cube

Abstract

Expansive soil like Black Cotton soil is a highly plastic soil that normally contains active clay minerals. When the water changes in expansive soil, the volume would be changed as well. These volume changes can lead to either swelling or shrinkage. Black cotton soil creates a problem in construction sites of Gelan area because of its swell and shrink behavior. When it comes in contact with water excessive swelling is caused and when water content decreases shrinkage occurs. Because of this movement lightly loaded structures such as foundations, pavements, canal beds, linings, and residential buildings that are found in this area are severely damaged. In the present study, an alternative method of soil stabilization using the combined effect of Marble dust and waste paper sludge is investigated based on laboratory test results. Black cotton soil is collected from construction site of Gelan area of two test pits of depth 1.5 meter. Laboratory tests for natural Black cotton soil and mixed with waste paper sludge and marble dust have studied. Standard compaction and unconfined compressive strength tests were performed by mixing Black cotton soil samples of two test pits with Waste paper sludge of 5, 10 and 15% by mass of soil. From these tests addition of 5% Waste Paper sludge is obtained as optimum content to improve soil strength. By taking the optimum waste paper sludge, Marble dust of 10, 20, 30 and 40% by mass is added to further improve the properties of the soil. The result shows that there is significant improvement of the soil in plasticity, swelling and strength characteristics. From the study it is concluded that addition of 5% waste paper sludge with 30% waste paper sludge is optimum amount to improve the properties of the soil. The optimum amount of marble dust and waste paper sludge also improved the compressibility characteristics of the soil.

Key words: Waste Paper Sludge, Marble dust, Black Cotton Soil, Stabilization

Chapter One

Introduction

1.1 Background

Expansive soil is a highly plastic soil that normally contains active clay minerals. It is a commonly identified problem which has made scientists concern about the design, protection, and operating of highway and structural systems. Expansive soils can be found in arid/semi-arid areas, where even moderate expansive soils can cause major damages to the structure or in humid environments where just expansive soils with high plasticity index can lead the structure to be damaged. When the water changes in expansive soil, the volume would be changed as well. These volume changes can lead to either swelling or shrinkage and that is why expansive soils are also known as swell/shrink soils. Although expansion can be the result of the chemically induced changes, most of the times soils which have swelling and shrinkage behavior contain expansive clay minerals. It can be resulted in the fact that, the more the clay exists in the soil, the higher the soil swells and the more water the soil can absorb (Faezehossadat Khademi, 2016).

Expansive soil is commonly known as black cotton soil because of it's color and it's suitability for growing cotton. It starts swell or shrink excessively due to change in moisture content. When an engineering structure is associated with black cotton soil, it experiences either settlement or heave depending on the stress level and the soil swelling pressure (Bhavsar et al., 2014). Black cotton soils are residual deposits formed from lava or trap rocks, cover a very large area of the world. They are rich in montmorillonite which is responsible for its expansive nature but illite is also present when their parent rock is rich in potash bearing mineral. The presence of this montmorillonite, which is highly responsible for the attendant shrink-swell behavior of the soil depending on the amount of available moisture in the soil, is the root cause of the many problems such as pavement failure and excessive settlement associated with the soil. Shrinkage during the dry season often lead to surface cracks that could open up to 50mm or more and several millimeters deep. To tackle the problem of excessive settlement that could undermine the integrity of the foundation during construction of buildings on the black cotton soil, researchers have attempted to stabilize the soil so as to improve the geotechnical properties of the soil especially in ascertaining the compressibility of the soil (Ikeagwuani, 2016).

One of the challenges faced by civil engineers is the design of foundation for sites having expansive Soils. Most economical and effective method for stabilizing expansive soils is using admixtures that present change in volume. Many problems arise from the industrial development. One of them is the improper and in effective disposal of its waste. Generally, industrial waste causes many serious environment problems. So utilization of industrial waste in construction industry is the best way to dispose it. Using industrial waste in construction industry is beneficial in many ways such as disposal of waste, saving bio diversities, increasing soil properties like strength, reduce permeability, etc., preserve the natural soil and making economical structures (Bhavsar et al., 2014).

This study is aimed at investigating the combined effect of marble dust and waste paper sludge to improve the geotechnical properties of black cotton soils. It uses waste materials for the improvement of black cotton soil. These materials are obtained from industries which are polluting the environment.

1.2 Statement of problem

Black cotton soil creates a problem in construction sites of Gelan area because of its swell and shrink behavior. When it comes in contact of water excessive swelling is caused and when water content decreases shrinkage occurs. Because of this movement lightly loaded structures such as foundations, pavements, canal beds, linings, and residential buildings that are found in this area are severely damaged. The traditional practice to solve the problematic nature of soils is to remove the soil to the required depth and replace it with selected non expansive materials. It needs excavation of the expansive soil, transportation of the selected non expansive material and compaction to the required specification which increases the project cost and time. On the other case problems arise from the industrial development of Gelan. One of them is the improper and in ineffective disposal of its waste which creates a major environmental pollution to the area which should be disposed properly. In this study, an alternative method of soil stabilization of Black cotton soil using the combined effect of marble dust and waste paper sludge is studied.

1.3 Objective

1.3.1 General objective

The general objective of this study is to investigate of the combined effect of marble dust and waste paper sludge on geotechnical properties of black cotton soil.

1.3.2 Specific objectives

- To investigate the index properties and to determine soil type based on USCS and AASHTO soil classification system for the soil of study area.
- To assess the influence of marble dust and waste paper sludge on compaction characteristics of soil.
- To determine effect of marble dust and waste paper sludge on unconfined compressive strength of soil.
- To determine the optimum amount of marble dust and waste paper sludge to improve the properties of the soil.

1.4 Scope of the Study

This study has been supported by secondary resources and a series of laboratory experiments. However, the findings of the research are limited to two test pits of soil samples in Gelan area considered in the research which are Black cotton soil. The results are also specific to the type of chemical additives which are waste paper sludge and marble dust and to test procedures that have been adopted in the experimental work.

1.5 Limitation of the Study

The micro fabric and mineralogical characteristics of untreated and treated soil are not determined by scanning electron microscope and X-Ray diffraction studies which are used to characterize the full scale of the soil behavior.

1.6 Significance of the Study

This Study work add a knowledge of Black cotton soils and will be indicative of the better method of improvement of such soils. In the construction of buildings, chemical stabilization minimizes cost of construction, because it reduces the cost for the removal of expansive soil and replacement with other material. Since this Study uses industrial wastes for stabilization of soil, it also reduces environmental pollution and act as a better way of utilizing waste materials.

The Study will serve as a reference guide for practicing Civil Engineers and Researchers that practice in the area of study. This is useful in the sense that, it will reduce initial costs of removal of expansive soil and replacement with new material. It will be used to make use abundant waste materials in to useful products to improve soil properties.

1.7 Organization of the thesis

The presentation of this thesis work is organized in five Chapters.

Chapter 1 comprises the introduction part, which include the background of the study, problem statement, objectives of the study, significance and scope of the study.

Chapter 2 presents the literature review. It mainly includes genesis of expansive soils, Mineralogy of expansive soils, Classification and distribution of expansive soils, mechanism of swelling, Consolidation of soils and Stabilization of soils.

Chapter 3 presents materials and methods which consist of description of study area, materials used in the thesis work such as soil, marble dust and Waste paper sludge and the methods adopted to collect data.

Chapter 4 presents result and discussions which consists of detail laboratory test results and discussions for the natural black cotton soil of two Test pits, addition of waste paper sludge on black cotton soil and combined effect of waste paper sludge and marble dust on geotechnical properties of black cotton soil.

Chapter 5 presents conclusions and recommendations that summarizes the whole findings and recommendations

Chapter Two

Literature Review

2.1 Expansive soils

Essentially expansive soil is one that changes in volume in relation to changes in water content. The clay particle consists of Silica, Alumina and minerals such as kaolinite, montmorillonite and illite. The clay minerals in expansive soils have intense absorption power for water molecules. As a result, these materials swell, and thus increase in volume, when they get wet and shrink when they dry. Swelling pressures can cause heaving, or lifting, of structures whilst shrinkage can cause differential settlement. Failure results when the volume changes are unevenly distributed beneath the foundation (Jones et al., 2012).

Expansive soils can be found in arid/semi-arid areas, where even moderate expansive soils can cause major damages to the structure or in humid environments where just expansive soils with high plasticity index can lead the structure to be damaged. The behaviors of an expansive soil can be affected by many factors, among which the principal ones are the availability of moisture, and the amount and type of the clay-size particles in the soil (Faezehossadat & Jeff, 2016). The response of expansive soils in the form of swelling and shrinkage due to changes in water content is frequently expressed superficially as heaving and settlement of lightly loaded geotechnical structures such as pavements, railways, roadways, channel and foundations or reservoir linings (Abdulaziz et al., 2013).

2.2 Clay Mineralogy

The term clay can refer both to a size and to a class of minerals. As a size term, it refers to all constituents of a soil smaller than a particular size, usually 0.002 mm in engineering classifications. As a mineral term, it refers to specific clay minerals that are distinguished by (1) small particle size, (2) a net electrical charge, (3) plasticity when mixed with water and (4) high weathering resistance. Three important clay minerals are described for engineering purposes as follows (Baser, 2009).

Kaolinite

It is found in Kaolinite group, generally non expansive and consist of tetrahedron and octahedron sheets. The bonding between successive layers is by van der Waals forces and hydrogen bonds. The bonding is sufficiently strong that there is no interlayer swelling in the presence of water.

Illite

It is one of the constituent mineral of Mika-like group, which includes Illite and vermiculites. Mika- like groups can be expansive but generally do not pose significant problems. Illites has a basic structure consisting of a sheet of alumina octahedrons between and combined with two sheets of silica tetrahedrons. In the octahedral sheet there is partial substitution of aluminum by magnesium and iron, and in the tetrahedral sheet there is partial substitution of silicon by aluminum. The combined sheets are linked together by fairly weak bonding due to (non-exchangeable) potassium ions held between them (Baser, 2009).

Montmorillonite

Montmorillonite has the same basic structure as illite. In the octahedral sheet there is a partial substitution of aluminum by magnesium. The space between the combined sheets is occupied by water molecules and (exchangeable) cations other than potassium. There is a weak bond between the combined sheets due to these ions. Considerable swelling of montmorillonite can occur due to additional water being adsorbed between the combined sheets. The large swelling capacity of montmorillonites, particularly sodium montmorillonites, marks these minerals as the most troublesome ones with respect to engineering design and construction (Yesilbas, 2004).

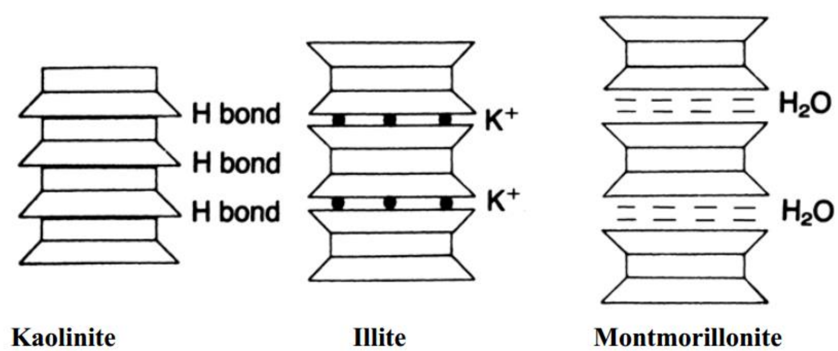

Figure 2.1 Schematic Representations of Clay Minerals (Baser, 2009)

2.3 Black Cotton Soil

Black clays or tropical black earth or black cottons are known to be potentially expansive soils which are "black" or "greyish black" or in their eroded phase "greyish white" heavy loam or clay (usually 50%), with predominant clay mineral of the smectite group, rich in alkali earth elements and the horizons sometimes contain calcium carbonate or magnesium oxide concretions (Gidigasu S. S. R and Gawu S. K. Y, 2013).

The black color in Black cotton soil is due to the presence of titanium oxide in small concentration. The Black cotton soil has a high percentage of clay, which is predominantly montmorillonite in structure and black or blackish grey in color (Jayatheertha et al., 2019).

2.3.1 Parent material

Black cotton soils have been identified on igneous, sedimentary and metamorphic rocks. They are formed mainly by the chemical weathering of mafic (basic) igneous rocks such as basalt, norite, andesites, diabases, dolerites, gabbros and volcanic rocks and their metamorphic derivatives (e.g. gneisses) which are made up calcium rich feldspars and dark minerals which are high in the weathering order, in poorly drained areas with well-defined wet and dry seasons. All constituents weather to form amorphous hydrous oxides and under suitable conditions clay minerals develop. The absence of quartz leads to the formation of fine grained, mostly clay size, plastic soils which are highly impermeable and easily becomes waterlogged. In addition abundant magnesium and calcium present in the rock adds to the possibility of formation of black cotton soil with its attendant swelling problem. The black cotton soils have also formed over sedimentary materials such as shales, limestones, slates etc (Gidigasu S. S. R and Gawu S. K. Y, 2013).

Black cotton soils are used for agriculture but are proved to be serious threat to construction founded on it. These soils have the property of high swelling due to absorbing of water and shrinkage due to evaporation of water in summer seasons. This swelling and shrinkage nature is attributed to the presence of mineral montmorillonite. Because of this high swelling and shrinkage nature, the structures constructed on these soils experience cracks, making it unsuitable for foundation (Reddy et al., 2018).

2.3.2 Distribution of Expansive soils in Ethiopia

Expansive soils are problematic in tropical countries, because of wide temperature variations and because of distinct dry and wet seasons, leading to wide variations in moisture content of soils (Singh & Vasaikar, 2015). In Ethiopia expansive soils are observed in areas such as central Ethiopia, following the major trunk roads of Addis-Ambo, Addis-Welliso, Addis-Tarmaber, Addis-Gohastion and Addis-Modjo. Similarly regional states such as Mekelle, Gambella, and the most southern, southwestern and south eastern parts of Addis Ababa are found to be covered with expansive soils (Mada, 2016).

2.4 Classification of Expansive Soils

Soil identification tests have been combined in a number of different classification schemes. The different classification systems are categorized into two:

2.4.1 Classification Using General Methods

American Association of State High Way and Transportation Officials (AASHTO) and Unified soil classification systems (USCS) are the most widely used general classification systems.

i. **AASHTO Classification**

Soils that are considered to be potentially expansive are rated by A-6 or A-7 by AASHTO classification

ii. **Unified Soil Classification Systems**

In this classification system a correlation is made between swell potential and unified soil classification as follows.

Table 2.1 Classification of Expansive soil based on USCS (Berhane, 2018)

Category	Soil classification system
Little or no expansion	GW, GP, GM, SW, SP, SM
Moderate expansion	GW, SC, ML, MH
High volume change	CL OL, CH, OH

2.4.2 Classification Specific to Expansive Soil

A parameter determined from the expansive soil identification tests have been combined in a number of different classification schemes to give qualitative rating on the expansiveness of the soil. An indirect prediction of swell potential includes correlations based on index properties, swell and a combination of them. Some of such classification systems are:

2.4.2.1 Expansive soil classification based on plasticity index

i. Method of Chen

(Chen, 1988) presented a single index method for identifying expansive soils using only plasticity index. In this method relation has been made between the swelling potential of clays and the plasticity index as shown in Table 2.2

Table 2.2 Expansive soil classification based on plasticity index (Chen, 1988)

Swelling Potential	Plasticity Index
Low	0-15
Medium	10-35
High	20-55
Very High	35 and above

2.4.2.2 Expansive soil classification based on Shrinkage index

Method of United State Bureau of Reclamation (USBR):- This method is developed by Holtz and Gibbs; it is based on direct correlation of observed volume change with colloid content, plastic index and shrinkage limit (Berhane, 2018). The classification is as given in Table 2.3.

Table 2.3 Classification based on bureau of reclamation method (Berhane, 2018)

Colloid Content (%)	Plasticity Index (%)	Shrinkage Limit (%)	Probable expansion (%)	Degree of expansion (%)
<15	<18	>15	<10	Low
12-23	15-28	10-16	10-20	Medium
20-31	25-41	7-12	20-30	High
>28	>35	<11	>30	Very High

2.4.2.3 Expansive soil classification based on the activity

Activity of a soil is normally calculated as the ratio of plasticity index of the soil to its percentage clay size fraction.

Activity is defined as:

$$Activity = \frac{\text{plastic index}}{\text{Percent of clay} < 0.002\text{mm}} \quad \ldots\ldots 2.1$$

Table 2.4 Classification of Expansive soil based on Activity (Asuri & Keshavamurthy, 2016)

Activity	Potential expansion
Ac<0.75	Low(Inactive)
0.75<Ac<1.25	Medium(Normal)
Ac>1.25	High(Active)

The classification criteria based on particle size related properties has limitations, the swelling of the soil is due to the amount of expanding lattice type clay minerals present in the soil rather than the percentage of clay size fraction present in the soil (Asuri & Keshavamurthy, 2016).

2.4.2.4 Expansive soil classification based on particle size composition

Many researchers have proposed criteria based on percentage clay size fraction (i.e., <0.002 mm size) or colloid content (i.e., content of particles of size less than 0.001 mm) to predict the swell potential of fine-grained soils (Asuri & Keshavamurthy, 2016).

Table 2.5 Classification of Expansive soil based on particle size composition (Asuri & Keshavamurthy, 2016)

Degree of Expansion/ Swell potential	Percent clay size fraction(Chen 1965)	Colloidal content (Holtz and Gibbes 1956)
Low	<30	<15
Medium	30-60	13-23
High	60-95	20-31
Very high	>95	>28

2.4.2.5 Expansive soil classification based on Free Swell Ratio

The dominant clay minerals present in fine-grained soils control the physical and engineering behavior of the soils. Determination of the dominant clay minerals in the soils, at present, requires procedures involving sophisticated instrumentation and the knowledge to interpret the results from such tests. A user-friendly approach based on free swell ratio, defined as the ratio of the equilibrium sediment volume of 10-g oven dried soil in distilled water to that in carbon tetra chloride, has emerged as a simple methodology to predict the swelling potential (Sridharan, 2004).

Table 2.6 Classification of expansive soil based on Free swell ratio (Sridharan, 2004)

Free Swell Ratio	Clay Type	Swell Potential	Dominant Clay mineral type
≤1.0	Non Swelling	Negligible	Kaolinite
1.0-1.5	Mixture of Swelling and Non-Swelling	Low	Mixture of Kaolinite and Montmorillonite
1.5-2.0	Swelling	Moderate	Montmorillonite
2.0-4	Swelling	High	Montmorillonite
>4	Swelling	Very high	Montmorillonite

2.5 Mechanics of Swelling

Swelling of clay minerals is directly related with diffused double layer and cation exchange capacity of them. The negatively charged clay particle surface and the concentration of positive ions in solution adjacent to the particle form what is referred to as a diffuse double layer. Overlapping diffuse double layers between clay particles generate inter particle repulsive forces or microscale “swelling pressures”. Interaction of the diffuse double layers and, hence, swelling potential, increases as the thickness of this layer increases. The thickness of this layer is associated with valence of cations, concentration of cations, temperature and pH (Baser, 2009).

2.6 Consolidation of Soils

When a soil is subjected to a compressive force, like all other materials, its volume decreases. The property of the soil due to which a decrease in volume occurs under compressive force is known as the compressibility of soil. The compression of soils can occur due to one or more of the following causes.

1. Compression of solid particles and water in the voids
2. Compression and expulsion of air the voids
3. Expulsion of water in the voids

Compression of solid particles is negligibly small. Compression of water in the voids is also extremely small, as the water is almost incompressible in the range of stresses involved in soil engineering. Therefore the compression due to the first cause is not much significant.

Air exists only in partially saturated soils and dry soils. The compression of the air rapid as it is highly compressible. Further, air is expelled quickly as soon as the load is applied. However, the compression due to the second cause is not relevant for saturated soils.

Initial Primary and secondary Consolidation

The consolidation of a soil deposit can be divided in to 3 stages

1. **Initial consolidation**:-a load is applied to a partially saturated soil, a decrease in volume occurs due to expulsion and compression of air in the voids. A small decrease in volume also occurs due to compression of soil particles. The reduction in volume of the soil just after the application of the load is known as initial consolidation or initial compression. For saturated soils, the initial consolidation is mainly due to compression of solid particles.
2. **Primary consolidation**:- after initial consolidation, further reduction in volume occurs due to expulsion of water from voids, When a saturated soil is subjected to a pressure , initially all the applied pressure is taken up by water as an excess pore water pressure, as water is almost incompressible as compared with solid particles. A hydraulic gradient develops and the water starts flowing out and a decrease in volume occurs. The decrease depends upon the permeability of the soil and is, therefore, time dependent. This reduction in volume is called primary consolidation.
3. **Secondary consolidation**:- The reduction in volume continues a very slow rate even after the excess hydrostatic pressure developed by the applied pressure is fully dissipated and the primary consolidation is complete, This additional reduction in the volume is called secondary consolidation. The cause for secondary consolidation are not fully established. It is attributed to the plastic readjustment of the solid particles and the absorbed water to the new stress system. In most organic soils, it is generally small (Arora, 2004).

2.6.1 Soil Classification based on Consolidation Characteristics

2.6.1.1 Classification of soil based on compression index

Table 2.7 Classification of soil based on compression index (Lambe, T.W. and Whitman, 1979)

Compression Index (Cc)	Compressibility Class
<0.2	Low
0.2-0.8	Medium-High
0.8-2.6	High
>2.6	Very high

2.6.1.2 Classification of soil based on Coefficient of Volume Compressibility

Table 2.8 Classification of soil based on Coefficient of Volume Compressibility (Lambe, T.W. and Whitman, 1979)

Clay Type	Coefficient of Volume Compressibility (Mv) (m^2/MN)	Compressibility Classification
Very organic alluvial clays and peats	>1.5	Very high
Normally consolidated alluvial clays	0.3-1.5	High
Fluvio-glacial clays and lake clays	0.1-0.3	Medium
Boulder clays	0.05-0.1	Low
Heavily over consolidated boulder clays	<0.05	Very Low

2.6.1.3 Classification of soil based on Coefficient of Consolidation

Table 2. 9 Rate of consolidation-settlement of soils based on Coefficient of Consolidation (Lambe, T.W. and Whitman, 1979)

Clay Type	**Coefficient of Consolidation Cv (m^2/year)**	**Rate of Consolidation Settlement**
High Plasticity	0.1-1	Low
Medium Plasticity	1-10	Medium
Low Plasticity	10-100	High
Silts	>100	Very High

2.7 Soil stabilization

Soil stabilization is the process of improving the engineering properties of the soil and thus making it more stable. It is required when the soil available for construction is not suitable for the intended purpose. In its broadest sense, stabilization includes compaction, pre consolidation, drainage and many other such processes. However, the term stabilization is generally restricted to the processes which alter the soil material itself for improvement of its properties. A cementing material or chemical is added to a natural soil for the purpose of stabilization .It is used to reduce the permeability and compressibility of the soil mass in earth structures and to increase its shear strength. It is required to increase the bearing capacity of foundation soils. However, the main use of stabilization is to improve the natural soil for the construction of highways and buildings. The principles of soil stabilization are used for controlling the grading of soils and aggregates in the construction (Arora, 2004).

Generally, Soil stabilization is the improvement of strength or bearing capacity of soil by controlled compaction, proportioning and/or addition of suitable admixtures or stabilizers (Krishnappa, 2017). Improvements include increasing the dry unit weight, bearing capabilities, volume changes, stabilization processes improve the various engineering properties of the stabilized soil and generate an improved construction material. Increase in soil strength, durability stiffness, and reduction in soil plasticity and swelling/shrinkage potential are the benefit of soil stabilization (Firoozi et al., 2017).

2.7.1 Methods of Soil stabilization

2.7.1.1 Mechanical Soil Stabilization

The process of mechanical stabilization is one which entails the mixture of at least two or more types of natural soil in an attempt to change its gradation and by so doing improve the properties of the soil. This method tries to combine the engineering properties of the constituents of the soil mixture. It is aimed at reducing the void ratio by filling up the spacing between larger granular soil properties with finer soil particles through the combination of soils possessing different granular sizes followed by thorough compaction. This method of soil stabilization can otherwise be known as granular stabilization. The compaction process ensures that the void ratio is reduced improving the soil strength parameters such as cohesion (C) and angle of internal friction (∅) (Archibong et al., 2020).

2.7.1.2 Chemical Stabilization

Chemical stabilization entails the stabilization of soil through the addition of different chemicals, although it is generally more expensive. Soil improvement by chemical stabilization can be grouped in to three chemical reactions: cation exchange, flocculation-agglomeration, and pozzolanic reaction.

Cation Exchange

The excess of ions of opposite charge (to those of the surface) over those of like charge present in the diffused double layer are called exchangeable ions. These ions can be replaced by a group of different ions having the same total charge by altering the chemical composition of the equilibrium electrolyte solution (Baser, 2009).

Negatively charged clay particles absorb cations of specific type and amount. The ease of replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valence cations easily replace cations of lower valence. For ions of the same valence, the size of hydrated ions becomes very important; the larger the ion, the greater the replacement power. If other conditions are equal, trivalent cations are held more tightly than divalent and divalent cations are held more tightly than monovalent cations.

A typical replaceability series is

$Na^+<Li^+<K^+<Rb^+<Cs^{2+}<Mg^{2+}<Ca^{2+}<Ba^{2+}<Cu^{2+}<Al^{3+}<Fe^{3+}<Th^{4+}$

Na^+ up to Rb^+ ions have the same valance therefore replaceability depends on the size of hydration ion so Rb^+ is larger ion than Na^+ that means Rb^+ has larger replaceability potential and when comparing Na^+ to Th^{4+} because Th^{4+} is higher balance cation than Na^+ replaceaility potential of Th^{4+} is higher than Na^+.

Example of the cation exchange

$Ca^{2+} + Na^+clay \rightarrow Ca^{2+}\ clay + (Na^+)$

The above example shows lower valance cation that is Na^+ is replaced by higher valance cation Ca^{2+}(Baser, 2009).

Flocculation – Agglomeration

Cation exchange reaction result in the flocculation and agglomeration of the soil particles with consequent reduction in the amount of clay size materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity. Due to change in texture, a significant reduction in the swelling of the soil occurs (Baser, 2009).

Pozzolanic Reaction

Time depending pozzolanic reactions play a major role in the stabilization of the soil, since they are responsible for the improvement in the various soil properties. Pozzolanic constituents produces calcium silicate hydrate (CSH) and calcium aluminate haydrate (CAH).

$Ca^{2+} + 2(OH)^- + SiO_2$ **(Clay Silica)** $\rightarrow$ CSH

$Ca^{2+} + 2(OH)^- + Al_2O_3$ **(Clay Alumina)** $\rightarrow$ CAH

The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystalizes to form an interlocking structure thus, strength of the soils increases (Mada, 2016).

2.8 Industrial Wastes as additives of Soil Stabilization

Soil stabilization is the process of altering the properties of soil by applying some modifiers to meet specified Engineering requirements of soil layers. It was carried out by various methods, and one of them is mixing with the Stabilizing additives such as lime and cement. The demand of lime and cement has been increasing in the construction industry which causes increasing their cost (Gizachew & Makebo, 2019).

Chemical stabilization is a major category of soil stabilization involving the use of chemical agents for initiating reactions within the soil for modification of its geotechnical properties. Cement and lime stabilization have been the most common stabilization methods adopted for soil treatment(James & Pandian, 2016). Soil–cement has been used as a base material as an adoption of improved measure in many projects, such as slope protection of dams and embankments, pavement of highways, building pads, terminals for rail and truck, composting facilities, cheap base for streets, parking lots, channels and reservoir linings, mass soil–cement placement for dikes, foundation stabilization etc. Lime stabilization has been used successfully on many projects to minimize swelling and improve soil plasticity and workability (Firoozi et al., 2017). The strength of the soil generally being improved, partially as a result of the decrease in the plastic properties of the soil and partially due to the formation of the cementing material (Archibong et al., 2020).

Cement stabilization results in good compressive strength and is preferred for cohesion less to moderately cohesive soil but loses effectiveness in the case of highly plastic soil. Lime stabilization is the preferred method of treatment for plastic clays; however, it is ineffective in sulphate-rich clays and performs poorly under extreme conditions. Because of the cost of cement and lime stabilization, there is a need to concentrate on improving properties of soils using cost effective practices like treating with industrial wastes with those having cementitious value. In the light of such drawbacks, a lot of research has been undertaken to address the issues faced with each stabilization method, particularly the use of solid wastes. Reuse of solid wastes has gained a lot of priority for achieving sustainable waste management and, hence, they have been adopted in soil stabilization as standalone stabilizers as well as additives to augment the performance of conventional stabilizers like lime and cement. Solid wastes classified into four major categories based on their source of generation as (i) industrial, (ii) agricultural, (iii) domestic, and (iv) mineral solid wastes (James & Pandian, 2016).

Industrial wastes (by-products) can be used solely or as admixtures so that natural sources are used more efficiently and the environment is protected from waste deposits. Increasing demand for marble product in the construction industry raises the generation of waste marble dust. The marble cutting plants are dumping the waste marble powder in any nearby pit or vacant spaces near their unit, although notified areas have been marked for dumping. This leads to serious environmental and dust pollution and occupation of vast area of land (Saygili, 2015). Other waste like waste paper sludge is a major problem nowadays. The Sludge from the paper mills are produced in large quantities, due to the large usage of paper. These wastes can be used for stabilization of soil First, they are typically less costly due to the fact that they are a waste product that already needs to be disposed of. Second, finding alternative uses for these materials keeps them out of landfills, ultimately saving already depleting landfill space (Elias, 2015).

2.8.1 Marble Dust

It is the by-product of the marble industry which is generated during cutting and grinding of marble. The literatures reveal that waste generation is approximately 40% of the total marble handled per annum. It has relevance because annually about 68 million of marble is manufactured all over the world. The waste is produced from the industries in the form of both solid and slurry (Choksi et al., 2018).

Marble is a non-foliated metamorphic rock composed of re-crystallized carbonate minerals, most commonly calcite or dolomite. Geologists use the “marble” to refer to metamorphosed limestone, Marble is a metamorphic rock resulting from the transformation of a pure limestone. The purity of marble is responsible for its color and appearance; it is white if the limestone is composed solely of calcite. Marble is used for construction and decoration; marble is durable, has a noble appearance, and is consequently in great demand. Chemically, marbles are crystalline rocks composed predominantly of calcite, dolomite or serpentine minerals. The other mineral constituents vary from origin to origin. Quartz, muscovite, tremolite, actinolite, micro line, talc, garnet, osterite and biotite are the major mineral impurities whereas SiO_2, limonite, $Fe2O_3$, manganese $3H_2O$ and FeS_2 are the major chemical impurities associated with marble (Patel et al., 2017).

2.8.2 Waste Paper Sludge

The sludge for the soil stabilization behaves a clay-like material consisting of short fibers, ink and other impurities. It consists of minerals like Silcon dioxide, Calcium oxide, magnesium oxide, Sulfur Tri oxide, Aluminum oxide and Feric Oxide. Waste Paper Sludge contains calcium and least extent of silica content and because of magnesium content, it reacts like cement. Paper production generally leads in deposition of unyielding waste. For the building up of high quality of paper, paper filaments can be remanufactured till it attains waste paper sludge. This waste contributes the landfill Disposal of immense amount of waste caused problems like polluting of lakes, rivers etc (Banakar & Nandini, 2018).

2.9 Previous similar works

Marble Powder have impact on Engineering Properties of Black Cotton Soil. (Bhavsar et al., 2014) studied replacing soil with marble dust of 30%, 40%, & 50% replacement of soil by its dry weight, it gave maximum improvement in the swelling and linear shrinkage properties of black cotton soil. Plastic index has reduced from 26.1 for original soil to 18.14% for 50% of marble dust and dry density of the soil has increased and optimum moisture content has decreased with the increasing amount of marble. Linear shrinkage has reduced with the increasing amount of marble from 23.7% for black cotton soil to 4% when mixed with 50% marble by mass of the soil

To investigate the effect of marble Powder on index properties of clay soil (Patel et al., 2017) have done experiments with addition 20,30,40,60 % of marble Powder by weight of dry soil The test results showed significant change in consistency limits of samples containing marble dust. The liquid limit would decrease from 31.3% to 23.5%. The plasticity index decreased from 21.02 % to 4.35%. (Mada, 2016) has done experiments by blending expansive subgrade soil with increasing percentage by weight (5% to 30%). With the higher percentage of marble dust (30%), the swelling potential of the natural soil changed from 'High' to 'Medium', LL reduced from 88% to 63%, PI reduced from 52% to 34%, it has been noted that the subgrade class improves for both indicating significant reduction in project cost as result of reduction in pavement thickness.

(Elias, 2015) studied the effect of waste paper sludge (WPS) on strength of clay soil. The compaction and Unconfined compressive tests were carried out on clay soil and soil with 2, 5,7,10,15,20,25 percent WPS by weight to study the compaction behavior. Concluded that addition of 2% WPS to soil exhibited the highest maximum dry density when compared to other percentages. UCS for natural soil was 316.4 and increased to 423 for 5% of WPS .It was found that the changes in UCS were significant up to 5% of WPS. (Raman et al., 2019) studied by using 2,4,6,8,10,12 and 14 % waste paper sludge by weight of soil, Liquid Limit has been reduced to 34.3% from 71.52 % when treated with Waste Paper. Plastic Limit has been reduced to 22.48% from 28.48% and Plasticity index has been reduced to 11.82% from 43.52% when treated with Waste Paper Sludge compared with untreated soil. Differential swelling index has been reduced and dry density has been increased when treated with Waste Paper Sludge. (Teja et al., 2016) studied Improvement of Properties of Highly Swelling Soil by using Waste Paper Sludge. The result showed Plasticity index has reduced from 43.52% to 11.82%. (Jhariya & Parte, 2018) studied Stabilization of Black Cotton Soil by the Waste Paper Sludge (Hypo-Sludge) resulted in reduction of plastic index.

Table 2.10 Summary of researches on stabilization of Expansive soil using Marble dust

Nam and year	**Tittle**	**Percentage by mass used**	**Findings**
(Bhavsar et al., 2014)	Impact of Marble Powder on Engineering Properties of Black Cotton Soil	30, 40 and 50%	• Improvement in the swelling and linear shrinkage properties of black cotton soil • dry density of the soil has increased • Plastic index has reduced from 26.1 for original soil to 18.14% for 50% of marble dust
(Mada, 2016)	Application of Marble Dust to Improve the Engineering Properties of Expansive Soils to be used as Road Bedding Material	5, 10, 15, 20, 25 and 30%	• swelling potential of the natural soil changed from 'High' to 'Medium • Reduction in liquid limit and plastic limit
(Patel et al., 2017)	Use of Waste Marble Powder to Improve the Characteristics of Black Cotton Soil	20,30,40 and 60 %	• Reduction in liquid limit and plastic limit

Table 2.11 Summary of researches on stabilization of Expansive soil using Waste paper sludge

Name and year	Tittle	Percentage by mass used	Findings
(Teja et al., 2016)	Improvement of Properties of Highly Swelling Soil by using Waste Paper Sludge	2,4,6,8,10, 12 and 14 %	• Plasticity index has reduced from 43.52% to 11.82% when treated with Waste Paper Sludge with untreated soil.
(Elias, 2015)	Strength development of soft soil stabilized with waste paper sludge	2, 5, 7, 10, 15, 20 and 25%	• UCS for natural soil was 316.4 and increased to 423 for 5% of waste paper sludge
(Jhariya & Parte, 2018)	Stabilization of Black Cotton Soil by the Waste Paper Sludge (Hypo-Sludge)	5, 10, 15 and 20%	• Liquid limit of soil decreases from 64% to 54% with increase in Hypo-sludge (%). • Plasticity index of soil decreases from 36 % to 12.22% with increases in Hypo-sludge content up to 20%.

Chapter Three

Materials and methods

3.1 Overview of Study Area

Gelan is found in east Shewa zone, Oromia Region, Ethiopia with a total planning area of 7,516.8 hectares. It is located at 25kms in southeast direction on the Addis Ababa- Adama highway. The current boundary of Gelan and Dukem towns in the southeast is made by artificial boundary formed at the junction of Ethio-Djibouti rail way and Addis Ababa-Adama high way. The town is bordered in the East by Dalota and Mero mountain chain, Wedesso Mountain chain and Abayi Silto peasant associations in the North, Akaki of Addis Ababa in the North-West and Lake Aba Samu'el in north-West. In absolute terms, , its geographical coordinates are 8°52'0" North latitude, 37°47'0" East longitude and it is found in 2051-2373km above sea level. Its average annual rainfall is about 920mm and annual average temperature is 20^0C. Type of area is Populated place - a city, town, village, or other agglomeration of buildings where people live and work.

Topography of Addis Ababa declines from northern Addis Ababa as well as eastern and southern parts of Gelan town to the ground water catchment area of Akaki. This allows surface and rain water of northern Addis Ababa and the surrounding hilltops flow to the ground water catchment zone of Akaki through Little and Great Akaki Rivers. There is watershed (running from north to south direction) dividing streams flowing to Akaki ground water catchment zone and those streams flowing to Dukem direction. With exception to the surrounding hilltops. Gelan town is characterized by flat topography which is covered with volcanic and porous nature of soil and rocks.

Table 3. 1 General description of Gelan area

Type	Populated place – a city, town ,village or other agglomeration of buildings where people live and work
Region	East Shewa zone, Oromia Region, Ethiopia
Latitude	8° 52' 0" North
Longitude	37° 47' 0" East
Average annual rainfall	920mm
Annual average temperature	20^0C

Soil samples from two test pits of depth 1.5m are taken from the Gelan area at a location of latitude 8°49'30.1''N and longitude 38°51'37.8''E for Test Pit 1 and latitude 8°49'28.7''N and longitude 38°51'38.4''E for Test Pit 2. Elevation of the site is 2085m and 2083m above sea level for Test Pit 1 and Test Pit 2 respectively.

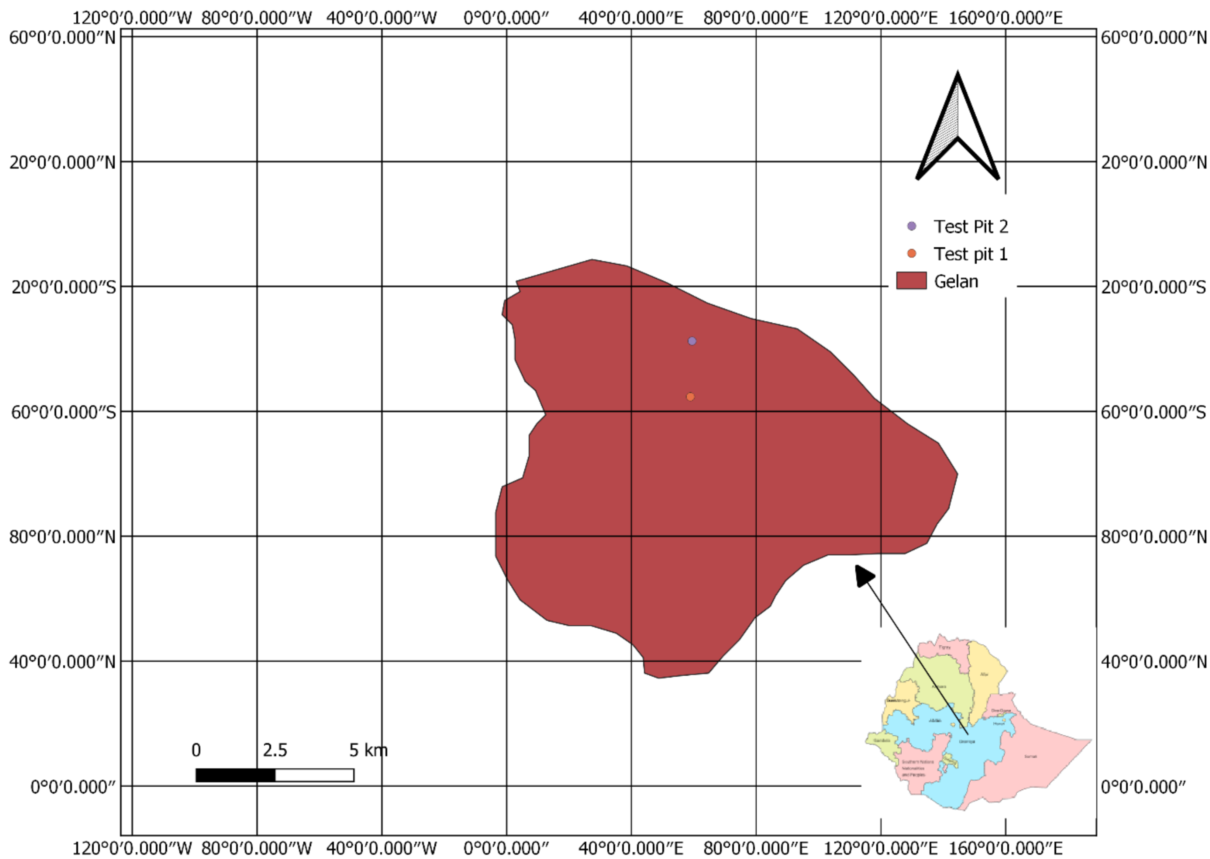

Figure 3.1 Gelan area description

3.2 Materials

3.2.1 Black Cotton Soil

Disturbed and Undisturbed soil samples collected from construction site of two test pits of depth 1.5m each from Gelan area. Totally two disturbed and two undisturbed soil samples were collected form two test pits. The construction site is Food processing company which is constructed by Hora Trading on 13000 square meters.

(a) (b)

Figure 3.1.a Black Cotton soil Samples Test Pit and b. Undisturbed Sample

3.2.2 Waste paper sludge

Figure 3. 2 Waste paper sludge used for the study

Waste Paper Sludge (WPS) is a solid waste material collected from the Paper recycling Industry. It is the end product obtained from pulping and removing of impurities several times. When there is pulp in the waste paper sludge, it will be returned to the recycling processes and the pulp will be extracted again until the waste is free of pure pulp. Waste Paper Sludge becomes a new innovation material that can be used as material for soil stabilizing agent.

Waste paper sludge is collected form Suzo paper recycling PLC which is found in Gelan area. Suzo Paper recycling Industry PLC was founded on December 2008 in Ethiopia with the aim to recycling and manufacturing of paper raw materials and related products. It is producing over 10,000 tons of jumbo roll tissue papers annually and supplying these raw materials to 16 paper converting companies in Ethiopia.

Waste paper sludge used for this study is brown in color and has pH value of 8.75, which is slightly basic. Specific gravity of Waste paper sludge is 2.3. Complete silicate analysis test is performed in Geological Survey of Ethiopia to determine the chemical composition in percent of Waste paper sludge and described in Table 3.2.

Table 3.2 Chemical composition of Waste Paper Sludge in percent

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
28.58	4.29	10.22	19.38	2.96	0.88	0.36	0.06	0.14	0.25	2.03	31.39

3.2.3 Marble dust

For this study Marble dust is collected from Sof Umar Marble production Industry which is found in Gelan area. Collected Marble dust is white in color and has the grain size distribution of 71.5% sand and 28.5% fine.

Marble comes in the form of fine limestone in the beginning. When limestone is exposed to high temperatures and high pressure, it turns into marble. The reason for this is that limestone consists of calcite, which is recrystallized and its crystals grow and become more coherent at high temperature and pressure, and this results in the formation of a denser stone containing almost equal-angle crystals. Marble exists in different colors due to the presence of slight amounts of impurities that are combined with limestone.

Marble dust used for this study is white in color and has pH value of 10.1, which is slightly basic. Specific gravity of marble dust is 2.8. Complete silicate analysis test is performed in Geological Survey of Ethiopia to determine the chemical composition in percent of marble dust and described in Table 3.3.

Table 3.3 Chemical composition of Marble dust in Percent

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
17.86	<0.01	<0.01	44.68	2.36	<0.01	<0.01	<0.01	0.03	0.02	0.04	35.29

(a) (b)

Figure 3.3 Marble dust deposit in Gelan area (a) and Marble dust used in laboratory (b)

Marble dust and waste paper sludge are used for stabilization in this study because these materials are industrial waste products so that they can be obtained easily without cost. These materials are locally available in the study area so it reduces cost for transportation of material. This waste contributes the landfill disposal of immense amount of waste caused problems like environmental pollution so utilization of these waste products for stabilization also saves the environment from pollution.

Marble dust was collected by digging the deposit of marble which is found near the marble industry and waste paper sludge was collected by taking the end product from paper recycling company.

3.3 Test program

In the present study laboratory tests were conducted on natural untreated representative samples of soil to characterize the soil. To assist the laboratory testing and subsequent identification of soil, field identification was under taken before taking samples. The field investigation included identification of soil based on observation of colour and soil texture on the site where the sample was collected. The laboratory tests conducted include

The following laboratory tests have been carried on natural Black cotton soil

- Natural Moisture content
- Grain size distribution
- Atterberg Limit test
- Specific gravity
- Compaction test
- Unconfined compression Strength test
- Free swell test
- Swelling Pressure Test
- Consolidation Test

Standard compaction and unconfined compressive strength tests were performed by mixing Black cotton soil samples of two test pits with Waste paper sludge of 5, 10 and 15% by mass of soil. The percentage proportions are taken based on literature reviews. From these tests optimum Waste Paper Sludge content that has improved strength of soil is obtained.

Table 3.4 Test program for soil mixed with waste paper sludge

	Percentage (%)	
Soil mixture	Soil	Waste Paper sludge
Natural Black cotton soil	100	0
95% Black cotton soil + 5 % Waste paper sludge	95	5
90% Black cotton soil + 10 % Waste paper sludge	90	10
85% Black cotton soil + 15 % Waste paper sludge	85	15

By taking the optimum waste paper sludge, Marble dust is added to the Waste Paper Sludge-Black cotton Soil mix to further improve the properties of the soil. Marble dust is mixed with soil by 10, 20, 30 and 40% by mass of Black Cotton Soil. The percentage proportions are taken based on literature reviews. To determine the combined effect of Waste Paper Sludge and Marble dust on Black cotton soil the following tests were performed.

- Atterberg Limits
- Free swell test
- Compaction test
- Unconfined compressive strength (UCS)

Table 3.5 Test program for soil mixed with waste paper sludge and marble dust

	Percentage (%)		
Soil mixture	Soil	Waste Paper sludge	Marble dust
Natural Black cotton soil	100	0	0
85% Black cotton soil + 5 % WPS + 10MD	85	5	10
75% Black cotton soil + 5 % WPS + 20% MD	75	5	20
65% Black Cotton soil+ 5 % WPS + 30% MD	65	5	30
55% Black cotton soil + 5 % WPS + 40% MD	55	5	40

From these tests optimum content of Waste Paper Sludge and Marble dust that improved properties of soil is obtained. To further determine the effect of optimum content of this mix on improving properties of the soil, the following test is performed on the determined mixture of Black cotton soil with optimum content of Waste Paper Sludge and Marble dust. This test is

- Consolidation test

Table 3.6 Test program for consolidation test

	Percentage (%)		
Soil mixture	Soil	Waste Paper sludge	Marble dust
Natural Black cotton soil	100	0	0
65% Black Cotton soil+ 5 % WPS + 30% MD	65	5	30

Finally the comparison of properties of Natural soil and the stabilized soil is done and recommendation is given

3.4 Test Procedures

For this study the following tests are performed. These tests are grain size distribution, natural moisture content, specific gravity, compaction, unconfined compressive strength, atterberg limit, free swell and consolidation tests.

3.4.1 Grain Size Distribution

The grain-size analysis is carried out to determine the relative proportions of different grain sizes which makes up a given soil mass. The purpose of these tests is to determine the grain size distribution (i.e.; grain size versus percent by weight) of soil, and to determine the percentage of fines (i.e.; material passing the No. 200 sieve) in soil. Wet sieve analysis is performed to determine the distribution of particles larger than 75 µm (No.200 sieve). Sedimentation process using hydrometer analysis method is carried out to determine the distribution of the finer particle size (usually silt and clay). After complete grain size analysis of both, the relative proportion of different size groups in each soil sample is determined. The test was conducted in accordance with (ASTM-D6913, 2017).

3.4.2 Soil Classification

The most widely used soil classification systems for engineering purposes are American Association of State High Way and Transportation Officials (AASHTO) and Unified soil classification system (USCS).

3.4.3 Natural Moisture content

This test was performed to determine the water (moisture) content of soils. The natural moisture content is the ratio of the weight of water to the weight of the solids in a given mass of soil. This ratio is usually expressed as percentage. It is performed in accordance with (ASTM-D2216, 2019).

3.4.4 Specific Gravity test

Specific gravity of soil solids, Gs, is the mass density of the mineral solids in soil normalized relative to the mass density of water. Alternatively, it can be viewed as the mass of a given volume of soil solids normalized relative to the mass of an equivalent volume of water (ASTM-D854, 2014).

The test includes the determination of the specific gravity for the natural soil. The test was conducted in accordance with (ASTM-D854, 2014) testing procedure. The specific gravity calculation is based on three measurements: Mass of the flask filled with distilled water to the etch mark, M_a , mass of the flask filled with water and soil to the etch mark, M_b; and mass of the dry soil, M_o.

Specific gravity of soil solids, G_s, is calculated as

$$G_s=\frac{Mo}{Mo+(Ma-Mb)} \qquad (3.1)$$

3.4.5 Compaction test

This test includes the determination of the maximum dry density and the optimum moisture content in accordance with (ASTM-D698, 2012) testing procedures. The test is conducted for natural soil and for the mixture of soil with waste paper sludge and marble dust. By varying the moisture content for each trial, air dried soil sample of about 2.5 kg is used. Each sample is then compacted in three layers of 25 number of blows. For each compacted sample moisture content is determined then the values of the dry densities are plotted against their respective moisture contents. Maximum dry density (MDD) is obtained as the maximum point on the resulting curves. The corresponding value of moisture contents at maximum dry densities, gives the optimum moisture content (OMC). Compaction test for the natural soil of two test pits are performed in accordance with (ASTM-D698, 2012). Black cotton soil is blended with 5, 10 and 15% of waste paper sludge by mass of soil and standard compaction test is performed and after determination of optimum waste paper sludge based on Compaction and UCS tests the soil is mixed with optimum content of waste paper sludge and 10, 20, 30and 40% of marble dust by mass of soil and standard compaction test is performed.

Figure 3.4 Sample preparation for Standard compaction Test

3.4.6 Unconfined Compressive Strength Test

Unconfined compressive strength testing provides a quick and simple means to measure the unconfined compressive strength (qu) and undrained shear strength (su) of normally consolidated and slightly over consolidated cylindrical specimens of cohesive soil. This information is used to estimate the bearing capacity of spread footings and other structures when placed on deposits of cohesive soil (ASTM-D2166, 2016). Undrained shear strength is half of unconfined compressive strength. Unconfined compressive strength test for the natural black cotton soil of two test pits is performed in accordance with (ASTM-D2166, 2016).

Undisturbed soil sample is used for the determining of unconfined compressive strength of a natural soil. Remolded samples of soil mixed with marble dust and waste paper sludge were prepared by using the corresponding OMC and compacting samples to get the respective MDD of the soil samples as obtained from the standard compaction tests. Black cotton soil is mixed with 5, 10 and 15% of waste paper sludge by mass of soil and unconfined compressive strength test is performed and optimum content of waste paper sludge to improve the strength of the soil is determined. After determination of optimum waste paper sludge based on Compaction and UCS tests the soil is mixed with predetermined optimum content of waste paper sludge and 10, 20, 30and 40% of marble dust by mass of soil and UCS is performed to determine the combined effect of marble dust and waste paper sludge on strength of soil.

3.4.7 Atterberg Limit Tests

The test is a consistency Limit identification test on the basis of moisture content. It include, the determination of; the liquid limits, plastic limits and the plasticity index of a soil. The liquid limit and plastic limit tests provide information regarding the effect of water content (w) on the mechanical properties of soil. The results of this test are used to classify soil and to estimate the swell potential of soil. Atterberg limit test is performed in accordance with (ASTM-D4318, 2017).

For the plastic limit determination, soil sample that passes sieve number 40 is used. Distilled water is used to make little mud balls and a pea-sized mud ball is used and it roll out onto the frosted plate to form a rod with a diameter 3mm. The process is repeated until the soil crumbles while making the rod, at this point the water content of the soil is its plastic limit. This test is also performed for the Sample of Black cotton soil of two test pits mixed with optimum content of waste paper sludge and 10, 20, 30 and 40% of marble dust by mass of soil.

For the Liquid limit determination, 50g of soil sample that passes Sieve number 40 is used. The soil sample is then mixed with distilled water and it is spread to the device cup. Grooving tool is used to cut a groove the device cup. The crank is turned on the liquid limit device at a rate of 2 cranks per second. Count and record the number of cranks that are required to close the groove. Liquid limit is defined as the water content at which the groove closes at exactly 25 cranks. To derive liquid limit using the multipoint method, the procedure is repeated at four different water contents, and the data are plotted on a graph of w versus number of cranks. This test is also performed for the Sample of Black cotton soil of two test pits mixed with optimum content of waste paper sludge and 10, 20, 30 and 40% of marble dust by mass of soil.


(a) (b)

Figure 3.5.a Sample preparation for Liquid limit test b. Performing of Liquid limit test

3.4.8 Free Swell Test

The test includes the determination of the free swell for the natural soil. The method was first suggested by Holtz and Gibbs, (1956) to measure the expansive potential of cohesive soils. Free swell is determined as the ratio of change in volume to the initial volume, expressed as percentage. The free swell test gives an approximation of the degree of expansiveness of the soil sample.

To determine free swell of a soil, two 10 g soil specimens of oven dry soil passing through 425 micron IS Sieve is used. Each soil specimen is poured in each of the two glass graduated cylinders of 100 ml capacity. One cylinder is filled with kerosene oil and the other with distilled water up to the 100 ml mark. After removal of entrapped air (by gentle shaking or stirring with a glass rod), the soils in both the cylinders is allowed to settle. Sufficient time not less than 24 h is allowed for the soil sample to attain equilibrium state of volume. Then final volume of soils in each of the cylinders is read out. Black cotton soil is mixed with optimum waste paper sludge waste and 10, 20, 30and 40% of marble dust by mass of soil and free swell test is performed. Free swell index is obtained as

$$\text{Free swell index} = \frac{V_d - V_k}{V_k} \times 100\% \quad \text{……………………………………………………..(3.2)}$$

Where

- V_d is the volume of soil specimen read from the graduated cylinder containing distilled water
- V_k is the volume of soil specimen read from the graduated cylinder containing kerosene

3.4.9 Consolidation Test

When a layer of fine-grained (cohesive) soil, including ML, CL, and CH, is subjected to an increase in effective stress through an increase overburden stress, the soil undergoes a long-term reduction in void ratio, e, which is accompanied by settlement of the soil layer. To quantify both the ultimate amount of settlement and the time rate of settlement in the soil layer, a one-dimensional consolidation test is performed in the laboratory. Using laboratory-derived parameters, field settlement behavior of the soil layer can be predicted (ASTM-D2435, 2020).

Remolded samples of the natural soil and soil mixed with marble dust and waste paper sludge were prepared by using the corresponding OMC and compacting samples to get the respective MDD of the soil samples as obtained from the standard compaction tests. The compacted sample is placed in the consolidation ring of diameter 75mm, and height of 20mm, then it is subjected to a vertical incremental pressure. For each increment axial load deformation is recorded at time interval of 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30 min and 1, 2, 4, 8 and 24 hr. For the natural soil and mixture of soil with marble dust and waste paper sludge optimum moisture content is used to remold the samples.

Figure 3.7 Consolidation test using Odometer

Chapter Four

Result and Discussion

4.1 Introduction

In this chapter laboratory test results for Natural black cotton soil and for the mixture of soil with marble dust and waste paper sludge are briefly discussed. Revision on the physical properties of soil has also been summarized to make the comparison between treated and untreated soil samples. From results comparisons are outlined for the natural soil and for the mixture of soil mixed with marble dust and waste paper sludge. The tests include Atterberg limits, free swell, compaction, unconfined compressive strength and consolidation tests.

4.2 Laboratory Test Results for Natural Black Cotton soil

Black cotton soil of two test pit have classified as A-7-5 based on AASHTO Soil classification and MH or OH based on USCS Soil classification system. Which indicates that the Soil in the study area is highly compressible, semi-pervious to impervious, fair to poor shear strength and poor workability. It also shows the soil in the study area has high plasticity based on USCS. Liquid limit of the soil is 135 and 96 for Test pit 1 and Test pit 2 respectively and Plastic index of 60 and 42.67 for Test Pit 1 and Test Pit 2 respectively which shows that the soil has high swelling potential according to (Chen, 1988). From standard compaction test result maximum dry density of Natural black cotton of Test pit 1 and Test Pit 2 is 1.12g/$cm^3$and 1.102 g/cm^3 respectively. Free Swell index of Natural Black Cotton soil of Test pit 1 and Test pit 2 is 140 and 141 respectively. The summary of properties of soil used is described in Table 4.1.

Table 4.1 Summary of Properties of Black cotton soil of two test pits

Properties	**Test Pit 1**	**Test Pit 2**
Natural Moisture Content (%)	36	42
Percentage passing no 200 sieve (%)	90.8	74
Liquid Limit	135	96
Plastic Limit	75	53.33
Plastic index	60	42.67
Specific Gravity	2.38	2.42
AASHTO Soil classification	A-7-5	A-7-5
Unified Soil Classification	MH or OH	MH or OH
Free Swell Index (%)	140	141
Maximum Dry Density (g/cm^3)	1.12	1.102
Optimum Moisture Content (%)	35	44
UCS (KN/m^2)	170.95	157
Swelling Pressure (KN/m^2)	55	24

To determine Grain size distribution wet sieve and hydrometer analysis test is performed. From the results the soil sample is 9.2 % sand and 90.8 % fine for Test Pit 1 and 26% sand 74% fine for Test Pit 2.

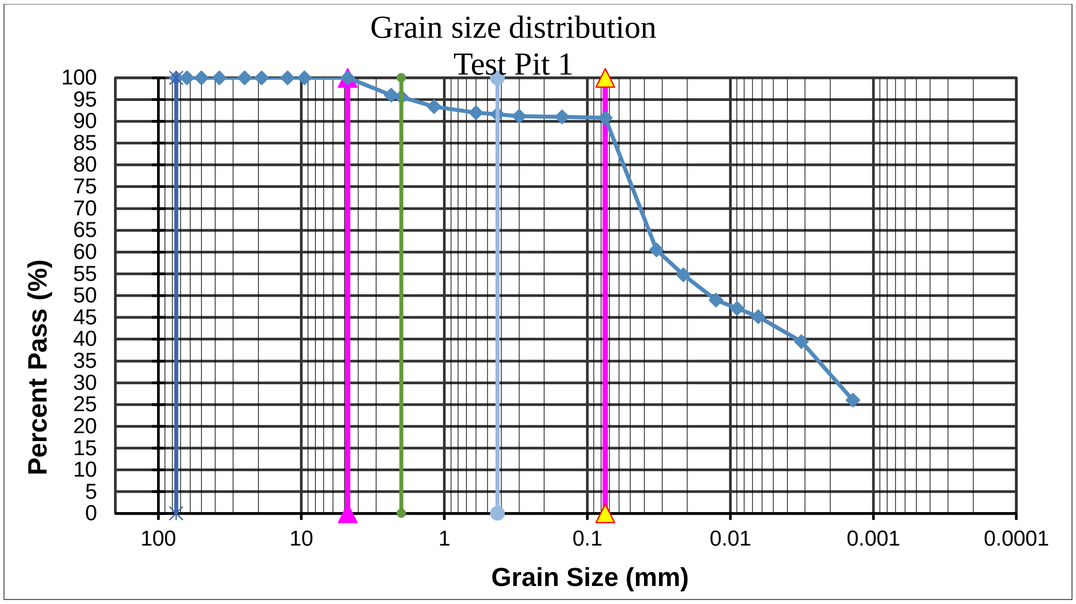

Figure 4.1 Grain Size distribution of soil of Test Pit 1

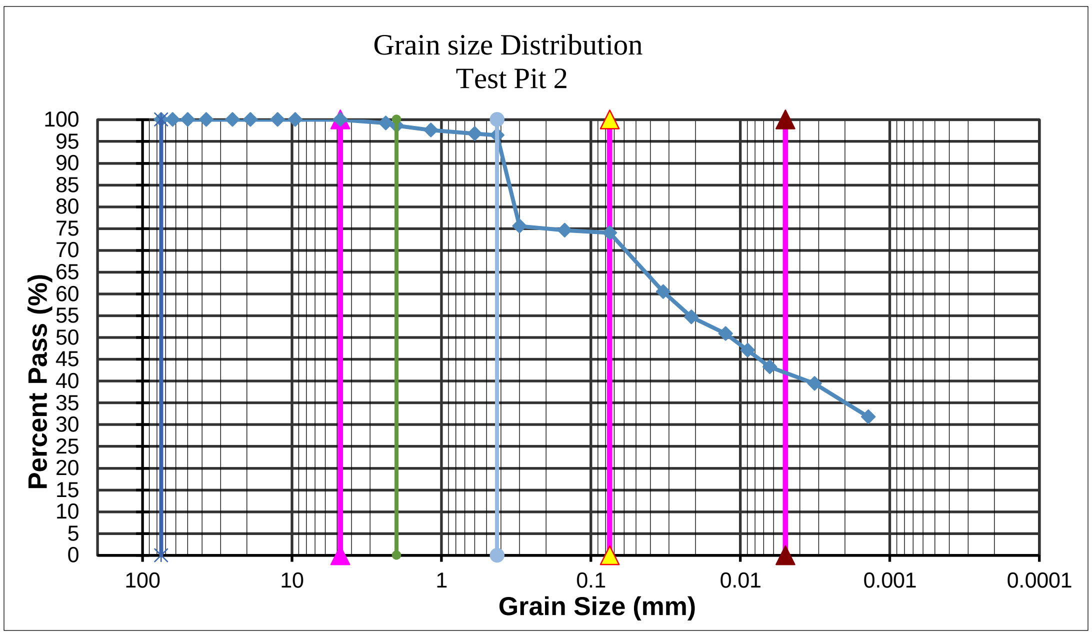

Figure 4.2 Grain Size distribution of soil of Test Pit 2

4.3 Effect of Waste paper sludge on Properties of Black Cotton Soil

4.3.1 Effect of Waste Paper sludge on Maximum Dry Density and optimum Moisture Content

Black cotton soil is blended with 5, 10 and 15% of waste paper sludge by mass of soil and standard compaction test is performed to determine optimum moisture content and maximum dry density.

Maximum Dry Density of Black cotton Soil of Test Pit 1 and Test Pit 2 is 1.121 g/cm^3 and 1.102 g/cm^3 respectively. With the addition of Waste paper sludge of 5% by mass of soil, the maximum dry density has increased to 1.218 g/cm^3 and 1.167 g/cm^3 for Test Pit 1 and Test Pit 2 respectively. Further addition of Waste Paper sludge increased the maximum dry density of a soil but relatively in less value compared with 5% addition of waste paper sludge. Generally the maximum dry density of soil decreases gradually with an increase of waste paper sludge content of 10 and 15% for both soil samples. This is due to comparatively low specific gravity and light weight behavior of waste paper sludge. Waste paper sludge with lower specific gravity fills the soil voids and it contributes to a decrease in density.

Optimum moisture content of Natural Black Cotton soil of test pit 1 and test pit 2 is 35% and 44% respectively. Addition of 5% waste paper sludge reduced the optimum moisture content to 26.45% and 30.6% for test pit 1 and test pit 2 respectively but further addition of waste paper sludge increased the optimum moisture content. The effect of Waste paper sludge on maximum dry density and Optimum moisture content is summarized in Table 4.2 and Table 4.3.

Table 4.2 Effect of Waste paper sludge on maximum dry density and optimum moisture content for test pit 1

Test pit 1		
Waste Paper Sludge (%)	MDD(g/cm3)	OMC (%)
Natural Black Cotton Soil	1.121	35
95% Black Cotton Soil + 5% Waste Paper sludge	1.218	26.45
90% Black Cotton Soil + 10% Waste Paper sludge	1.151	39.8
85% Black Cotton Soil + 15% Waste Paper sludge	1.15	40.33

The curve shifted to the left top position in the case of treating the soil with Waste paper sludge of 5% as shown in figure 4.3 and 4.4. It indicates that addition of Waste paper sludge decreased optimum moisture content and increased maximum dry density. But further addition of Waste paper sludge of 10 and 15% causes the curve to move to the right bottom position compared with 5 % addition of waste paper sludge which indicates that reduction in maximum dry density and increase in optimum moisture content.

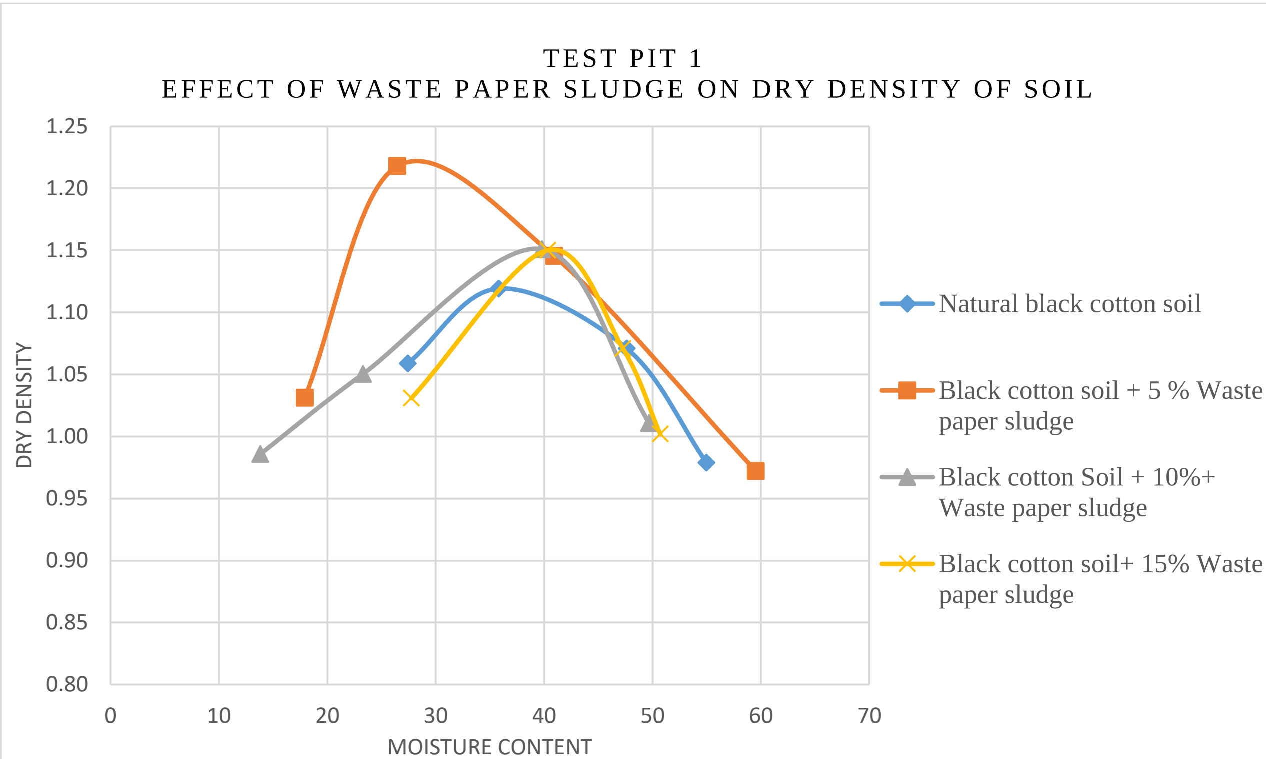

Figure 4.3 Effect of waste paper sludge on dry density of the soil for Test pit 1

Table 4.3 Effect of Waste paper sludge on maximum dry density and optimum moisture content for test pit 2

Test pit 2		
Waste Paper Sludge (%)	MDD	OMC (%)
Natural Black Cotton Soil	1.102	44
95% Black Cotton Soil + 5% Waste Paper Sludge	1.167	30.6
90% Black Cotton Soil + 10% Waste Paper Sludge	1.121	38.73
85% Black Cotton Soil + 15% Waste Paper Sludge	1.095	44

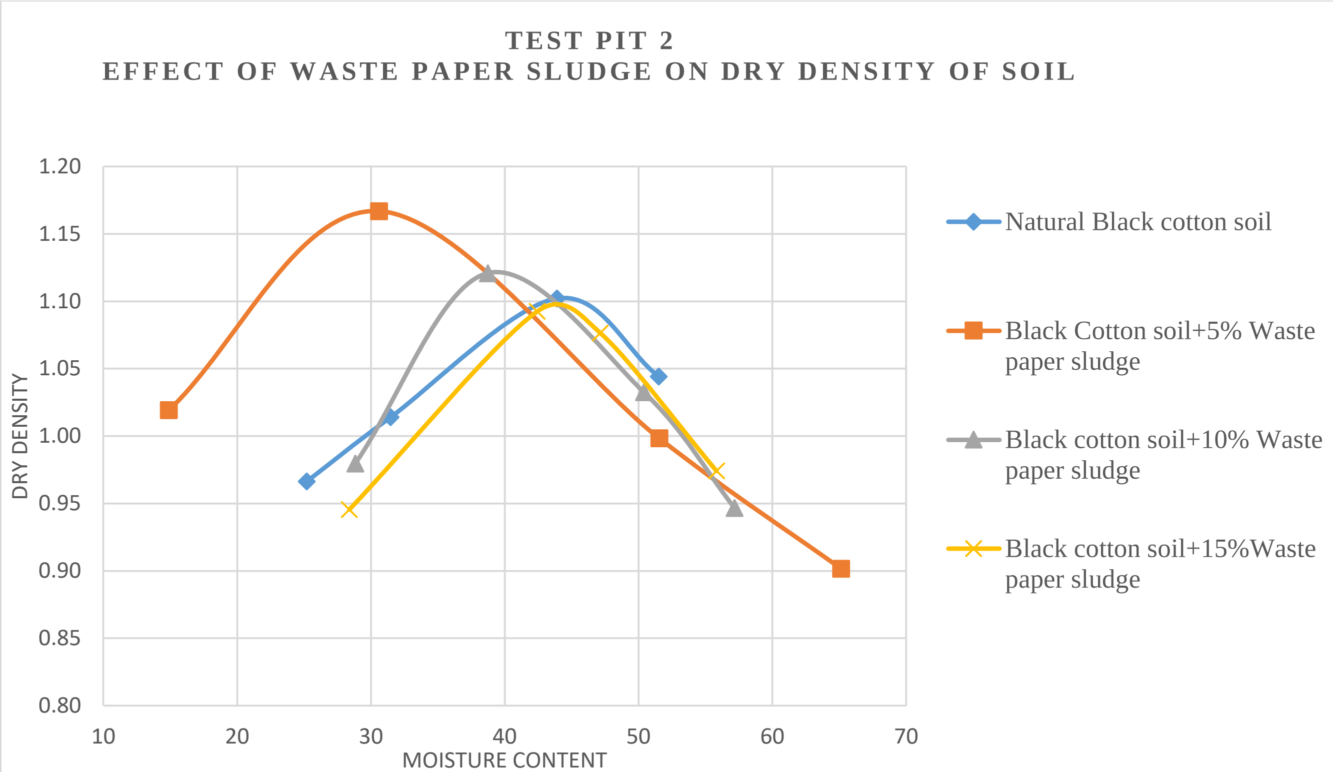

Figure 4.4 Effect of Waste paper sludge on dry density moisture content relation for Test Pit 2

4.3.2 Effect of Waste paper sludge on Unconfined Compressive Strength (UCS) of soil

Black cotton soil of each Test Pits are mixed with 5, 10 and 15% of waste paper sludge. The the samples that are mixed with different percentages of waste paper sludge are remolded by using optimum moisture content values which are determined from compaction tests. After remolding of the samples unconfined compressive strength test is performed.

Unconfined Compressive strength of Natural Black cotton Soil of Test Pit 1 and Test Pit 2 is 170.95 KN/m^2 and 157 KN/m^2 respectively. With the addition of Waste paper sludge of 5% by mass of soil, Unconfined Compressive strength of a soil has increased to 227.38 KN/m^2 and 237.07 KN/m^2 for Test Pit 1 and Test Pit 2 respectively. Further addition of Waste Paper sludge increased the strength of a soil but relatively in less value compared with 5% addition of waste paper sludge. The reduction of the strength is due to the reduction of the maximum dry density of the soil caused by the relatively less value of the specific gravity of the waste paper sludge compared to the soil. So 5% waste paper sludge is considered as the optimum amount for strength. The effect of Waste paper sludge on Unconfined Compressive strength is summarized in Table 4.4 and Table 4.5.

Table 4.4 Effect of addition of waste paper sludge on Unconfined Compressive strength of soil for Test Pit 1

Test Pit 1	
Waste Paper Sludge (%)	UCS (KN/m^2)
Natural Black Cotton Soil	170.95
95% Black Cotton Soil + 5% Waste Paper Sludge	227.38
90% Black Cotton Soil + 10% Waste Paper Sludge	209.94
85% Black Cotton Soil + 15% Waste Paper Sludge	202.34

Strength of the soil of Test Pit 1 is increased from 170.95 KN/m^2 to 227.38 KN/m^2 with the addition of 5% waste paper sludge and reduced to 209.94 KN/m^2 and 202.34 KN/m^2 with the addition of 10 and 15% waste paper sludge respectively. From Figure 4.5 the curve moved to the right top position for the addition of 5% waste paper sludge which shows that increased strength and moved to the right bottom position for the addition of 10 and 15% of waste paper sludge which indicates reduction in strength compared with 5% addition of waste paper sludge.

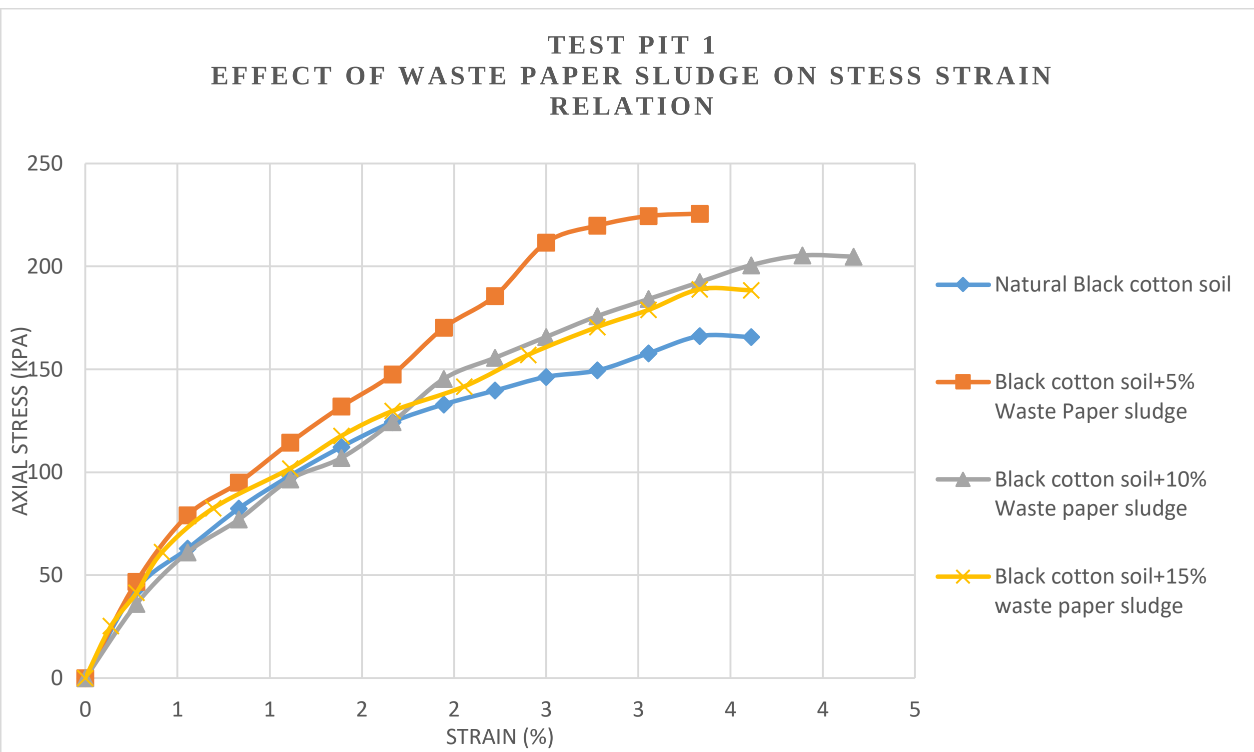

Figure 4.5 Effect of waste paper sludge on stress strain relation For Test Pit 1

Table 4.5 Effect of addition of waste paper sludge on Unconfined Compressive strength of soil for Test Pit 2

Test Pit 2	
Waste Paper Sludge (%)	UCS (KN/m^2)
Natural Black Cotton Soil	157
95% Black Cotton Soil + 5% Waste Paper Sludge	237.07
90% Black Cotton Soil + 10% Waste Paper Sludge	179.19
85% Black Cotton Soil + 15% Waste Paper Sludge	162.22

Strength of the soil of Test Pit 2 is increased from 157 KN/m^2 to 237.07 KN/m^2 with the addition of 5% waste paper sludge and reduced to 179.19 KN/m^2 and 162.22 KN/m^2 with the addition of 10 and 15% waste paper sludge respectively. From Figure 4.6 the curve moved to the right top position for the addition of 5% waste paper sludge which shows increased strength and moved to the right bottom position for the addition of 10 and 15% of waste paper sludge which indicates reduction in strength compared with 5% addition of waste paper sludge.

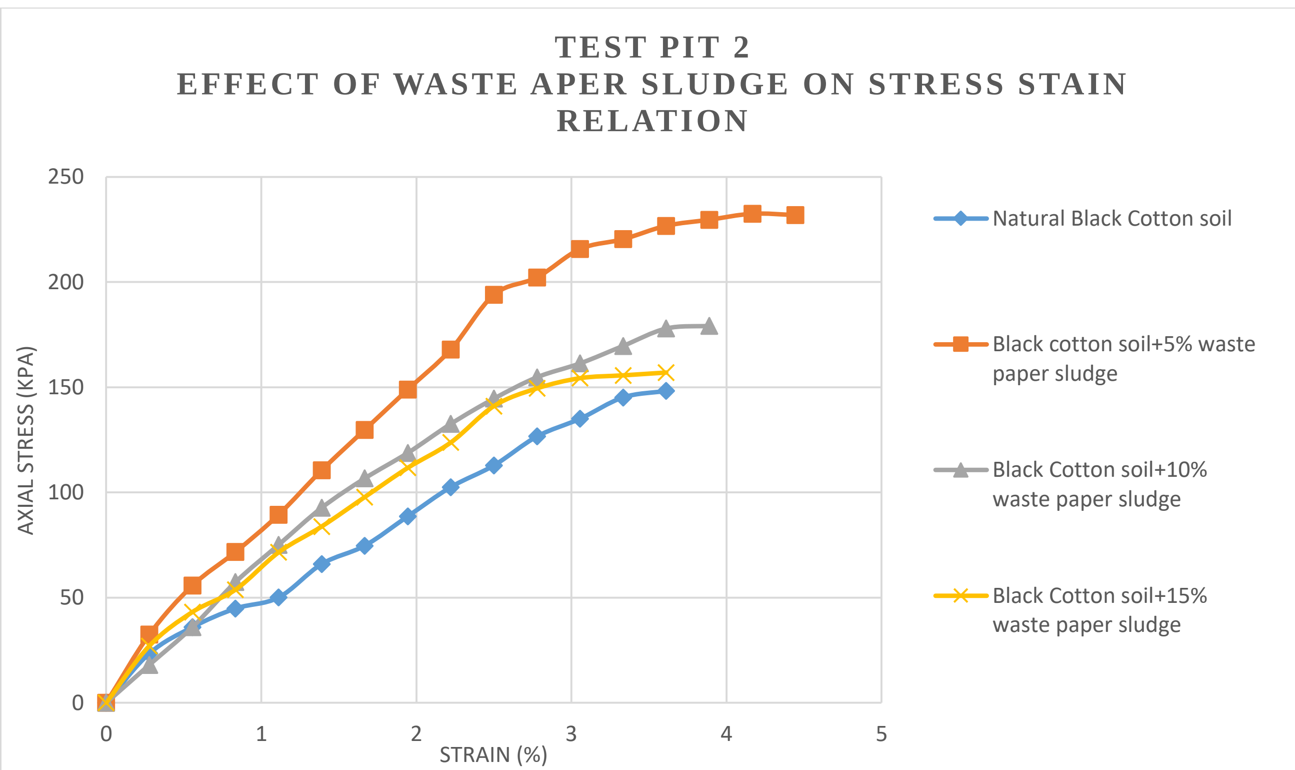

Figure 4.6 Effect of waste paper sludge on stress strain relation For Test Pit 2

4.4 Combined effect of Marble dust and Waste Paper Sludge on Properties of Black Cotton soil.

From the results of compaction test and Unconfined Compressive Strength of Black cotton soil mixed with 5, 10 and 15% of waste paper sludge by mass of soil shows that maximum dry density of a soil is increased at 5% of waste paper sludge and further increase reduced the dry density of the soil. The results of Unconfined Compressive strength tests shows that maximum strength is obtained at 5% addition of waste paper sludge. So 5% waste paper sludge is considered the optimum amount to improve the strength of the soil. 5% waste paper sludge is used as a constant and marble dust of 10, 20, 30 and 40% is mixed with this optimum content and the following tests are performed.

- Atterberg Limit test
  - ✓ Liquid Limit
  - ✓ Plastic limit
- Standard Compaction test
- Unconfined compression Strength test
- Free swell test

4.4.1 Combined effect of Marble dust and waste paper sludge on Atterberg Limits

Sample of Black cotton soil of two Test Pits are mixed with 5% waste paper sludge and 10, 20, 30 and 40% of marble dust by mass of soil and Liquid limit and plastic limit tests are performed and plastic index is determined for each mixed samples in accordance with the procedure of ASTM 2487.

Liquid limit of Natural Black Cotton soil of Test Pit 1 and Test Pit 2 is 135 and 96 respectively, and plastic limit of Natural Black Cotton soil of Test Pit 1 and Test Pit 2 is 60 and 46 respectively, these values are significantly reduced with the addition of Waste Paper Sludge and Marble dust as described in Table 4.6 and Table 4.7. Plasticity index is significantly reduced with the addition of waste paper sludge and marble dust. Cation exchange reactions result in the flocculation and agglomeration of the soil particles with consequent reduction in the amount of clay-size materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity.

Table 4.6 Combined effect of Waste paper sludge and marble dust on Atterberg limit values for Test Pit 1

Test Pit 1			
Waste paper sludge and Marble dust (%)	**Liquid Limit**	**Plastic Limit**	**Plastic Index**
Natural Black Cotton soil	135	60	75
95% Black Cotton Soil + 5% Waste paper sludge + 0% Marble Dust	87	52	35
85% Black Cotton Soil + 5% Waste paper sludge + 10% Marble Dust	83	50	33
75% Black Cotton Soil + 5% Waste paper sludge + 20% Marble Dust	60	38	22
65% Black Cotton Soil + 5% Waste paper sludge + 30% Marble Dust	48	27	21
55% Black Cotton Soil + 5% Waste paper sludge + 40% Marble Dust	36	23	13

Table 4.7 Combined effect of Waste paper sludge and marble dust on Atterberg limit values for Test Pit 2

Test Pit 2			
Waste paper sludge and Marble dust (%)	**Liquid Limit**	**Plastic Limit**	**Plastic Index**
Natural Black Cotton Soil	96	46	50
95% Black Cotton Soil + 5% Waste paper sludge + 0% Marble Dust	76	36	40
85% Black Cotton Soil + 5% Waste paper sludge + 10% Marble Dust	72	34	38
75% Black Cotton Soil + 5% Waste paper sludge + 20% Marble Dust	55	38	23
65% Black Cotton Soil + 5% Waste paper sludge + 30% Marble Dust	40	20	20
55% Black Cotton Soil + 5% Waste paper sludge + 40% Marble Dust	29	18	11

4.4.2 Combined effect of Marble dust and waste paper sludge on Maximum Dry Density and Optimum Moisture content

Black cotton soil is mixed with 5% waste paper sludge and 10, 20, 30and 40% of marble dust by mass of soil and standard compaction test is performed to determine optimum moisture content and maximum dry density.

Maximum Dry Density of Black cotton Soil of Test Pit 1 and Test Pit 2 is 1.121 g/cm^3 and 1.102 g/cm^3 respectively. With the addition of Waste paper sludge of 5% by mass of soil. The maximum dry density has increased to 1.218 g/cm^3 and 1.167 g/cm^3 for Test Pit 1 and Test Pit 2 respectively. Addition of Marble dust of 10, 20, 30 and 40% by mass of soil with 5% of waste paper sludge further increased the maximum dry density of a soil. This is due to comparatively high specific gravity behavior of marble dust. Marble dust with higher specific gravity fills the soil voids and it contributes to an increase in density.

Optimum moisture content of Natural Black Cotton soil of Test Pit 1 and Test Pit 2 is 35 and 44% respectively addition of 5% of waste paper sludge reduced the optimum moisture content, but addition 5% waste paper sludge with 10% marble dust has increased its value. Further addition of marble dust has then reduced the optimum moisture content of the soil as described in table 4.8 and table 4.9.

Table 4.8 The combined effect of Waste paper sludge and Marble dust on maximum dry density and optimum moisture content of a soil

Test pit 1		
Waste paper sludge and Marble dust (%)	**MDD(**g/cm^3)	**OMC (%)**
Natural Black Cotton Soil	1.12	35
95% Black Cotton Soil + 5% Waste paper sludge + 0% Marble Dust	1.218	26.45
85% Black Cotton Soil + 5% Waste paper sludge + 10% Marble Dust	1.25	30
75% Black Cotton Soil + 5% Waste paper sludge + 20% Marble Dust	1.3	30
65% Black Cotton Soil + 5% Waste paper sludge + 30% Marble Dust	1.31	31
55% Black Cotton Soil + 5% Waste paper sludge + 40% Marble Dust	1.368	27

Black Cotton soil treated with waste paper sludge and marble dust yielded the typical bell shaped compaction curves. The dry density for the untreated soil of Test Pit 1 was observed to be 1.12 g/cm^3. Even though the compaction curve is normal, the curve shifted to the left top position in the case of treating the soil with Waste paper sludge and marble dust as shown in figure 4.6, which also means addition of Waste paper sludge and marble dust decreased optimum moisture content and increased maximum dry density.

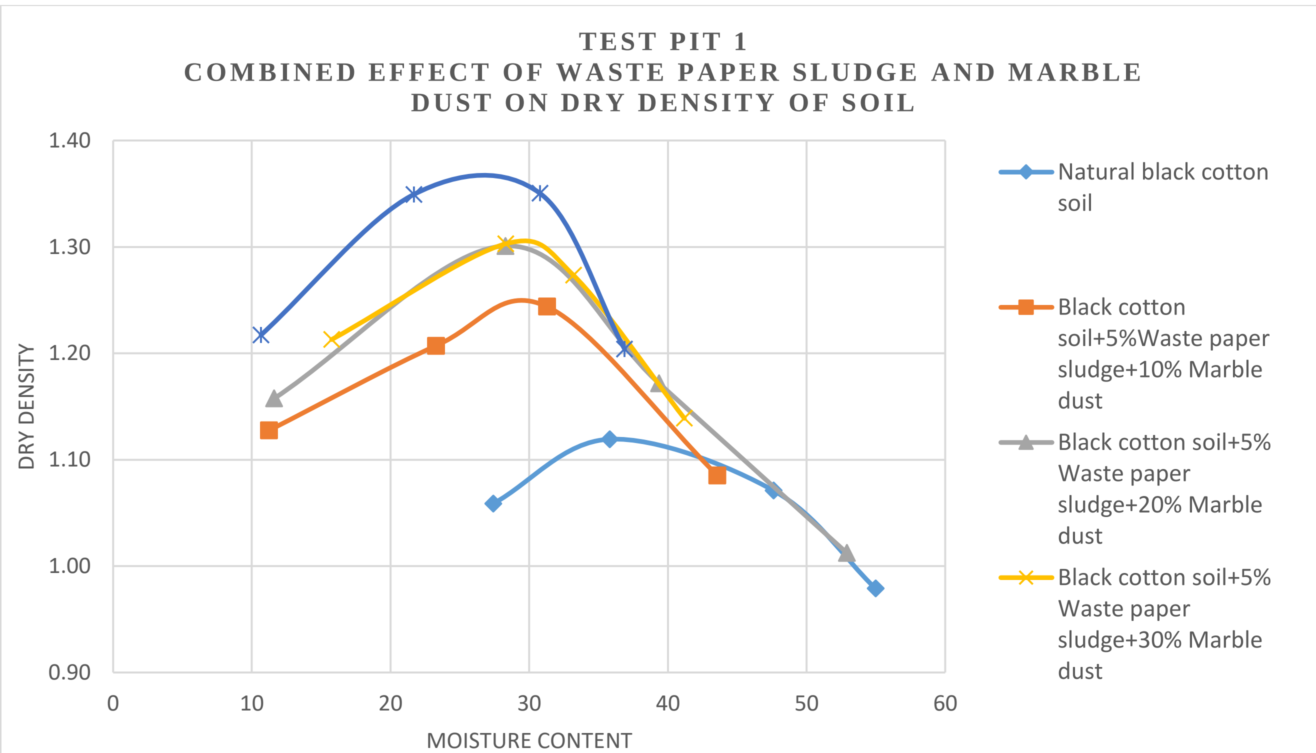

Figure 4.6 Combined effect of Marble dust and waste paper sludge on dry density-moisture content relation for Test Pit 1

Table 4.9 The combined effect of Marble dust and Waste paper sludge on maximum dry density and optimum moisture content of a soil for Test Pit 2

Test pit 2		
Waste paper sludge and Marble dust (%)	MDD	OMC (%)
Natural Black Cotton Soil	1.102	44
95% Black Cotton Soil + 5% Waste paper sludge + 0% Marble Dust	1.167	30.6

85% Black Cotton Soil + 5% Waste paper sludge + 10% Marble Dust	1.2	35
75% Black Cotton Soil + 5% Waste paper sludge + 20% Marble Dust	1.256	38
65% Black Cotton Soil + 5% Waste paper sludge + 30% Marble Dust	1.345	25.46
55% Black Cotton Soil + 5% Waste paper sludge + 40% Marble Dust	1.358	25

The dry density for the untreated soil of test pit 2 was observed to be 1.102 g/cm^3. The curve shifted to the left top position in the case of treating the soil with Waste paper sludge and marble dust as shown in figure 4.7, which also means addition of Waste paper sludge and marble dust decreased optimum moisture content and increased maximum dry density.

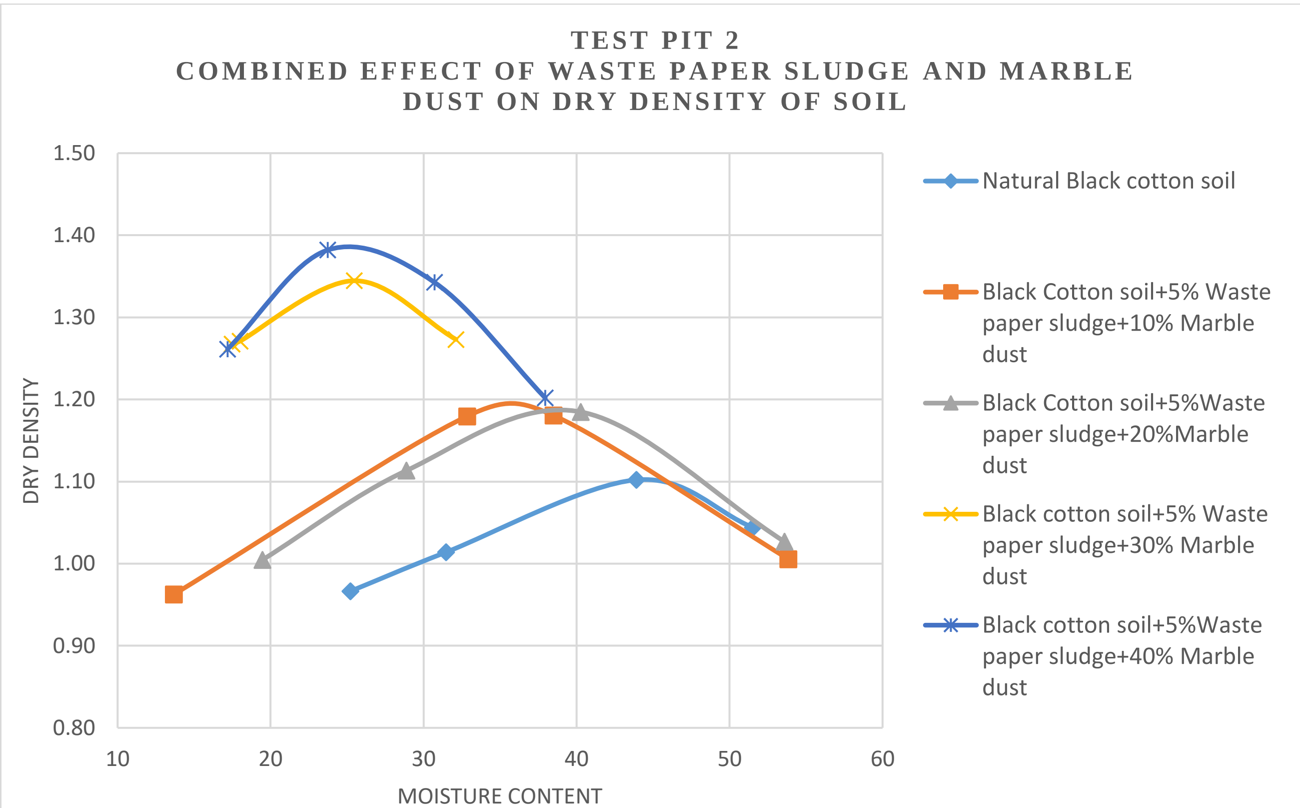

Figure 4.7 Combined effect of marble dust and waste paper sludge on dry density moisture content relation for Test Pit 2

4.4.2 Combined effect of Marble dust and waste paper sludge on Unconfined Compressive Strength (UCS) of a soil

Black cotton soil of each Test Pits is mixed with 5% waste paper sludge and 10, 20, 30 and 40 % of marble dust, compaction test is done for each mixed samples and described in section 4.3.2. Each samples are prepared at their respective MDD and OMC from the result of compaction tests. Then OMC is used to mix and remold the samples after that UCS test is performed and readings are taken for each sample.

Unconfined compressive strength of Natural Black cotton Soil of Test Pit 1 and Test Pit 2 is 170.95 KN/m^2 and 157 KN/m^2 respectively. From section 4.2.2 with the addition of waste paper sludge of different percentages by mass of soil, optimum amount of waste paper sludge is obtained as 5%. With the addition of marble dust by mass of the soil as 10, 20, 30 and 40% with the predetermined 5% waste paper sludge, the strength of the soil is further increased. It is seen that as the percentage of marble dust increases the strength of the soil also increased up to 30% of marble dust, and the strength of the soil decreased with the addition of 40% of marble dust.

It is observed that the unconfined compressive strength of the treated soil is increasing as the amount of waste paper sludge and marble dust is increasing up to 5% waste paper sludge with 30% marble dust. The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystallizes to form an interlocking structure thus, strength of the soils increases. But with the addition of 5% waste paper sludge with 40% marble dust the strength of the soil is decreased. The reason for the decrease for the unconfined compressive strength of the soil is due to the fact that the addition of excess cohesion less material to the clay soil reduce its natural cohesive force between the particles of clay soil.

Strength of a soil shows a significant increase by the addition of 5% waste paper sludge with 30% marble dust. The strength of a soil has increased from 170.95 KN/m^2 to 268.33 KN/m^2 for Test Pit 1and from 157 KN/m^2 to 253.6 KN/m^2 for Test Pit 2. So it is seen than addition of 5% waste paper sludge with 30% marble dust is an optimum amount for strength.

Table 4.10 Combined effect of Marble dust and waste paper sludge on Unconfined Compressive Strength (UCS) of a soil for test pit 1

Test Pit 1	
Waste paper sludge and Marble dust (%)	**UCS (KN/m^2)**
Natural Black Cotton Soil	170.95
95% Black Cotton Soil + 5% Waste paper sludge + 0% Marble Dust	227.38
85% Black Cotton Soil + 5% Waste paper sludge + 10% Marble Dust	242.67
75% Black Cotton Soil + 5% Waste paper sludge + 20% Marble Dust	246.19
65% Black Cotton Soil + 5% Waste paper sludge + 30% Marble Dust	268.33
55% Black Cotton Soil + 5% Waste paper sludge + 40% Marble Dust	193

Strength of a soil of Test pit 1 shows a significant increase by the addition of 5% waste paper sludge with 30% marble dust. The strength of a soil has increased from 170.95 KN/m^2 to 268.33 KN/m^2 and the strength of the soil decreased to 193KN/m^2 with the addition of 40% of marble dust. From Figure 4.6 the curve moved to the right top position for the addition of 5% waste paper sludge with 10, 20 and 30% of marble dust which shows increased strength and moved to the right bottom position for the addition of 5% of waste paper sludge with 40% marble dust which indicates reduction in strength.

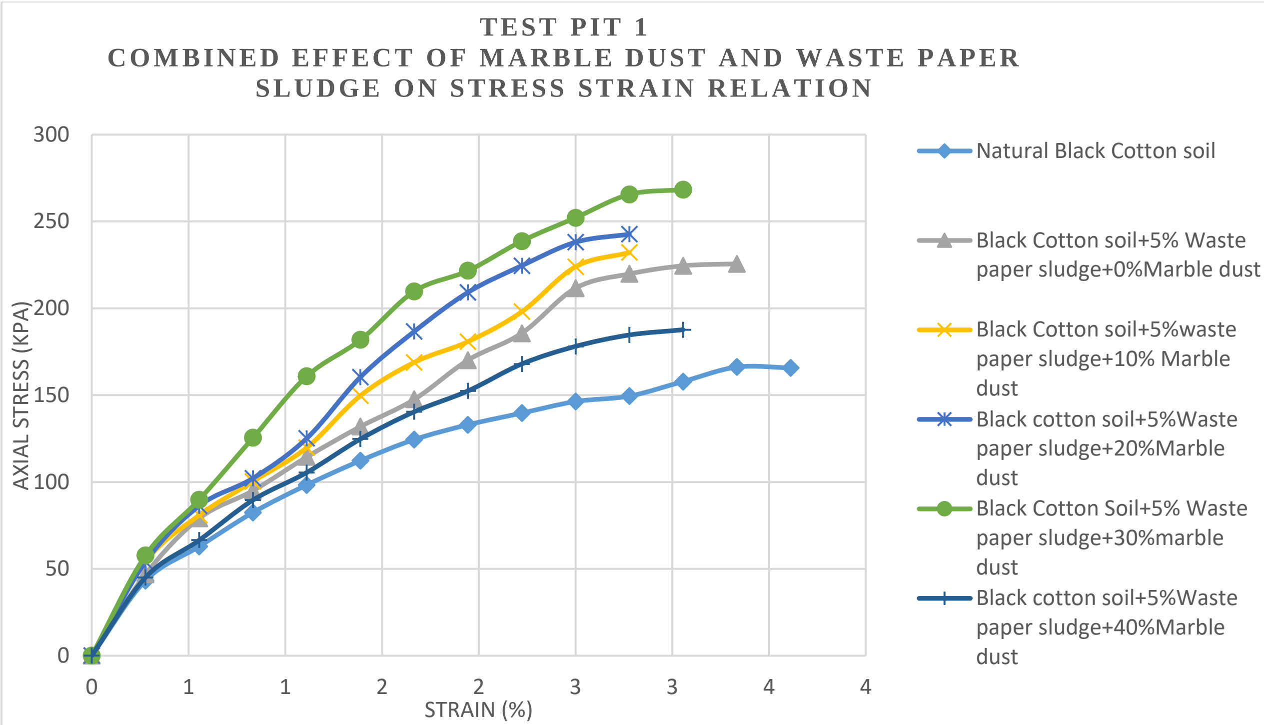

Figure 4.7 Combined effect of marble dust and waste paper sludge on stress-strain relation for Test Pit 1

Table 4.11 Combined effect of Marble dust and waste paper sludge on Unconfined Compressive Strength (UCS) of a soil for test pit 2

Test Pit 2	
Waste paper sludge and Marble dust (%)	**UCS (KN/m^2)**
Natural Black Cotton Soil	157
95% Black Cotton Soil + 5% Waste paper sludge + 0% Marble Dust	237.07
85% Black Cotton Soil + 5% Waste paper sludge + 10% Marble Dust	242
75% Black Cotton Soil + 5% Waste paper sludge + 20% Marble Dust	245
65% Black Cotton Soil + 5% Waste paper sludge + 30% Marble Dust	253.6
55% Black Cotton Soil + 5% Waste paper sludge + 40% Marble Dust	211.6

Strength of a soil of Test Pit 2 shows a significant increase by the addition of 5% waste paper sludge with 30% marble dust. The strength of a soil has increased from 157 KN/m^2 to 253.6 KN/m^2

and the strength of the soil decreased to 211.6 KN/m^2 with the addition of 5% waste paper sludge with 40% of marble dust.

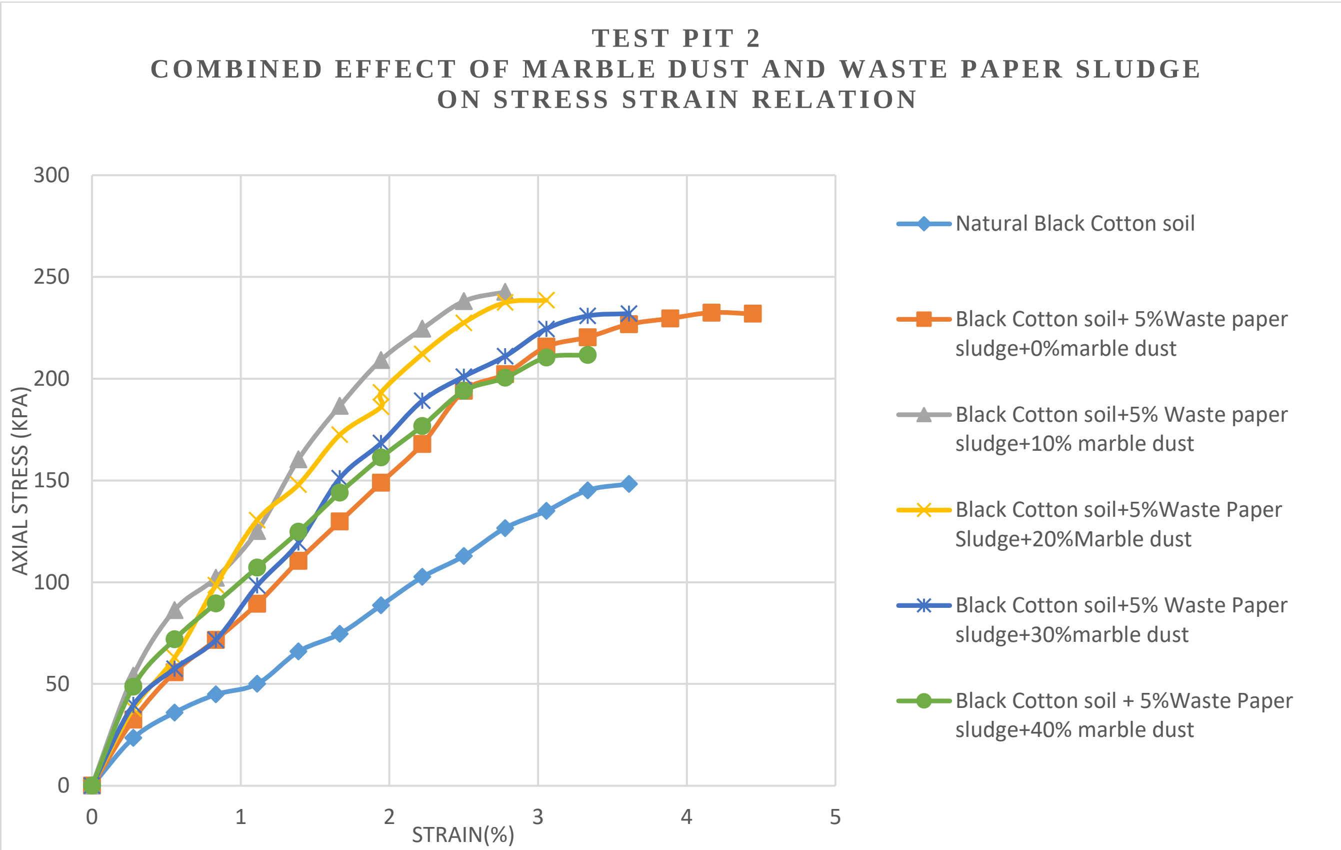

Figure 4.8 Combined Effect of Marble dust and Waste Paper sludge on Stress strain Relation of the soil for Test Pit 2

4.4.2 Combined effect of Marble dust and waste paper sludge on Free Swell

Black cotton soil is mixed with 5% waste paper sludge with 10, 20, 30and 40% of marble dust by mass of soil and free swell test is performed. Free swell index of Natural Black Cotton Soil of Test Pit 1 and Test Pit 2 is 140 and 141 respectively. Addition of marble dust of 10, 20, 30 and 40% by mass of soil with 5% of waste paper sludge reduced free swell index a soil. The combined effect of Waste paper sludge and Marble dust on free swell index of a soil is summarized in Table 4.12 and Table 4.13.

Table 4.12 The combined effect of Marble dust and Waste paper sludge dust on free swell index of a soil for Test pit 1

Test Pit 1	Free Swell Index
Natural Black Cotton Soil	140
85% Black Cotton Soil+5% Waste Paper Sludge+10% Marble dust	130
75% Black Cotton Soil+5% Waste Paper Sludge+20% Marble dust	110
65% Black Cotton Soil+5% Waste Paper Sludge+30% Marble dust	60
55% Black Cotton Soil+5% Waste Paper Sludge+40% Marble dust	55

Table 4.13 The combined effect of Marble dust and Waste paper sludge on free swell index of a soil for Test pit 2

Test Pit 2	Free Swell Index
Natural Black Cotton Soil	141
85% Black Cotton Soil+5% Waste Paper Sludge+10% Marble dust	105
75% Black Cotton Soil+5% Waste Paper Sludge+20% Marble dust	100
65% Black Cotton Soil+5% Waste Paper Sludge+30% Marble dust	70
55% Black Cotton Soil+5% Waste Paper Sludge+40% Marble dust	50

4.5 Consolidation Characteristics of the soil

4.5.1 Consolidation Test

The compression of a saturated soil under a steady static pressure is known as consolidation. It is entirely due to expulsion of water from the voids. It is similar to the action of squeezing of water from a saturated sponge under water. The soil behaves as a saturated sponge. As a consolidation of soil occurs, the water escapes. The solid particles shift from one position to other by rolling and sliding thus attain a closer packing. It is worth nothing that the decrease in volume of soil occurs not due to compression of solids or water but due to the shifting of positions of the particles as the water escapes. Small volume changes may insignificant in the ordinary range of stresses involved in soil engineering problems (Arora, 2004).

4.5.2 Compressibility Characteristics

Compressibility Characteristics of soils forms one of the important soil parameters required in design considerations. Coefficient of compressibility (Cv), Coefficient of volume compressibility (mv) and Compression index (Cc). These coefficients are derived from consolidation tests and are indicative of the compressibility of soils. They serve to give estimates of the amount of settlement due to primary consolidation.

The coefficient of compressibility (Cv) and the coefficient of volume compressibility (mv) are usually calculated for each load increment while the compression index(Cc) is derived from an e/ log p curve obtained by plotting voids ratio, e, against applied pressure, p, (log scale). In practice, (mv) is applied to over-consolidated clays and (Cc) to normally consolidated one (Arora, 2004).

4.5.3 Consolidation Characteristics for Natural Black Cotton Soil

Coefficient of vertical consolidation (Cv)

Time-deformation data are used to derive coefficient of vertical consolidation by using two methods which are log time and root time method. Based on Root time method Cv is found from 1.13 to 3.27 m^2 /year and from 0.48 to 1.46 m^2 /year for test pit 1 and test pit 2 respectively which shows medium rate of consolidation.

Void ratio

Void ratio (eo) of a Natural Black Cotton soil is 1.496 and 1.498 for Test Pit 1 and Test Pit 2 respectively. Voids ratio/ log pressure (e/log p) curves as shown in Figure (5.4) are found on top positions on the diagram due to their relatively higher void ratios. The higher the void ratio the higher the compressibility or settlement potential, the soil in the study area can be compressible to a higher degree because of its high void ratio. As a result, the soils would be expected to be compressible.

Coefficient of volume compressibility (mv)

Coefficient of volume Compressibility (Mv) for Natural Black Cotton soil is found in the range from 0.17 to 0.573 and from 0.086 to 0.322 for Test Pit 1 and Test Pit 2 respectively. Results of laboratory consolidation tests show that expansive clay soils have been found to be characterized by generally medium to high compressible and, therefore, high consolidation settlements on external loading. The high rates of consolidation- settlement exhibited by these clays would also mean structural settlements occurring. Long-term instability problems would therefore be expected for structures constructed on these clays.

Compression index (Cc)

Among the compressibility properties, compression index is by far the most important engineering property to estimate settlement of foundations. It is defined as the slope of void ratio versus logarithm of the applied load curve in one dimensional consolidation test graph. Compression index of Natural Black Cotton soil is found as 0.517 and 0.493 for Test Pit 1 and Test Pit 2 respectively.

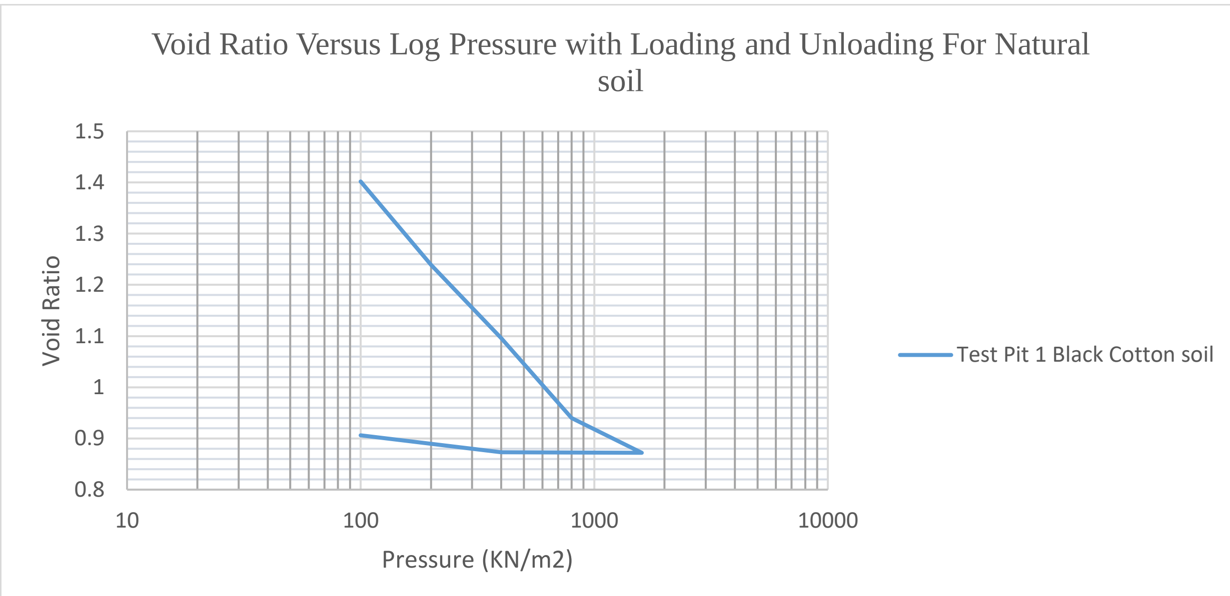

Figure 4.9 Void Ratio versus Log Pressure with Loading and Unloading for Natural soil for Test Pit 1

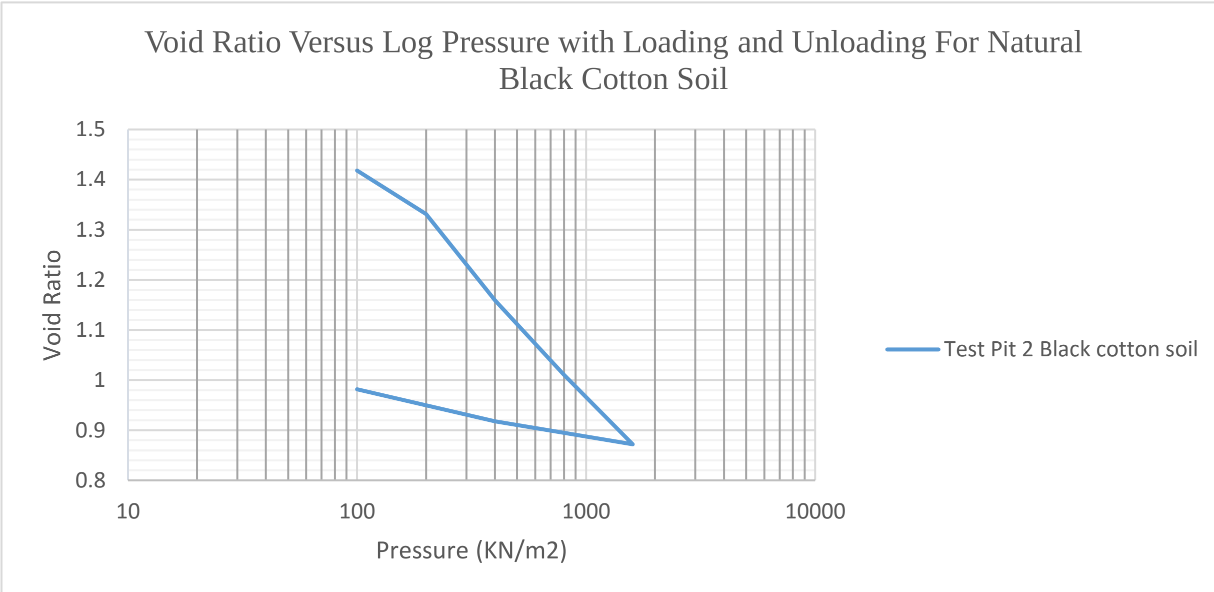

Figure 4.10 Void Ratio versus Log Pressure with Loading and Unloading for Natural Soil for Test Pit 2

4.5.4 Combined effect Marble dust and Waste Paper sludge on Consolidation Characteristics of the soil

Addition of 5% waste paper sludge with 30% marble dust has reduced the void ratio from 1.496 to 1.062 for Test Pit 1 and from 1.498 to 1.162 for Test Pit 2. Which causes the decrease in the settlement of the soil. Coefficient of consolidation (Cv) value is found in the range from 1.13 to 3.27 m^2 /year for Test Pit 1 and from 0.48 to 1.46 m^2 /year for Test Pit 2. It showed that the soil samples exhibited medium to high rates of consolidation due to their relatively low permeability that tend to limit drainage and dissipation of pore-water pressures. With the addition of 5 % waste paper sludge and 30% marble dust the Cv value is increased in the range from 0.88 to 9.97 m^2 /year for Test Pit 1 and from 1.05 to 6.88 m^2 /year for test pit 2 i.e rate of consolidation also increased.

With the addition of 5% waste paper sludge with 30% marble dust Compression index of a soil is reduced from 0.517 to 0.326 and from 0.493 to 0.402 for Test Pit 1 and Test Pit 2 respectively. i,e The compressibility of the soil is improved. From Voids ratio/ log pressure (e/log p) curves as shown in Figure (5.3) are found on top positions on the diagram due to their relatively higher void ratios. But with the addition of waste paper sludge and marble dust the curve moved down as a result, the compressibility of the soil is reduced.

Table 4.14 Summary of the combined effect of marble dust and waste paper sludge on consolidation of soil for Test Pit 1

Test Pit 1		
	Natural Black Cotton Soil	65%BCS+5%WSP+30%MD
eo	1.496	1.062
Cc	0.517	0.326
Specific Gravity(g/cm^3)	2.39	2.41
Overall settlement(mm)	4.732	3.41

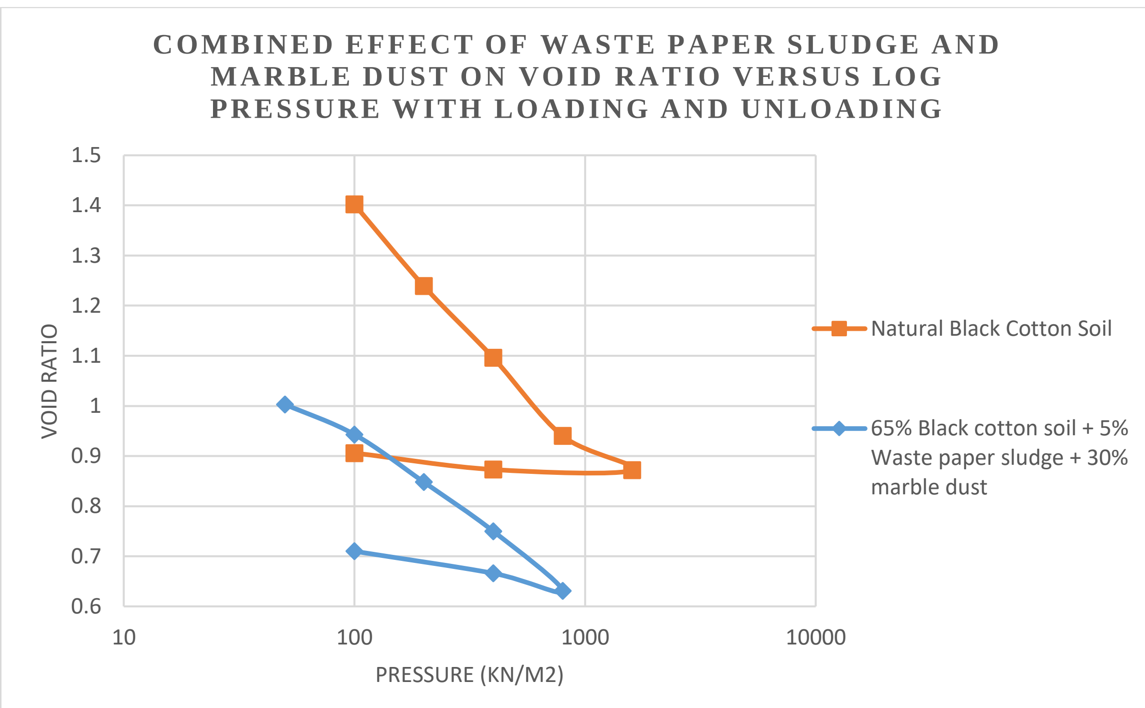

Figure 4.11 Combined effect of Waste paper sludge and Marble dust on Void Ratio Versus Log Pressure with Loading and Unloading for Test Pit 1

Table 4.15 Summary of the combined effect of marble dust and waste paper sludge on consolidation of soil for Test Pit 2

Test Pit 2		
	Natural Black Cotton Soil	65%BCS+5%WSP+30%MD
eo	1.498	1.162
Cc	0.493	0.402
Specific Gravity(g/cm^3)	2.42	2.53
Overall settlement(mm)	4.136	3.818

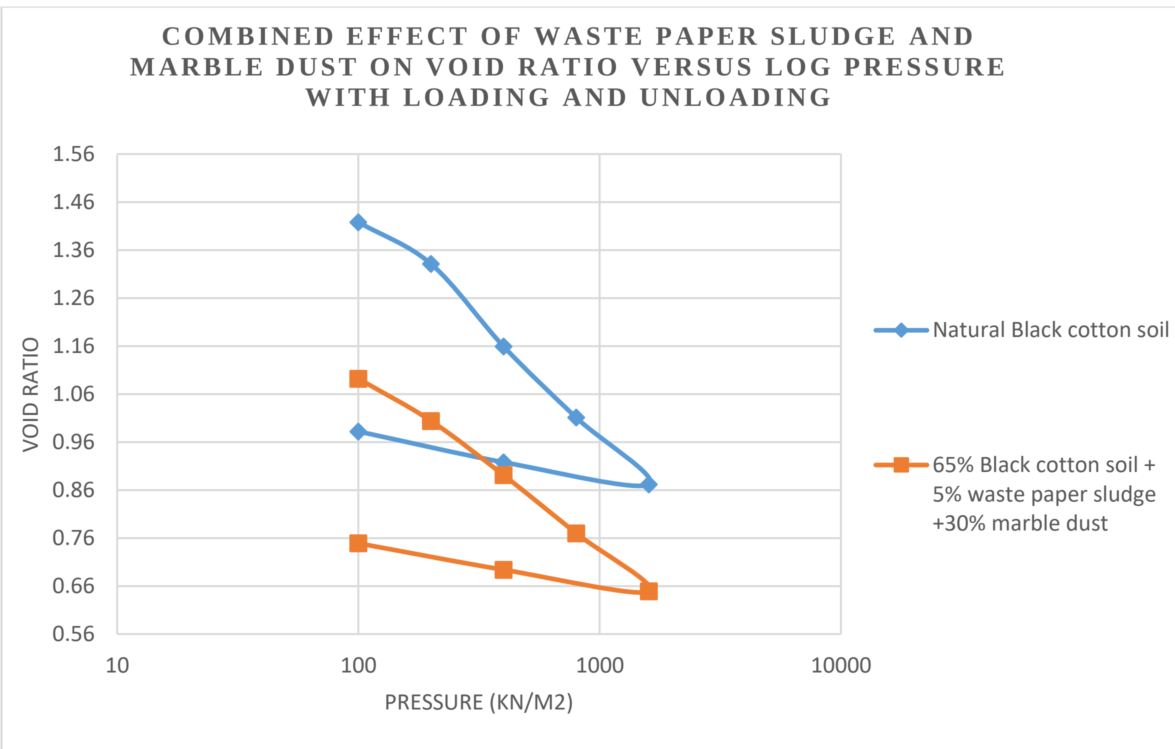

Figure 4.12 Combined effect of Waste paper sludge and Marble dust on Void Ratio Versus Log Pressure with Loading and Unloading for Test Pit 2

Table 4.16 Summary of the combined effect of marble dust and waste paper sludge on Coefficient of consolidation

	Test Pit 1		Test Pit 2	
	Natural soil	65% BCS + 5% WPS + 30% MD	Natural soil	65% BCS + 5% WPS + 30% MD
Pressure	Cv(m^2 /year)	Cv(m^2 /year)	Cv(m^2 /year)	Cv(m^2 /year)
100	1.45	9.97	1.46	1.13
200	1.35	6.52	1.37	1.05
400	0.77	5.13	0.64	6.88
799	0.33	3.99	0.29	2.87
1598	1.85	0.88	0.48	3.27

Chapter Five

Conclusions and Recommendations

5.1 Summary

In this study, the combined effect of marble dust and waste paper sludge to improve geotechnical properties of Black cotton soil is studied. Marble dust and waste paper sludge is added to the soil with different percentages. Then laboratory tests are conducted and results are discussed.

5.2 Conclusions

According to test results, the following outcomes can be summarized:

1. Addition of 5% waste paper sludge increased the maximum dry density and the unconfined compressive strength of the soil. Addition of 10 and 15 % of waste paper sludge reduced the maximum dry density and unconfined compressive strength of the soil. So it is concluded that 5% waste paper sludge is the optimum amount to improve the strength characteristics of the soil.
2. Addition of marble dust and waste paper sludge decreased liquid limit, plastic limit and plasticity index for both Test Pit 1 and Test Pit 2.
3. Black cotton Soil treated with combination of marble dust and waste paper sludge gave a significant improvement in strength than when the soil is treated with only Waste paper sludge. Addition of marble dust with 5% of waste paper sludge has increased the strength up to 30% addition of marble dust and further addition of marble dust reduced the strength. So addition of 5% Waste Paper sludge with 30% of Marble dust is an optimum dosage used for stabilizing the soil.
4. Optimum Content used to improve properties of the soil which is addition 5% Waste paper sludge with 30% marble dust significantly reduced the swelling potential of the soil so that the expansiveness of the soil is reduced.
5. Addition of 5% waste paper sludge and 30% marble dust has reduced the void ratio, Compression Index and total settlement of the soil.

5.3 Recommendation

Based on the finding of the research the following are the main recommendations

The Combined effect of marble dust and waste paper sludge has provided significant results in improving the engineering properties of the soil by laboratory tests. However, the results obtained should also be verified by corresponding field tests.

For the full scale characterization of the soil behavior, the micro fabric and mineralogical characteristics of untreated and treated soil should be determined by scanning electron microscope and X-Ray diffraction studies.

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Adama, Ethiopia

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APPENDICES

Appendix 1: Summary of Grain Size Distribution

1. **Wet sieve analysis for Test pit 1**

ASTM Sieve Number	Sieve size(mm)	Mass of sieve	Mass of sieve +soil	Individual mass retained	Cumulative mass retained	Cumulative mass retained	Percent passing or %finer
No.4	4.75	0.44	0.44	0	0	0.00	100.00
No.8	2.36	0.406	0.426	0.02	0.02	4.00	96.00
No.10	2	0.383	0.385	0.002	0.022	4.40	95.60
No.16	1.18	0.358	0.369	0.011	0.033	6.60	93.40
No.30	0.6	0.329	0.336	0.007	0.04	8.00	92.00
No.40	0.425	0.366	0.368	0.002	0.042	8.40	91.60
No.50	0.3	0.294	0.296	0.002	0.044	8.80	91.20
N0.100	0.15	0.278	0.279	0.001	0.045	9.00	91.00
N0.200	0.075	0.275	0.276	0.001	0.046	9.20	90.80
Pan		0.252	0.706	0.454	0.5	100.00	0.00

2. **Hydrometer for Test Pit 1**

Time	Elapsed Time, t,min	Actual Hydrometer Reading Ra	Temp (°C)	Effective Depth, L (cm)	K	Particle Diameter D (mm)	Percentage Finer Than D, P (%)	Corrected Percentage Finer Than D, P (%)
	0							
	2	36.000	22	10.19	0.01474	0.0333	66.61	60.48
	5	33.000	22	10.69	0.01474	0.0215	60.29	54.74
	15	30.000	22	11.18	0.01474	0.0127	53.96	49.00
	30	29.000	22	11.35	0.01474	0.0091	51.86	47.09
	60	28.000	22	11.51	0.01474	0.0065	49.75	45.17
	250	25.000	22	12.01	0.01474	0.0032	43.42	39.43
	1440	18.000	22	13.16	0.01474	0.0014	28.67	26.03

3. Wet sieve analysis for Test Pit 2

ASTM Sieve Number	Sieve size(mm)	Mass of sieve	Mass of sieve +soil	Individual mass retained	Cumulative mass retained	Cumulative mass retained	Percent passing or %finer
No.4	4.75	0.44	0.44	0	0	0.00	100.00
No.8	2.36	0.406	0.41	0.004	0.004	0.80	99.20
No.10	2	0.383	0.386	0.003	0.007	1.40	98.60
No.16	1.18	0.358	0.363	0.005	0.012	2.40	97.60
No.30	0.6	0.329	0.333	0.004	0.016	3.20	96.80
No.40	0.425	0.366	0.368	0.002	0.018	3.60	96.40
No.50	0.3	0.294	0.398	0.104	0.122	24.40	75.60
N0.100	0.15	0.278	0.283	0.005	0.127	25.40	74.60
N0.200	0.075	0.275	0.278	0.003	0.13	26.00	74.00
Pan		0.252	0.252	0.37	0.5	100.00	0.00

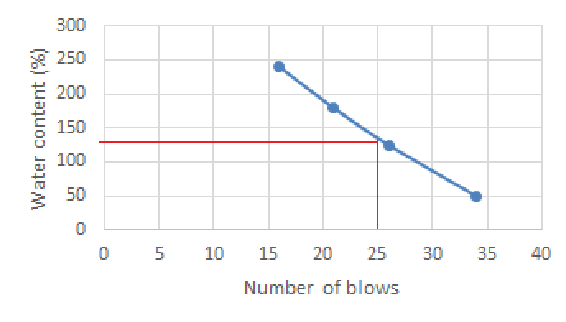
4. Hydrometer For Test Pit 2

Time	Elapsed Time, t,min	Actual Hydrometer Reading Ra	Temp (ºC)	Effective Depth, L (cm)	K	Particle Diameter D (mm)	Percentage Finer Than D, P (%)	Corrected Percentage Finer Than D, P (%)
	0							
	2	36.000	22	10.19	0.01474	0.0333	66.61	60.48
	5	33.000	22	10.69	0.01474	0.0215	60.29	54.74
	15	31.000	22	11.02	0.01474	0.0126	56.07	50.91
	30	29.000	22	11.35	0.01474	0.0091	51.86	47.09
	60	27.000	22	11.68	0.01474	0.0065	47.64	43.26
	250	25.000	22	12.01	0.01474	0.0032	43.42	39.43
	1440	21.000	22	12.67	0.01474	0.0014	34.99	31.77

Appendix 2: Summary of Atterberg Limit Tests

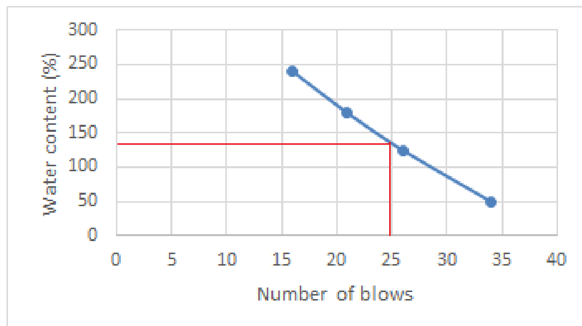
1. Test Pit 1 Natural soil

Test Pit 1 Natural soil				
Can no	A1	A2	A3	A4
Mass of wet soil+can	0.0258	0.031	0.028	0.025
Mass of dry soil+can	0.021	0.023	0.023	0.023
Mass of can	0.019	0.019	0.019	0.019
Mass of dry soil	0.002	0.004	0.004	0.004
Mass of moisture	0.005	0.008	0.005	0.002
Water content	240	179	125	50
No of blows	16	21	26	34
Liquid Limit	135			



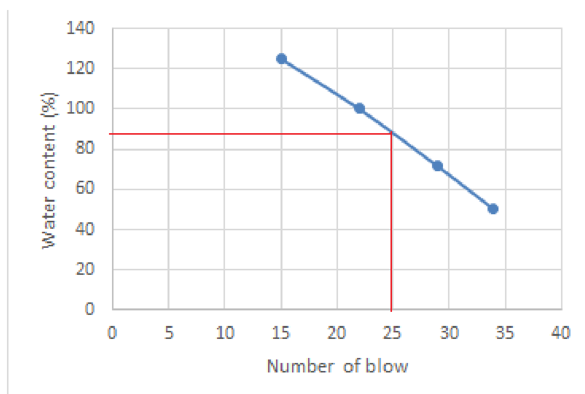
2. Test Pit 1 Black cotton soil+5% waste paper sludge+0%Marble dust

Test Pit 1 Black cotton soil+5% waste paper sludge+0%Marble dust				
Can no	B1	B2	B3	B4
Mass of wet soil+can	0.0292	0.044	0.0435	0.028
Mass of dry soil+can	0.024	0.037	0.037	0.024
Mass of can	0.019	0.03	0.03	0.019
Mass of dry soil	0.005	0.007	0.007	0.005
Mass of moisture	0.0052	0.007	0.0065	0.004
Water content	104.2	100	92.88	80
No of blows	17	20	26	35
Liquid Limit	87			



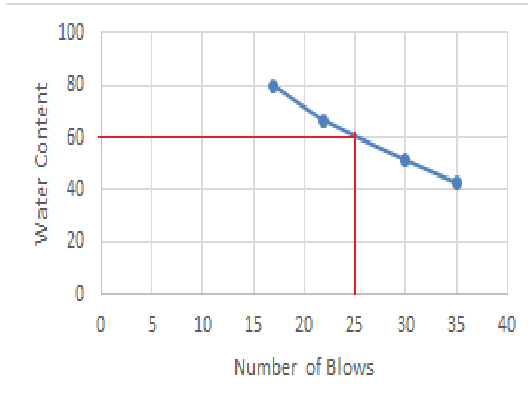
3. Test Pit 1 Black cotton soil+5% waste paper sludge+0%Marble dust

Test Pit 1 Black cotton Soil+ 5% Waste Paper sludge+10% Marble dust				
Can no	C1	C2	C3	C4
Mass of wet soil+can	0.029	0.03	0.03	0.03
Mass of dry soil+can	0.024	0.025	0.025	0.026
Mass of can	0.02	0.02	0.018	0.018
Mass of dry soil	0.004	0.005	0.007	0.008
Mass of moisture	0.005	0.005	0.005	0.004
Water content	125	100	71.43	50
No of blows	15	22	29	34
Liquid Limit	84			



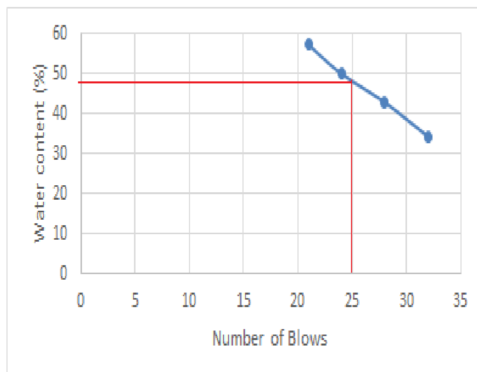
4. Test Pit 1 Black cotton Soil+ 5% Waste Paper sludge+20% Marble dust

Test Pit 1 Black cotton Soil+ 5% Waste Paper sludge+20% Marble dust				
Can no	D1	D2	D3	D4
Mass of wet soil+can	0.027	0.03	0.0286	0.028
Mass of dry soil+can	0.023	0.026	0.025	0.025
Mass of can	0.018	0.02	0.018	0.018
Mass of dry soil	0.005	0.006	0.007	0.007
Mass of moisture	0.004	0.004	0.0036	0.003
Water content	80	66.67	51.43	42.857
No of blows	17	22	30	35
Liquid Limit	60			



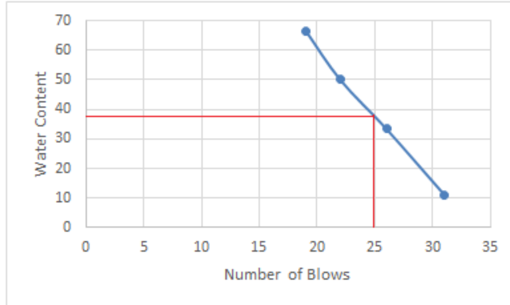
5. Test Pit 1 Black cotton Soil+ 5% Waste Paper sludge+30% Marble dust

Test Pit 1 Black cotton Soil+ 5% Waste Paper sludge+30% Marble dust				
Can no	E1	E2	E3	E4
Mass of wet soil+can	0.03	0.025	0.03	0.0294
Mass of dry soil+can	0.026	0.023	0.027	0.027
Mass of can	0.019	0.019	0.02	0.02
Mass of dry soil	0.007	0.004	0.007	0.007
Mass of moisture	0.004	0.002	0.003	0.0024
Water content	57.14	50.00	42.86	34.29
No of blows	21	24	28	32
Liquid Limit	48			



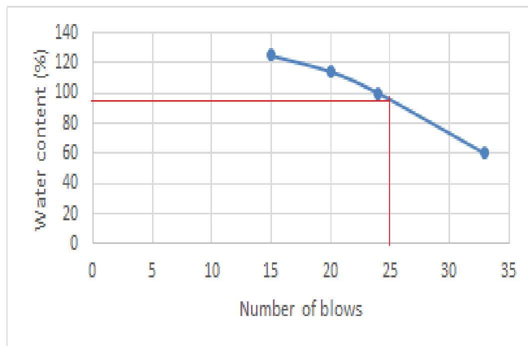
6. Test Pit 1 Black cotton Soil+ 5% Waste Paper sludge+30% Marble dust

Test Pit 1 Black cotton Soil+ 5% Waste Paper sludge+40% Marble dust				
Can no	E2	F1	F2	E1
Mass of wet soil+can	0.028	0.039	0.038	0.028
Mass of dry soil+can	0.024	0.036	0.036	0.027
Mass of can	0.018	0.03	0.03	0.018
Mass of dry soil	0.006	0.006	0.006	0.009
Mass of moisture	0.004	0.003	0.002	0.001
Water content	66.67	50.00	33.33	11.11
No of blows	19	22	26	31
Liquid Limit	38			



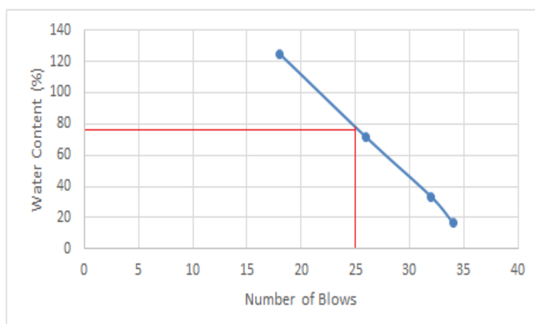
7. Test Pit 2 Natural Black Cotton Soil

Test Pit 2 Natural Black Cotton Soil				
Can no	F1	F2	F3	F4
Mass of wet soil+can	0.04	0.04	0.04	0.039
Mass of dry soil+can	0.035	0.0352	0.035	0.036
Mass of can	0.031	0.031	0.03	0.031
Mass of dry soil	0.004	0.0042	0.005	0.005
Mass of moisture	0.005	0.0048	0.005	0.003
Water content	125	114.29	100	60
No of blows	15	20	24	33
Liquid Limit	96			



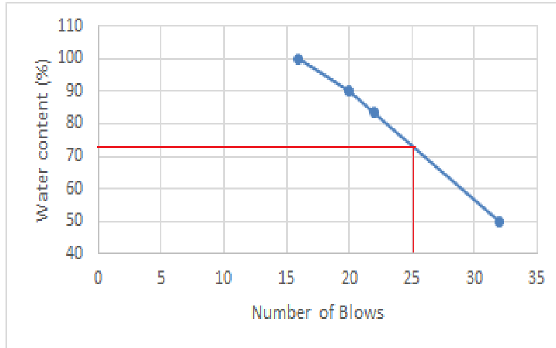
8. Test Pit 2 Black cotton soil+5% waste paper sludge+0%Marble dust

Test Pit 2 Black cotton soil+5% waste paper sludge+0%Marble dust				
Can no	G1	G2	G3	G4
Mass of wet soil+can	0.029	0.03	0.039	0.038
Mass of dry soil+can	0.024	0.025	0.037	0.037
Mass of can	0.02	0.018	0.031	0.031
Mass of dry soil	0.004	0.007	0.006	0.006
Mass of moisture	0.005	0.005	0.002	0.001
Water content	125	71.43	33.33	16.67
No of blows	18	26	32	34
Liquid Limit	76			



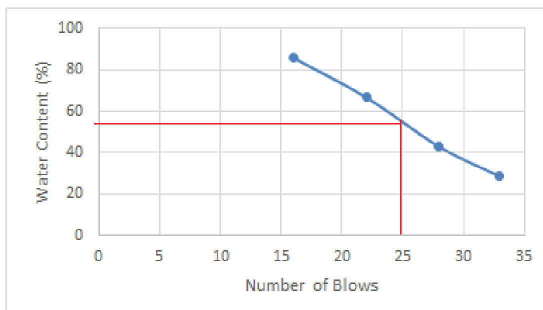
9. Test Pit 2 Black cotton soil+5% waste paper sludge+10%Marble dust

Test Pit 2 Black cotton soil+5% waste paper sludge+10%Marble dust				
Can no	H1	H2	H3	H4
Mass of wet soil+can	0.028	0.0276	0.03	0.028
Mass of dry soil+can	0.024	0.024	0.025	0.025
Mass of can	0.02	0.02	0.019	0.019
Mass of dry soil	0.004	0.004	0.006	0.006
Mass of moisture	0.004	0.0036	0.005	0.003
Water content	100	90	83.33	50
No of blows	16	20	22	32
Liquid Limit	72			



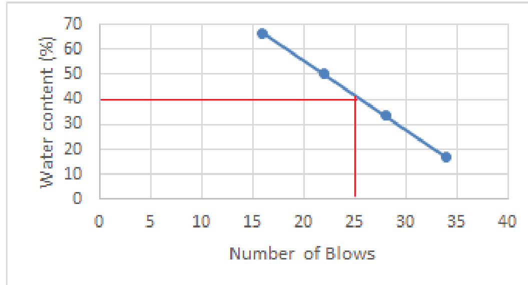
10. Test Pit 2 Black cotton soil+5% waste paper sludge+20%Marble dust

Test Pit 2 Black cotton soil+5% waste paper sludge+20%Marble dust				
Can no	I1	I2	I2	I4
Mass of wet soil+can	0.032	0.03	0.03	0.029
Mass of dry soil+can	0.026	0.026	0.027	0.027
Mass of can	0.019	0.02	0.02	0.02
Mass of dry soil	0.007	0.006	0.007	0.007
Mass of moisture	0.006	0.004	0.003	0.002
Water content	85.71	66.67	42.86	28.57
No of blows	16	22	28	33
Liquid Limit	55			



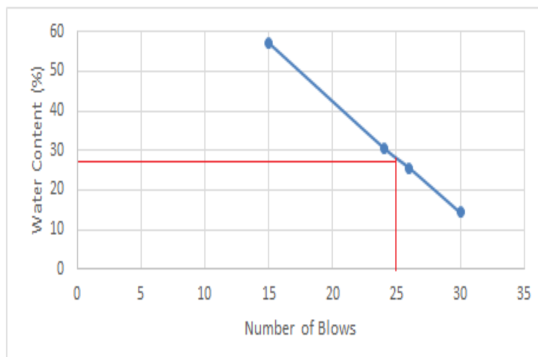
11. Test Pit 2 Black cotton soil+5% waste paper sludge+30%Marble dust

Test Pit 2 Black cotton soil+5% waste paper sludge+30%Marble dust				
Can no	J1	J2	J3	J4
Mass of wet soil+can	0.029	0.028	0.027	0.036
Mass of dry soil+can	0.025	0.025	0.025	0.035
Mass of can	0.019	0.019	0.019	0.029
Mass of dry soil	0.006	0.006	0.006	0.006
Mass of moisture	0.004	0.003	0.002	0.001
Water content	66.67	50	33.33	16.67
No of blows	16	22	28	34
Liquid Limit	40			



12. Test Pit 2 Black cotton soil+5% waste paper sludge+40%Marble dust

Test Pit 2 Black cotton soil+5% waste paper sludge+40%Marble dust				
Can no	K1	K2	K3	K4
Mass of wet soil+can	0.03	0.030	0.029	0.028
Mass of dry soil+can	0.026	0.027	0.027	0.027
Mass of can	0.019	0.018	0.020	0.02
Mass of dry soil	0.007	0.009	0.007	0.007
Mass of moisture	0.004	0.003	0.002	0.001
Water content	57.14	30.67	25.57	14.29
No of blows	15	24	26	30
Liquid Limit	29			



Summary of Combined effect of Waste paper sludge and marble dust on Plastic Limit

1. Test pit 1 Natural Black Cotton Soil

Test pit 1 Natural Black Cotton Soil			
Can no	A1	A2	A3
Mass of wet soil+can	0.027	0.027	0.027
Mass of dry soil+can	0.024	0.024	0.024
Mass of can	0.019	0.019	0.019
Mass of dry soil	0.005	0.005	0.005
Mass of moisture	0.003	0.003	0.003
Water content W%	59	60	61
Plastic Limit	60		

2. Test Pit 1 BCS+5% WPS + 0% MD

Test 1 Black Cotton Soil+5% Waste Paper Sludge+ 0% Marble dust			
can no	B1	B2	B3
Mass of wet soil+can	0.03	0.029	0.028
Mass of dry soil+can	0.027	0.025	0.025
Mass of can	0.018	0.019	0.019
Mass of dry soil	0.009	0.006	0.006
Mass of moisture	0.003	0.004	0.003
Water content W%	33.33	66.67	56.00
Plastic Limit	52.00		

3. Test Pit 1 BCS+5% WPS+ 10% MD

Test 1 Black Cotton Soil+5% Waste Paper Sludge+ 10% Marble dust			
Can no	C1	C2	C3
Mass of wet soil+can	0.026	0.028	0.026
Mass of dry soil+can	0.024	0.025	0.025
Mass of can	0.018	0.019	0.019
Mass of dry soil	0.006	0.006	0.006
Mass of moisture	0.002	0.003	0.001
Water content W%	33.33	50	16.67
Plastic Limit	50.00		

4.Test 1 BCS+5%WPS+20%MD

Test 1 Black Cotton Soil+5% Waste Paper Sludge+ 20% Marble dust			
Can no	D1	D2	D3
Mass of wet soil+can	0.030	0.029	0.029
Mass of dry soil+can	0.027	0.026	0.026
Mass of can	0.020	0.018	0.018
Mass of dry soil	0.007	0.008	0.008
Mass of moisture	0.003	0.003	0.003
Water content W%	42.86	37.5	33.64
Plastic Limit	38.00		

5. Test Pit 1 BCS+5% WPS+30% MD

Test 1 Black Cotton Soil+5% Waste Paper Sludge+ 30% Marble dust			
can no	A1	A2	A3
Mass of wet soil+can	0.024	0.022	0.022
Mass of dry soil+can	0.0235	0.021	0.021
Mass of can	0.018	0.018	0.018
Mass of dry soil	0.0055	0.003	0.003
Mass of moisture	0.0005	0.001	0.001
Water content W%	9.09	33.33	38.57
Plastic Limit	27.00		

6.Test Pit 1 5% WPS+ 40%MD

Test 1 Black Cotton Soil+5% Waste Paper Sludge+ 40% Marble dust			
Can no	B4	B5	B6
Mass of wet soil+can	0.02	0.023	0.023
Mass of dry soil+can	0.022	0.022	0.022
Mass of can	0.018	0.019	0.017
Mass of dry soil	0.004	0.003	0.005
Mass of moisture	0.001	0.001	0.001
Water content W%	25.66	33.33	10
Plastic Limit	23.00		

7. Test Pit 2 Natural Black Cotton Soil

Test pit 2 Natural Black Cotton Soil			
Can no	A4	A5	A5
Mass of wet soil+can	0.027	0.024	0.023
Mass of dry soil+can	0.025	0.022	0.022
Mass of can	0.02	0.019	0.019
Mass of dry soil	0.005	0.003	0.003
Mass of moisture	0.002	0.002	0.0009
Water content W%	41.34	66.67	30
Plastic Limit	46.00		

8. Test pit 2. 5% WPS+0% MD

Test 2 Black Cotton Soil+5% Waste Paper Sludge+0% Marble dust			
can no	A7	A6	A3
Mass of wet soil+can	0.026	0.024	0.023
Mass of dry soil+can	0.024	0.023	0.022
Mass of can	0.019	0.019	0.019
Mass of dry soil	0.005	0.004	0.003
Mass of moisture	0.002	0.0014	0.001
Water content W%	39	35.675	33.33
Plastic Limit	36.00		

9. Test Pit 2. 5% WPS+10%MD

Test 2 Black Cotton Soil+5% Waste Paper Sludge+10% Marble dust			
can no	A8	A9	A10
Mass of wet soil+can	0.023	0.023	0.025
Mass of dry soil+can	0.022	0.022	0.024
Mass of can	0.020	0.019	0.019
Mass of dry soil	0.002	0.003	0.005
Mass of moisture	0.001	0.001	0.001
Water content W%	48.66	33.33	20
Plastic Limit	34.00		

10. Test Pit 2. 5%WPS+20%MD

Test 2 Black Cotton Soil+5% Waste Paper Sludge+20% Marble dust			
Can no	B1	B2	B3
Mass of wet soil+can	0.0246	0.0226	0.021
Mass of dry soil+can	0.024	0.022	0.02
Mass of can	0.02	0.02	0.018
Mass of dry soil	0.004	0.002	0.002
Mass of moisture	0.0006	0.0006	0.001
Water content W%	16	30	50
Plastic Limit	32		

11. Test Pit 2. 5% WPS+30% MD

Test 2 Black Cotton Soil+5% Waste Paper Sludge+30% Marble dust			
Can no	A11	A12	A13
Mass of wet soil+can	0.0208	0.022	0.021
Mass of dry soil+can	0.02	0.021	0.02
Mass of can	0.016	0.016	0.015
Mass of dry soil	0.004	0.005	0.005
Mass of moisture	0.0008	0.001	0.001
Water content W%	20	20	20
Plastic Limit	20.00		

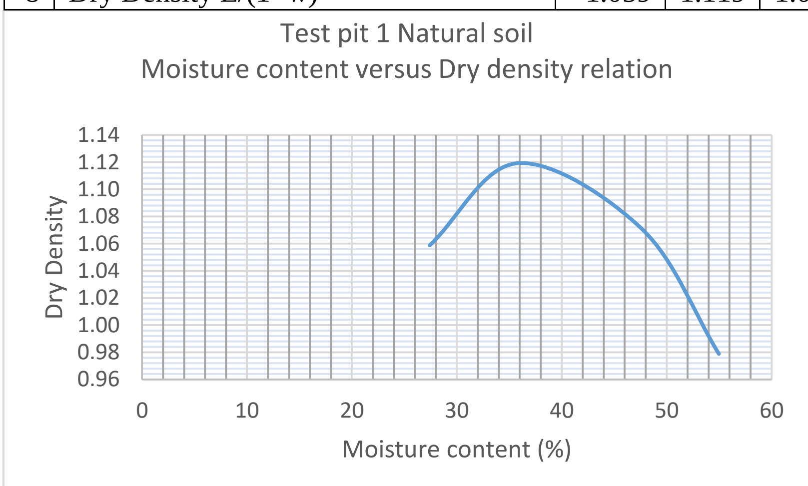
12. Test Pit 2. 5% WPS+40%MD

Test 1 Black Cotton Soil+5% Waste Paper Sludge+40% Marble dust			
Can no	B7	B8	B9
Mass of wet soil+can	0.024	0.024	0.023
Mass of dry soil+can	0.022	0.023	0.022
Mass of can	0.016	0.016	0.016
Mass of dry soil	0.006	0.007	0.006
Mass of moisture	0.001	0.001	0.001
Water content W%	23.05	14.29	16.67
Plastic Limit	18.00		

Appendix 3: Summary of Standard Compaction Test

1. Test pit 1 Natural Black Cotton soil

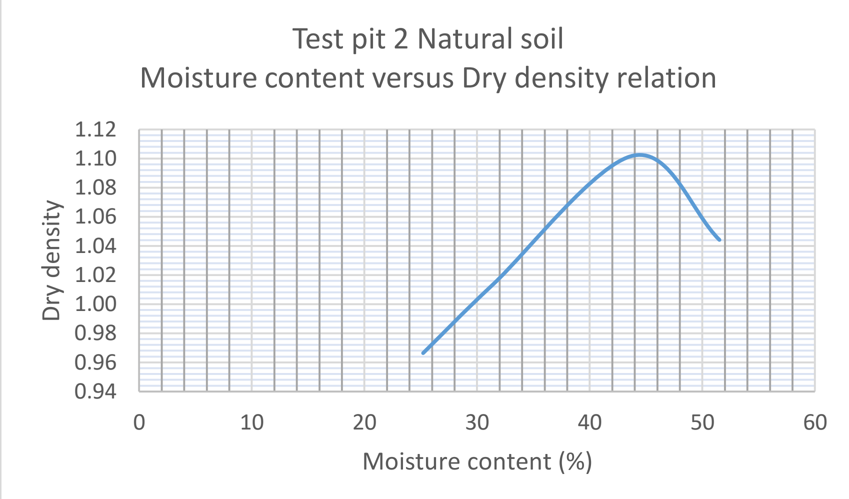
	Test pit 1 Natural Black Cotton soil				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5742	5913	5974	5910
	Calculation				
D	Wt of Compacted Soil (C-A)	1349	1520	1581	1517
E	Bulk Density (C-A)/B	1.349	1.52	1.581	1.517
	Water content Determination				
1	Container No	A1	A4	A7	A10
2	Weight of container	0.020	0.018	0.029	0.026
3	Weight of container + wt soil	0.047	0.047	0.054	0.079
4	Weight of container + Dry soil	0.041	0.039	0.046	0.060
5	Weight of water (3-4)	0.006	0.008	0.008	0.019
6	Weight of dry soil (4-2)	0.021	0.021	0.017	0.034
7	Water content w% (5/6)	27.42	35.81	47.65	54.98
8	Dry Density E/(1+w)	1.059	1.119	1.071	0.979



Optimum Moisture content (%)	35
Maximum Dry density (g/cm3)	1.12

2. Test pit 2 Natural Black Cotton Soil

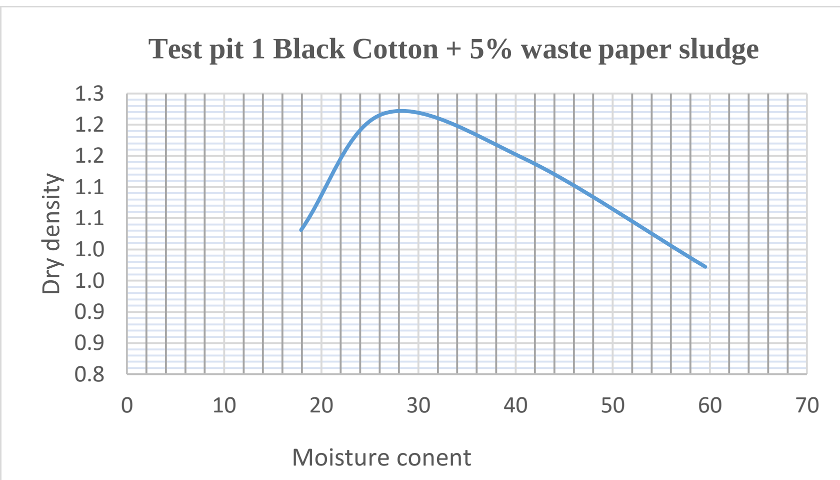
	Test pit 2 Natural Black Cotton Soil				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5603	5726	5979	5975
	Calculation				
D	Wt of Compacted Soil (C-A)	1210	1333	1586	1582
E	Bulk Density (C-A)/B	1.21	1.333	1.586	1.582
	Water content Determination				
1	Container No	B3	B4	B15	B19
2	Weight of container	0.02	0.03	0.029	0.029
3	Weight of container + wt soil	0.041	0.059	0.062	0.087
4	Weight of container + Dry soil	0.037	0.052	0.052	0.067
5	Weight of water (3-4)	0.004	0.007	0.010	0.020
6	Weight of dry soil (4-2)	0.017	0.022	0.023	0.038
7	Water content w% (5/6)	25.21	31.47	43.91	51.52
8	Dry Density E/(1+w)	0.966	1.014	1.102	1.044



Optimum Moisture content (%)	44
Maximum Dry density (g/cm3)	1.102

3. Test pit 1 Black Cotton + 5% waste paper sludge

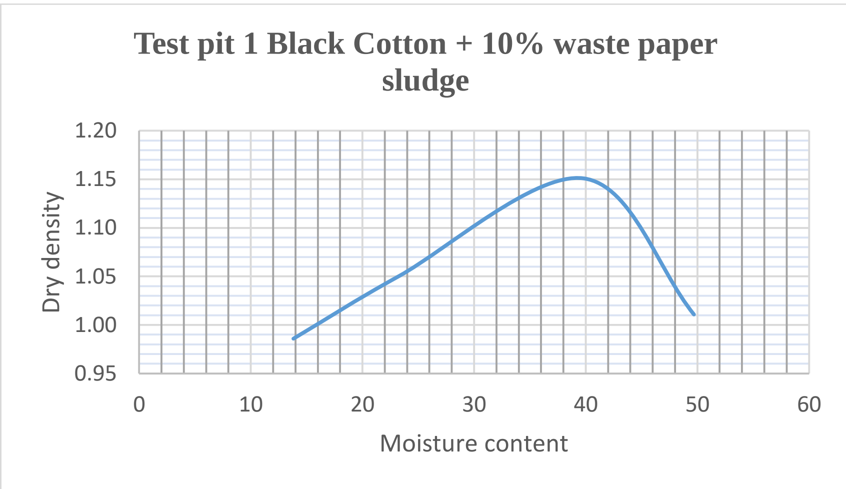
	Test pit 1 Black Cotton + 5% waste paper sludge				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5609	5933	6007	5944
	Calculation				
D	Wt of Compacted Soil	1216	1540	1614	1551
E	Bulk Density	1.216	1.54	1.614	1.551
	Water content Determination				
1	Container No	C1	C9	C10	C16
2	Weight of container	0.03	0.03	0.03	0.018
3	Weight of container + wt soil	0.076	0.065	0.075	0.061
4	Weight of container + Dry soil	0.069	0.058	0.062	0.045
5	Weight of water	0.007	0.007	0.013	0.016
6	Weight of dry soil	0.039	0.028	0.032	0.027
7	Water content	17.92	26.45	40.90	59.53
8	Dry Density	1.031	1.218	1.145	0.972



Optimum Moisture content (%)	26.454
Maximum Dry density (g/cm3)	1.218

4. Test pit 1 Black Cotton + 10% waste paper sludge

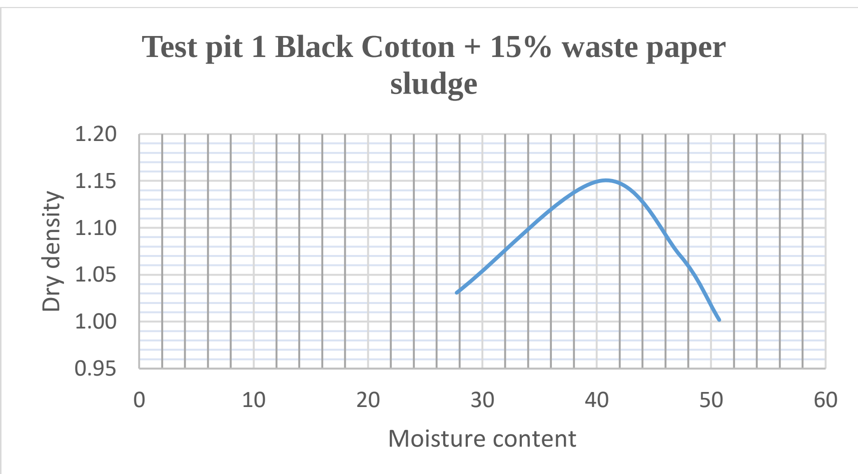
	Test pit 1 Black Cotton + 10% waste paper sludge				
	Observation and calculation	1	2	4	5
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5515	5688	6002	5906
	Calculation				
D	Wt of Compacted Soil	1122	1295	1609	1513
E	Bulk Density	1.122	1.295	1.609	1.513
	Water content Determination				
1	Container No	A2	A6	A11	A13
2	Weight of container	0.019	0.019	0.017	0.018
3	Weight of container + wt soil	0.039	0.042	0.053	0.058
4	Weight of container + Dry soil	0.037	0.038	0.043	0.045
5	Weight of water	0.002	0.004	0.010	0.013
6	Weight of dry soil	0.018	0.019	0.026	0.027
7	Water content	13.82	23.29	39.80	49.69
8	Dry Density	0.986	1.050	1.151	1.011



Optimum Moisture content (%)	39.805
Maximum Dry density (g/cm3)	1.151

5. Test pit 1 Black Cotton + 15% waste paper sludge

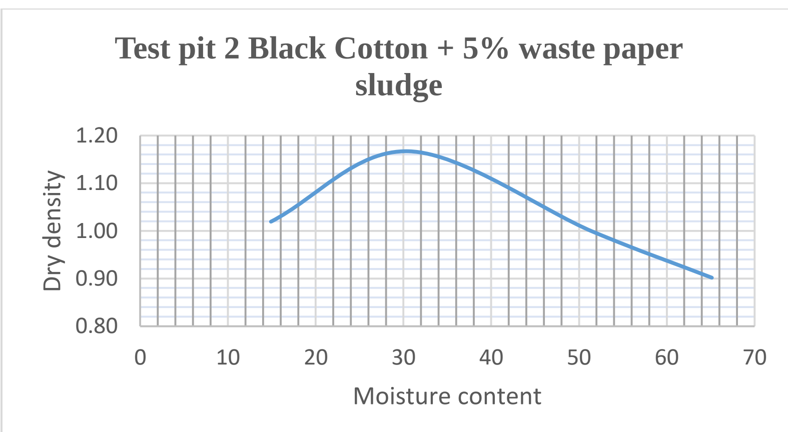
	Test pit 1 Black Cotton + 15% waste paper sludge				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5710	6007	5970	5903
	Calculation				
D	Wt of Compacted Soil	1317	1614	1577	1510
E	Bulk Density	1.317	1.614	1.577	1.51
	Water content Determination				
1	Container No	B3	B6	B8	B11
2	Weight of container	0.02	0.03	0.029	0.029
3	Weight of container + wt soil	0.051	0.065	0.057	0.070
4	Weight of container + Dry soil	0.044	0.055	0.048	0.056
5	Weight of water	0.007	0.010	0.009	0.014
6	Weight of dry soil	0.024	0.025	0.019	0.027
7	Water content	27.76	40.33	47.27	50.71
8	Dry Density	1.031	1.150	1.071	1.002



Optimum Moisture content (%)	40.331
Maximum Dry density (g/cm3)	1.15

6. Test pit 2 Black Cotton + 5% waste paper sludge

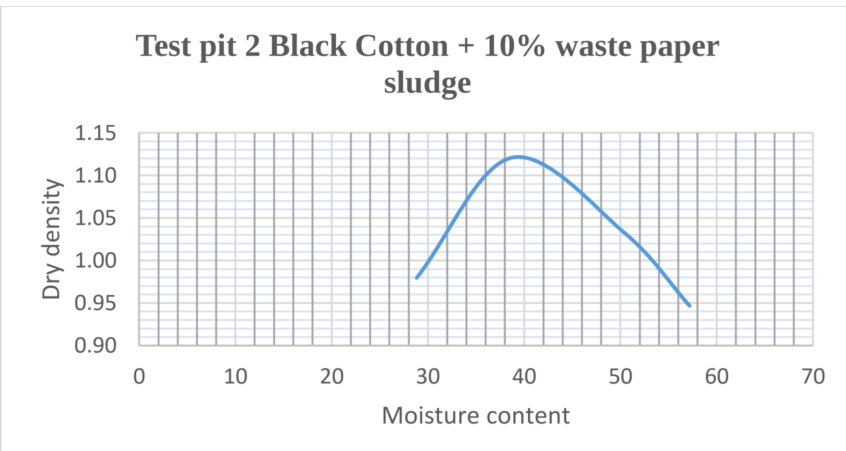
	Test pit 2 Black Cotton + 5% waste paper sludge				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5564	5917	5906	5882
	Calculation				
D	Wt of Compacted Soil	1171	1524	1513	1489
E	Bulk Density	1.171	1.524	1.513	1.489
	Water content Determination				
1	Container No	C1	C10	C16	C20
2	Weight of container	0.03	0.03	0.018	0.018
3	Weight of container + wt soil	0.055	0.051	0.047	0.046
4	Weight of container + Dry soil	0.052	0.046	0.037	0.035
5	Weight of water	0.003	0.005	0.010	0.011
6	Weight of dry soil	0.022	0.016	0.019	0.017
7	Water content	14.90	30.61	51.56	65.14
8	Average	14.90	30.61	51.56	65.14
9	Dry Density	1.019	1.167	0.998	0.902



Optimum Moisture content (%)	30.6
Maximum Dry density (g/cm3)	1.019

7. Test pit 2 Black Cotton + 10% waste paper sludge

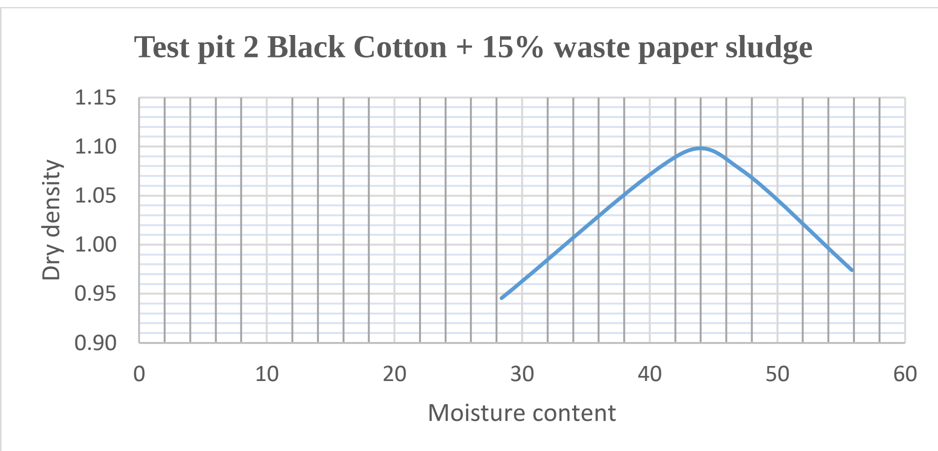
Test pit 2 Black Cotton + 10% waste paper sludge				
Observation and calculation	1	2	3	4
Mass of empty mold with base plates	4393	4393	4393	4393
Volume of mold	1000	1000	1000	1000
Mass of mod & base plate + compacted soil	5655	5948	5946	5881
Calculation				
Wt of Compacted Soil	1262	1555	1553	1488
Bulk Density	1.262	1.555	1.553	1.488
Water content Determination				
Container No	B3	B8	B10	B13
Weight of container	0.02	0.029	0.03	0.029
Weight of container + wt soil	0.038	0.050	0.066	0.073
Weight of container + Dry soil	0.034	0.044	0.054	0.057
Weight of water	0.004	0.006	0.012	0.016
Weight of dry soil	0.014	0.015	0.024	0.028
Water content	28.83	38.73	50.40	57.19
Average	28.83	38.73	50.40	57.19
Dry Density	0.980	1.121	1.033	0.947



Optimum Moisture content (%)	38.73
Maximum Dry density (g/cm3)	1.12

8. Test pit 2 Black Cotton + 15% waste paper sludge

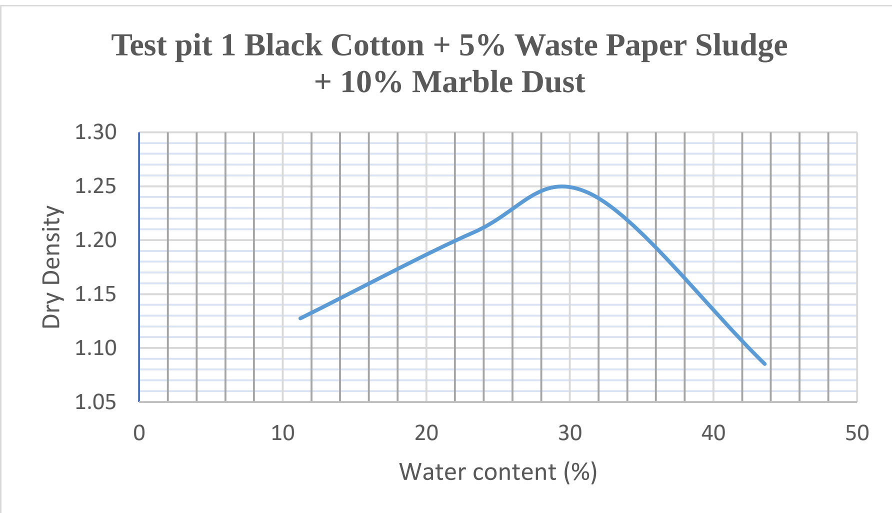
	Test pit 2 Black Cotton + 15% waste paper sludge				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5607	5949	5977	5911
	Calculation				
D	Wt of Compacted Soil	1214	1556	1584	1518
E	Bulk Density	1.214	1.556	1.584	1.518
	Water content Determination				
1	Container No	A2	A5	A8	A12
2	Weight of container	0.019	0.018	0.019	0.019
3	Weight of container + wt soil	0.047	0.038	0.045	0.055
4	Weight of container + Dry soil	0.041	0.032	0.037	0.042
5	Weight of water	0.006	0.006	0.008	0.013
6	Weight of dry soil	0.022	0.014	0.018	0.023
7	Water content	28.39	42.43	47.14	55.84
9	Dry Density	0.946	1.092	1.077	0.974



Optimum Moisture content (%)	44
Maximum Dry density (g/cm3)	1.095

9. Test pit 1 Black Cotton + 5% Waste Paper Sludge + 10% Marble Dust

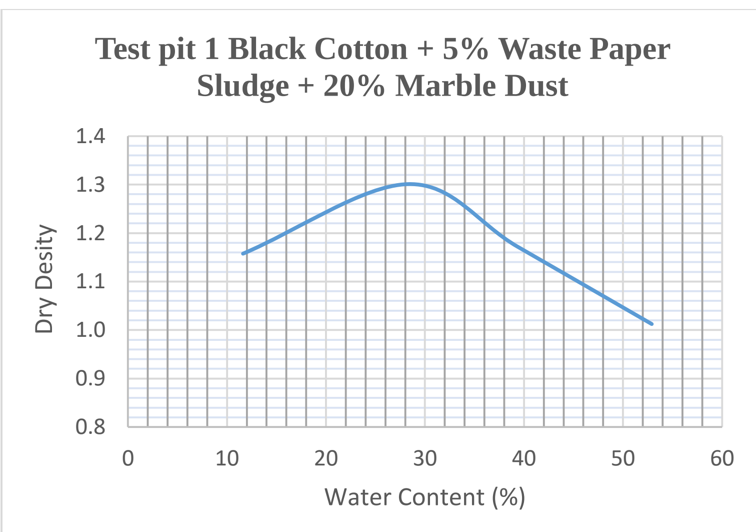
	Test pit 1 Black Cotton + 5% Waste Paper Sludge + 10% Marble Dust				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5647	5881	6026	5951
	Calculation				
D	Wt of Compacted Soil	1254	1488	1633	1558
E	Bulk Density	1.254	1.488	1.633	1.558
	Water content Determination				
1	Container No	D2	D5	D8	D12
2	Weight of container	0.018	0.028	0.019	0.029
3	Weight of container + wt soil	0.038	0.050	0.040	0.063
4	Weight of container + Dry soil	0.036	0.046	0.035	0.053
5	Weight of water	0.002	0.004	0.005	0.010
6	Weight of dry soil	0.018	0.018	0.016	0.024
7	Water content	11.23	23.28	31.28	43.57
8	Dry Density	1.127	1.207	1.244	1.085



Optimum Moisture content (%)	30
Maximum Dry density (g/cm3)	1.25

10. Test pit 1 Black Cotton + 5% Waste Paper Sludge + 20% Marble Dust

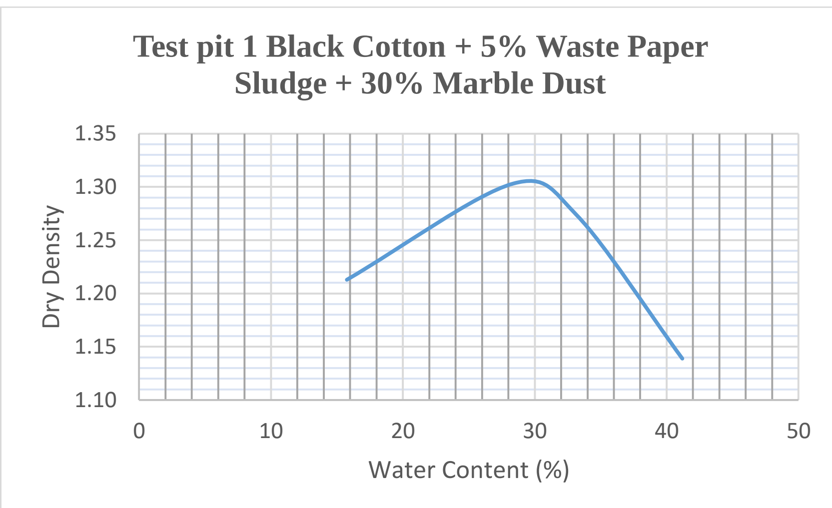
	Test pit 1 Black Cotton + 5% Waste Paper Sludge + 20% Marble Dust				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5685	6062	6026	5941
	Calculation				
D	Wt of Compacted Soil	1292	1669	1633	1548
E	Bulk Density	1.292	1.669	1.633	1.548
	Water content Determination				
1	Container No	E3	E6	E7	E10
2	Weight of container	0.018	0.029	0.017	0.03
3	Weight of container + wt soil	0.028	0.075	0.052	0.082
4	Weight of container + Dry soil	0.027	0.065	0.042	0.064
5	Weight of water	0.001	0.010	0.010	0.018
6	Weight of dry soil	0.009	0.036	0.025	0.034
7	Water content	11.62	28.29	39.36	52.90
8	Average	11.62	28.29	39.36	52.90
9	Dry Density	1.157	1.301	1.172	1.012



Optimum Moisture content (%)	30
Maximum Dry density (g/cm3)	1.3

11. Test pit 1 Black Cotton + 5% Waste Paper Sludge + 30% Marble Dust

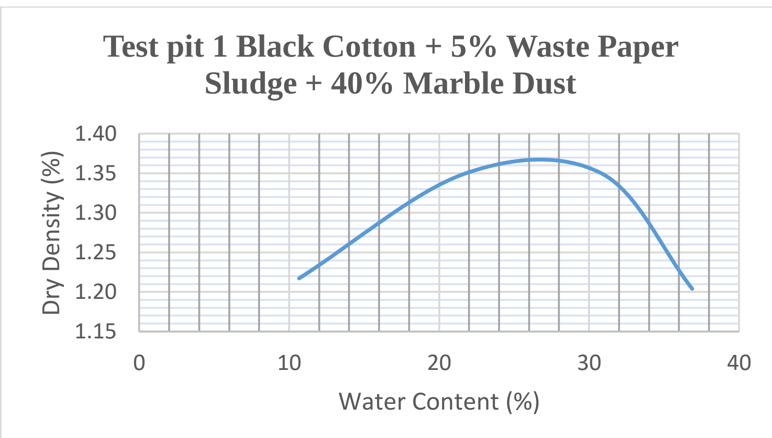
	Test pit 1 Black Cotton + 5% Waste Paper Sludge + 30% Marble Dust				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5797	6065	6089	6001
	Calculation				
D	Wt of Compacted Soil	1404	1672	1696	1608
E	Bulk Density	1.404	1.672	1.696	1.608
	Water content Determination				
1	Container No	B1	B4	B7	B12
2	Weight of container	0.02	0.022	0.02	0.02
3	Weight of container + wt soil	0.043	0.044	0.044	0.060
4	Weight of container + Dry soil	0.040	0.039	0.038	0.048
5	Weight of water	0.003	0.005	0.006	0.012
6	Weight of dry soil	0.02	0.017	0.018	0.028
7	Water content	15.76	28.32	33.20	41.19
8	Dry Density	1.213	1.303	1.273	1.139



Optimum Moisture content (%)	31
Maximum Dry density (g/cm3)	1.31

12. Test pit 1 Black Cotton + 5% Waste Paper Sludge + 40% Marble Dust

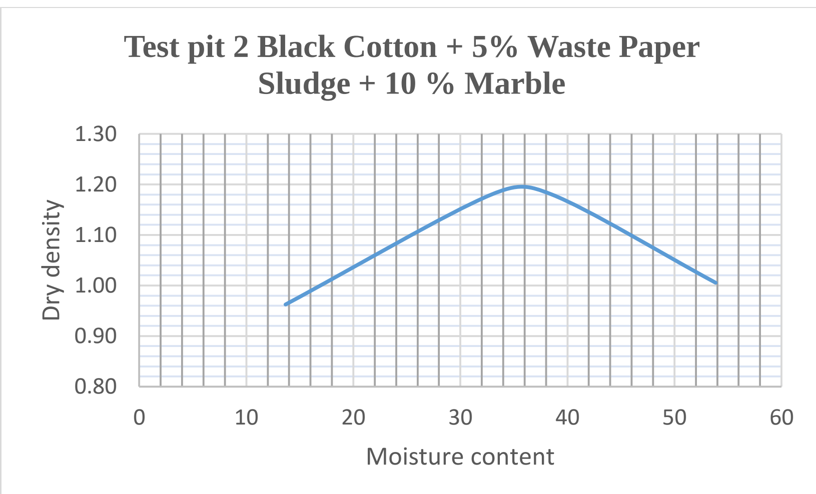
	Test pit 1 Black Cotton + 5% Waste Paper Sludge + 40% Marble Dust				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5740	6035	6159	6041
	Calculation				
D	Wt of Compacted Soil	1347	1642	1766	1648
E	Bulk Density	1.347	1.642	1.766	1.648
	Water content Determination				
1	Container No	D'1	D'5	D'9	D'10
2	Weight of container	0.02	0.019	0.02	0.02
3	Weight of container + wt soil	0.040	0.048	0.050	0.051
4	Weight of container + Dry soil	0.038	0.043	0.043	0.043
5	Weight of water	0.002	0.005	0.007	0.008
6	Weight of dry soil	0.018	0.024	0.023	0.023
7	Water content	10.66	21.69	30.77	36.88
8	Average	10.66	21.69	30.77	36.88
9	Dry Density	1.217	1.349	1.351	1.204



Optimum Moisture content (%)	27
Maximum Dry density (g/cm3)	1.368

13. Test pit 2 Black Cotton + 5% Waste Paper Sludge + 10 % Marble Dust

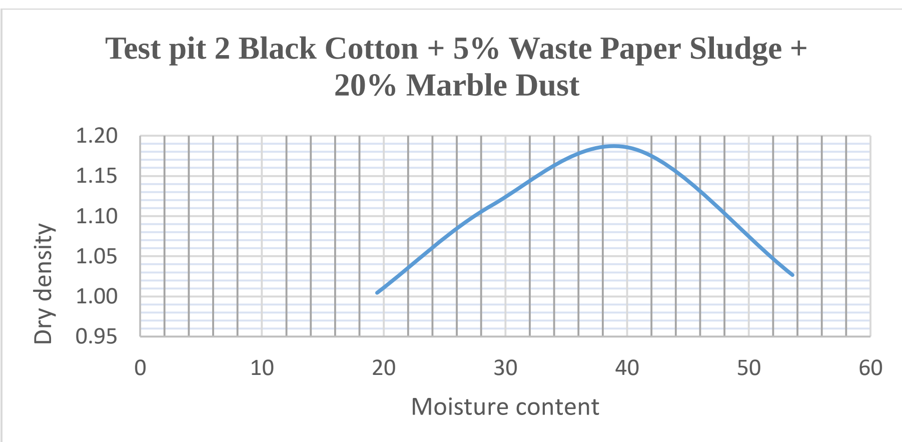
	Test pit 2 Black Cotton + 5% Waste Paper Sludge + 10 % Marble Dust				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5487	5960	6028	5940
	Calculation				
D	Wt of Compacted Soil	1094	1567	1635	1547
E	Bulk Density	1.094	1.567	1.635	1.547
	Water content Determination				
1	Container No	B16	C11	B7	A21
2	Weight of container	0.031	0.03	0.029	0.031
3	Weight of container + wt soil	0.062	0.069	0.065	0.063
4	Weight of container + Dry soil	0.058	0.059	0.055	0.052
5	Weight of water	0.004	0.010	0.010	0.011
6	Weight of dry soil	0.027	0.029	0.026	0.021
7	Water content	13.67	32.84	38.50	53.85
8	Dry Density	0.962	1.180	1.181	1.006



Optimum Moisture content (%)	35.00
Maximum Dry density (g/cm3)	1.20

14. Test pit 2 Black Cotton + 5% Waste Paper Sludge + 20% Marble Dust

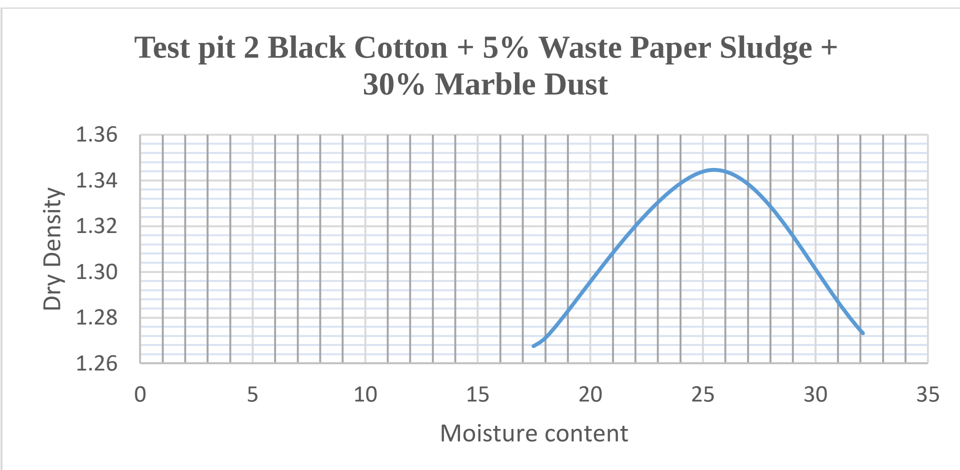
	Test pit 2 Black Cotton + 5% Waste Paper Sludge + 20% Marble Dust				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5593	5828	6055	5970
	Calculation				
D	Wt of Compacted Soil	1200	1435	1662	1577
E	Bulk Density	1.2	1.435	1.662	1.577
	Water content Determination				
1	Container No	C22	B8	D22	B6
2	Weight of container	0.018	0.030	0.028	0.030
3	Weight of container + wt soil	0.031	0.066	0.074	0.085
4	Weight of container + Dry soil	0.029	0.058	0.061	0.066
5	Weight of water	0.002	0.008	0.013	0.019
6	Weight of dry soil	0.011	0.028	0.033	0.036
7	Water content	19.46	28.88	40.27	53.59
8	Average	19.46	28.88	40.27	53.59
9	Dry Density	1.004	1.113	1.185	1.027



Optimum Moisture content (%)	38
Maximum Dry density (g/cm3)	1.185

15. Test pit 2 Black Cotton + 5% Waste Paper Sludge + 30% Marble Dust

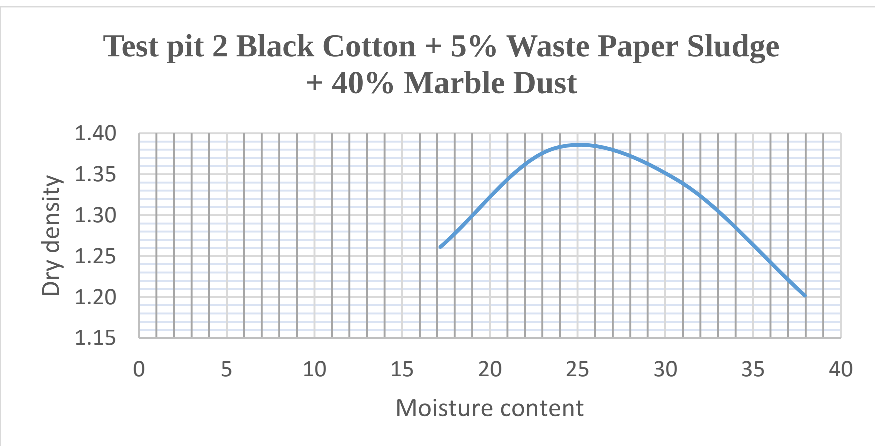
	Test pit 2 Black Cotton + 5% Waste Paper Sludge + 30% Marble Dust				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5882	5893	6080	6075
	Calculation				
D	Wt of Compacted Soil	1489	1500	1687	1682
E	Bulk Density	1.489	1.5	1.687	1.682
	Water content Determination				
1	Container No	B13	A19	A20	C2
2	Weight of container	0.03	0.029	0.029	0.029
3	Weight of container + wt soil	0.076	0.070	0.067	0.067
4	Weight of container + Dry soil	0.069	0.064	0.059	0.058
5	Weight of water	0.007	0.006	0.008	0.009
6	Weight of dry soil	0.039	0.035	0.03	0.029
7	Water content	17.47	18.00	25.46	32.11
8	Dry Density	1.268	1.271	1.345	1.273



Optimum Moisture content (%)	25.463
Maximum Dry density (g/cm3)	1.375

16. Test pit 2 Black Cotton + 5% Waste Paper Sludge + 40% Marble Dust

	Test pit 2 Black Cotton + 5% Waste Paper Sludge + 40% Marble Dust				
	Observation and calculation	1	2	3	4
A	Mass of empty mold with base plates	4393	4393	4393	4393
B	Volume of mold	1000	1000	1000	1000
C	Mass of mod & base plate + compacted soil	5871	6103	6148	6051
	Calculation				
D	Wt of Compacted Soil	1478	1710	1755	1658
E	Bulk Density	1.478	1.71	1.755	1.658
	Water content Determination				
1	Container No	A1	A6	A9	A10
2	Weight of container	0.019	0.018	0.019	0.02
3	Weight of container + wt soil	0.053	0.050	0.050	0.050
4	Weight of container + Dry soil	0.048	0.044	0.043	0.042
5	Weight of water	0.005	0.006	0.007	0.008
6	Weight of dry soil	0.029	0.026	0.024	0.022
7	Water content	17.18	23.73	30.71	37.95
8	Average	17.18	23.73	30.71	37.95
9	Dry Density	1.261	1.382	1.343	1.202



Optimum Moisture content (%)	25
Maximum Dry density (g/cm3)	1.358

Appendix 4: Summary of Free Swell Tests

1. Combined effect of waste paper sludge and marble dust on Free Swell For Test pit 1

Test Pit 1	Measuring Cylinder No		Reading after 24 hours		Free Swell Index (%)
	Kerosene	Distilled Water	Kerosene	Distilled Water	
Natural Black Cotton Soil	10	10	10	24	140
Black Cotton Soil+5% Waste Paper Sludge+10% Marble dust	10	10	10	23	130
Black Cotton Soil+5% Waste Paper Sludge+20% Marble dust	10	10	10	21	110
Black Cotton Soil+5% Waste Paper Sludge+30% Marble dust	10	10	10	16	60
Black Cotton Soil+5% Waste Paper Sludge+40% Marble dust	10	10	10	15.5	55

2. Combined effect of waste paper sludge and marble dust on Free Swell For Test pit 2

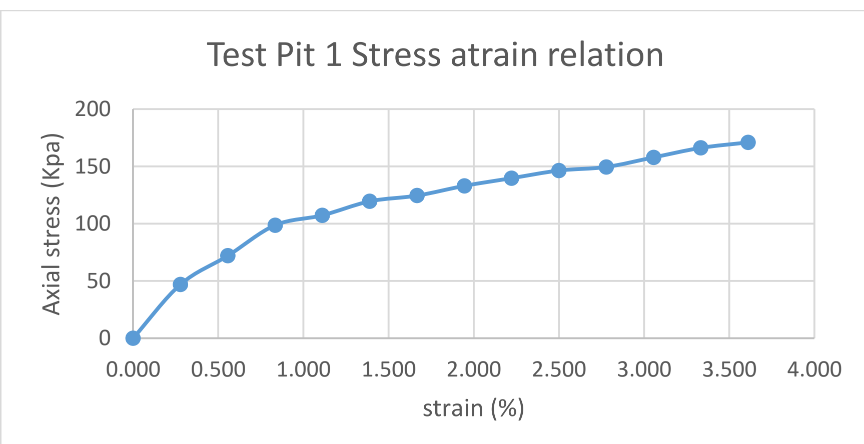
Test Pit 2	Measuring Cylinder No		Reading after 24 hours		Free Swell Index
	Kerosene	Distilled Water	Kerosene	Distilled Water	
Natural Black Cotton Soil	10	10	10	24.1	141
Black Cotton Soil+5% Waste Paper Sludge+10% Marble dust	10	10	10	20.5	105
Black Cotton Soil+5% Waste Paper Sludge+20% Marble dust	10	10	10	20	100
Black Cotton Soil+5% Waste Paper Sludge+30% Marble dust	10	10	10	17	70
Black Cotton Soil+5% Waste Paper Sludge+40% Marble dust	10	10	10	15	50

Appendix 5. Summary of Unconfined Compressive Strength Test

1. **Unconfined compressive strength for Natural soil for Test Pit 1**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	150.39	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	113.82	Length (mm)	72
Weight of Water (gm)	36.57	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	81666.86
Weight of Dry Sample (gm)	113.82	Bulk Density (gm/cm^3)	1.842
Water content	32.13	Dry Density (gm/cm^3)	1.394
		Rate (mm/mm)	1.5
Sample Type	Undisturbed	Machine correction (KN/div)	0.00205

Test Pit 1 Unconfined compressive strength for original soil								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	26	0.2	0.003	0.278	1134.26	1137.41	0.053	46.861
40	40	0.4	0.006	0.556	1134.26	1140.56	0.082	71.894
60	55	0.6	0.008	0.833	1134.26	1143.71	0.113	98.582
80	60	0.8	0.011	1.111	1134.26	1146.86	0.123	107.249
100	67	1	0.014	1.389	1134.26	1150.01	0.137	119.433
120	70	1.2	0.017	1.667	1134.26	1153.16	0.144	124.440
140	75	1.4	0.019	1.944	1134.26	1156.32	0.154	132.965
160	79	1.6	0.022	2.222	1134.26	1159.47	0.162	139.676
180	83	1.8	0.025	2.500	1134.26	1162.62	0.170	146.351
200	85	2	0.028	2.778	1134.26	1165.77	0.174	149.472
220	90	2.2	0.031	3.056	1134.26	1168.92	0.185	157.838
240	95	2.4	0.033	3.333	1134.26	1172.07	0.195	166.159
260	98	2.6	0.036	3.611	1134.26	1175.22	0.201	170.947

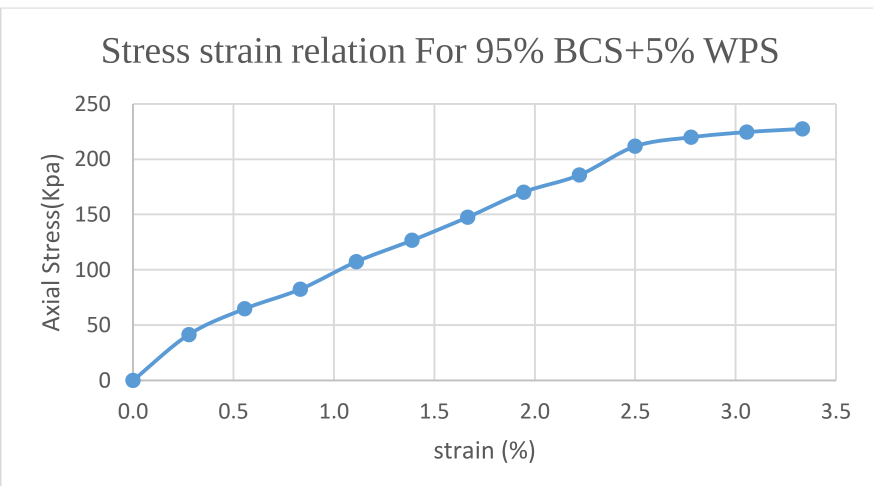


2. **Effect of Addition of 5% Waste paper sludge on Unconfined Compressive strength For Test Pit 1**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	149.12	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	118.73	Length (mm)	72
Weight of Water (gm)	30.39	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	81666.86
Weight of Dry Sample (gm)	118.73	Bulk Density (gm/cm^3)	1.826
Water content	25.6	Dry Density (gm/cm^3)	1.454
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

Effect of Addition of 5% Waste paper sludge on Unconfined compressive strength For Test Pit 1

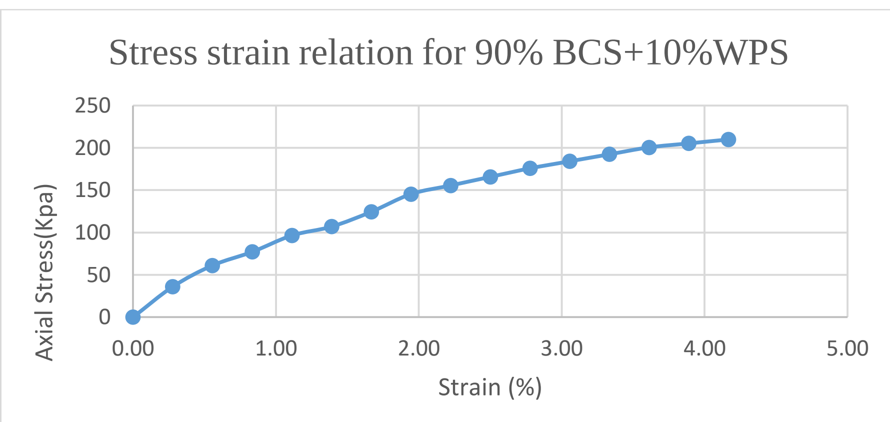
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	23	0.2	0.003	0.278	1134.26	1137.41	0.047	41.454
40	36	0.4	0.006	0.556	1134.26	1140.56	0.074	64.705
60	46	0.6	0.008	0.833	1134.26	1143.71	0.094	82.451
80	60	0.8	0.011	1.111	1134.26	1146.86	0.123	107.249
100	71	1	0.014	1.389	1134.26	1150.01	0.146	126.564
120	83	1.2	0.017	1.667	1134.26	1153.16	0.170	147.551
140	96	1.4	0.019	1.944	1134.26	1156.32	0.197	170.196
160	105	1.6	0.022	2.222	1134.26	1159.47	0.215	185.646
180	120	1.8	0.025	2.500	1134.26	1162.62	0.246	211.592
200	125	2	0.028	2.778	1134.26	1165.77	0.256	219.812
220	128	2.2	0.031	3.056	1134.26	1168.92	0.262	224.481
240	130	2.4	0.033	3.333	1134.26	1172.07	0.267	227.376



3. **Effect of Addition of 10% Waste paper sludge on Unconfined Compressive strength**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	150.11	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	108.9	Length (mm)	72
Weight of Water (gm)	41.21	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	81666.86
Weight of Dry Sample (gm)	108.9	Bulk Density (gm/cm^3)	1.838
Water content	37.84	Dry Density (gm/cm^3)	1.333
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

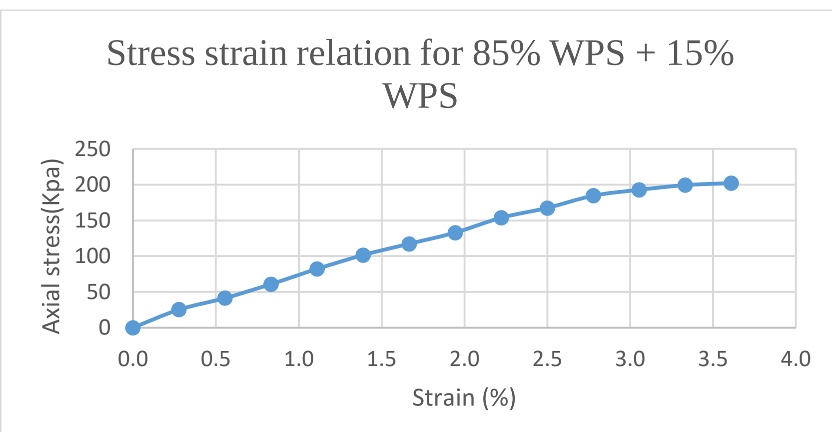
Effect of Addition of 10% Waste paper sludge on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	20	0.2	0.003	0.278	1134.26	1137.41	0.041	36.047
40	34	0.4	0.006	0.556	1134.26	1140.56	0.070	61.110
60	43	0.6	0.008	0.833	1134.26	1143.71	0.088	77.074
80	54	0.8	0.011	1.111	1134.26	1146.86	0.111	96.524
100	60	1	0.014	1.389	1134.26	1150.01	0.123	106.955
120	70	1.2	0.017	1.667	1134.26	1153.16	0.144	124.440
140	82	1.4	0.019	1.944	1134.26	1156.32	0.168	145.376
160	88	1.6	0.022	2.222	1134.26	1159.47	0.180	155.589
180	94	1.8	0.025	2.500	1134.26	1162.62	0.193	165.747
200	100	2	0.028	2.778	1134.26	1165.77	0.205	175.850
220	105	2.2	0.031	3.056	1134.26	1168.92	0.215	184.145
240	110	2.4	0.033	3.333	1134.26	1172.07	0.226	192.395
260	115	2.6	0.036	3.611	1134.26	1175.22	0.236	200.601
280	118	2.8	0.039	3.889	1134.26	1178.37	0.242	205.284
300	121	3	0.042	4.167	1134.26	1181.52	0.248	209.941



4. **Effect of Addition of 15% Waste paper sludge on Unconfined Compressive strength**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	148.34	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	106.14	Length (mm)	72
Weight of Water (gm)	42.2	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	81666.86
Weight of Dry Sample (gm)	106.14	Bulk Density (gm/cm^3)	1.816
Water content	39.76	Dry Density (gm/cm^3)	1.3
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

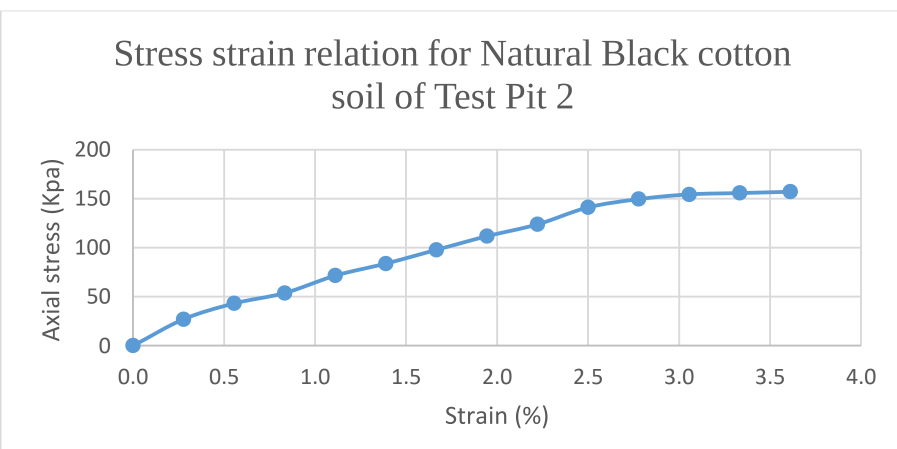
Effect of Addition of 15% Waste paper sludge on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	14	0.2	0.003	0.278	1134.26	1137.41	0.029	25.233
40	23	0.4	0.006	0.556	1134.26	1140.56	0.047	41.339
60	34	0.6	0.008	0.833	1134.26	1143.71	0.070	60.942
80	46	0.8	0.011	1.111	1134.26	1146.86	0.094	82.224
100	57	1	0.014	1.389	1134.26	1150.01	0.117	101.607
120	66	1.2	0.017	1.667	1134.26	1153.16	0.135	117.329
140	75	1.4	0.019	1.944	1134.26	1156.32	0.154	132.965
160	87	1.6	0.022	2.222	1134.26	1159.47	0.178	153.821
180	95	1.8	0.025	2.500	1134.26	1162.62	0.195	167.510
200	105	2	0.028	2.778	1134.26	1165.77	0.215	184.642
220	110	2.2	0.031	3.056	1134.26	1168.92	0.226	192.913
240	114	2.4	0.033	3.333	1134.26	1172.07	0.234	199.391
260	116	2.6	0.036	3.611	1134.26	1175.22	0.238	202.345



5. **Unconfined compressive strength for Natural soil for Test Pit 2**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	146.13	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	101.03	Length (mm)	76
Weight of Water (gm)	45.1	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	101.03	Bulk Density (gm/cm^3)	1.695
Water content	44.64	Dry Density (gm/cm^3)	1.172
		Rate (mm/mm)	1.5
Sample Type	Undisturbed	Machine correction (KN/div)	0.00205

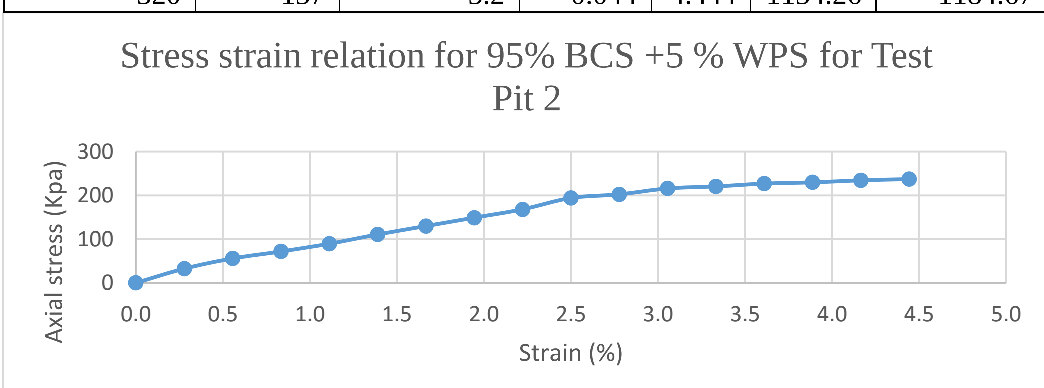
Test Pit 2 Unconfined compressive strength for original soil								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	15	0.2	0.003	0.278	1134.26	1137.41	0.031	27.035
40	24	0.4	0.006	0.556	1134.26	1140.56	0.049	43.137
60	30	0.6	0.008	0.833	1134.26	1143.71	0.062	53.772
80	40	0.8	0.011	1.111	1134.26	1146.86	0.082	71.499
100	47	1	0.014	1.389	1134.26	1150.01	0.096	83.782
120	55	1.2	0.017	1.667	1134.26	1153.16	0.113	97.774
140	63	1.4	0.019	1.944	1134.26	1156.32	0.129	111.691
160	70	1.6	0.022	2.222	1134.26	1159.47	0.144	123.764
180	80	1.8	0.025	2.500	1134.26	1162.62	0.164	141.061
200	85	2	0.028	2.778	1134.26	1165.77	0.174	149.472
220	88	2.2	0.031	3.056	1134.26	1168.92	0.180	154.331
240	89	2.4	0.033	3.333	1134.26	1172.07	0.182	155.665
260	90	2.6	0.036	3.611	1134.26	1175.22	0.185	156.992



6. **Effect of Addition of 5% Waste paper sludge on Unconfined Compressive strength for Test Pit 2**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	150.49	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	111.61	Length (mm)	76
Weight of Water (gm)	38.88	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	111.61	Bulk Density (gm/cm^3)	1.746
Water content	34.84	Dry Density (gm/cm^3)	1.295
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

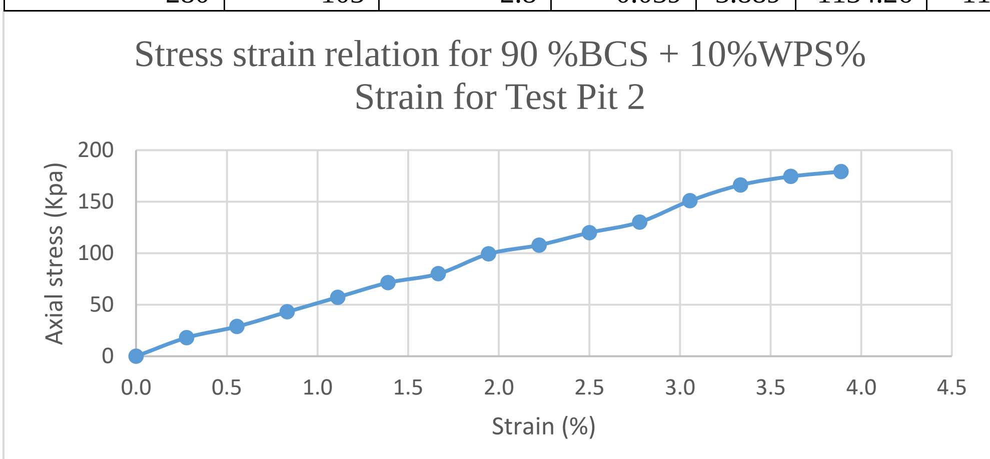
Effect of Addition of 5% Waste paper sludge on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	18	0.2	0.003	0.278	1134.26	1137.41	0.037	32.442
40	31	0.4	0.006	0.556	1134.26	1140.56	0.064	55.718
60	40	0.6	0.008	0.833	1134.26	1143.71	0.082	71.696
80	50	0.8	0.011	1.111	1134.26	1146.86	0.103	89.374
100	62	1	0.014	1.389	1134.26	1150.01	0.127	110.520
120	73	1.2	0.017	1.667	1134.26	1153.16	0.150	129.773
140	84	1.4	0.019	1.944	1134.26	1156.32	0.172	148.921
160	95	1.6	0.022	2.222	1134.26	1159.47	0.195	167.965
180	110	1.8	0.025	2.500	1134.26	1162.62	0.226	193.959
200	115	2	0.028	2.778	1134.26	1165.77	0.236	202.227
220	123	2.2	0.031	3.056	1134.26	1168.92	0.252	215.712
240	126	2.4	0.033	3.333	1134.26	1172.07	0.258	220.380
260	130	2.6	0.036	3.611	1134.26	1175.22	0.267	226.766
280	132	2.8	0.039	3.889	1134.26	1178.37	0.271	229.639
300	135	3	0.042	4.167	1134.26	1181.52	0.277	234.232
320	137	3.2	0.044	4.444	1134.26	1184.67	0.281	237.070



7. **Effect of Addition of 10% Waste paper sludge on Unconfined compressive strength for test Pit 2**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	147.32	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	105.36	Length (mm)	76
Weight of Water (gm)	41.96	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	105.36	Bulk Density (gm/cm^3)	1.709
Water content	39.83	Dry Density (gm/cm^3)	1.222
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

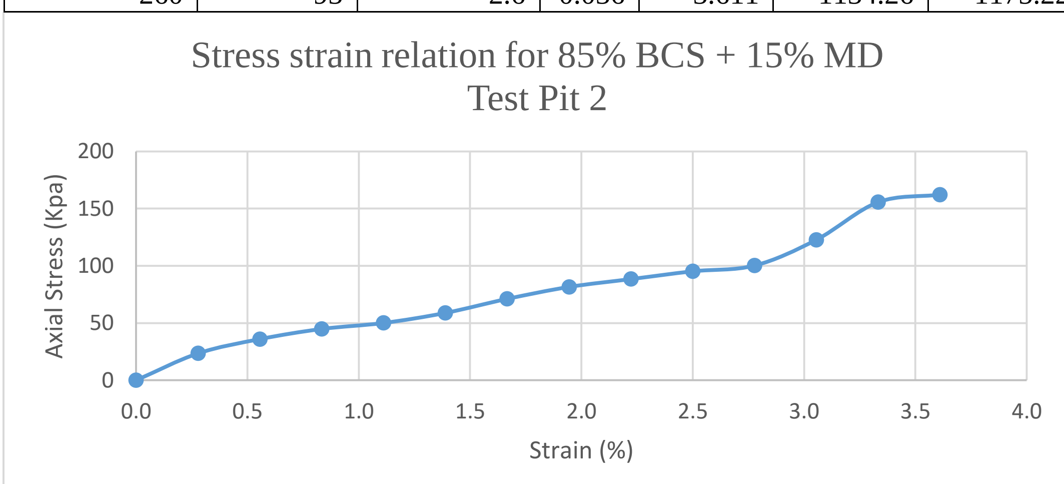
Effect of Addition of 10% Waste paper sludge on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	10	0.2	0.003	0.278	1134.26	1137.41	0.021	18.023
40	16	0.4	0.006	0.556	1134.26	1140.56	0.033	28.758
60	24	0.6	0.008	0.833	1134.26	1143.71	0.049	43.018
80	32	0.8	0.011	1.111	1134.26	1146.86	0.066	57.200
100	40	1	0.014	1.389	1134.26	1150.01	0.082	71.304
120	45	1.2	0.017	1.667	1134.26	1153.16	0.092	79.997
140	56	1.4	0.019	1.944	1134.26	1156.32	0.115	99.281
160	61	1.6	0.022	2.222	1134.26	1159.47	0.125	107.851
180	68	1.8	0.025	2.500	1134.26	1162.62	0.139	119.902
200	74	2	0.028	2.778	1134.26	1165.77	0.152	130.129
220	86	2.2	0.031	3.056	1134.26	1168.92	0.176	150.823
240	95	2.4	0.033	3.333	1134.26	1172.07	0.195	166.159
260	100	2.6	0.036	3.611	1134.26	1175.22	0.205	174.436
280	103	2.8	0.039	3.889	1134.26	1178.37	0.211	179.188



8. **Effect of Addition of 15% Waste paper sludge on Unconfined Compressive strength for Test Pit 2**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	114.15	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	96.92	Length (mm)	72
Weight of Water (gm)	17.23	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	81666.86
Weight of Dry Sample (gm)	96.92	Bulk Density (gm/cm^3)	1.398
Water content	17.78	Dry Density (gm/cm^3)	1.187
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

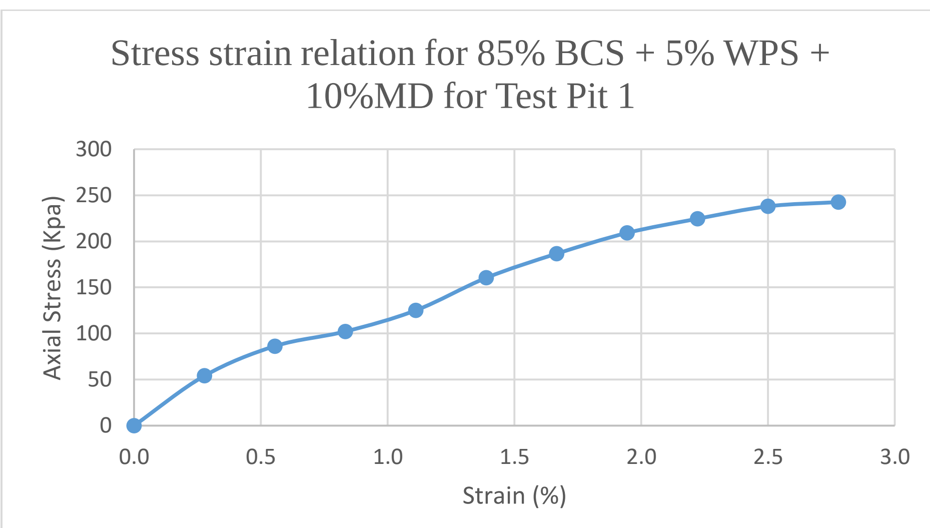
Effect of Addition of 15% Waste paper sludge on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	13	0.2	0.003	0.278	1134.26	1137.41	0.027	23.430
40	20	0.4	0.006	0.556	1134.26	1140.56	0.041	35.947
60	25	0.6	0.008	0.833	1134.26	1143.71	0.051	44.810
80	28	0.8	0.011	1.111	1134.26	1146.86	0.057	50.050
100	33	1	0.014	1.389	1134.26	1150.01	0.068	58.825
120	40	1.2	0.017	1.667	1134.26	1153.16	0.082	71.109
140	46	1.4	0.019	1.944	1134.26	1156.32	0.094	81.552
160	50	1.6	0.022	2.222	1134.26	1159.47	0.103	88.403
180	54	1.8	0.025	2.500	1134.26	1162.62	0.111	95.216
200	57	2	0.028	2.778	1134.26	1165.77	0.117	100.234
220	70	2.2	0.031	3.056	1134.26	1168.92	0.144	122.763
240	89	2.4	0.033	3.333	1134.26	1172.07	0.182	155.665
260	93	2.6	0.036	3.611	1134.26	1175.22	0.191	162.225



9. **Effect of Addition of 5% and 10% marble dust Waste paper sludge on Unconfined Compressive strength for Test Pit 1**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	143.4	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	109.9	Length (mm)	76
Weight of Water (gm)	33.5	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	109.9	Bulk Density (gm/cm^3)	1.663
Water content	30.48	Dry Density (gm/cm^3)	1.275
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

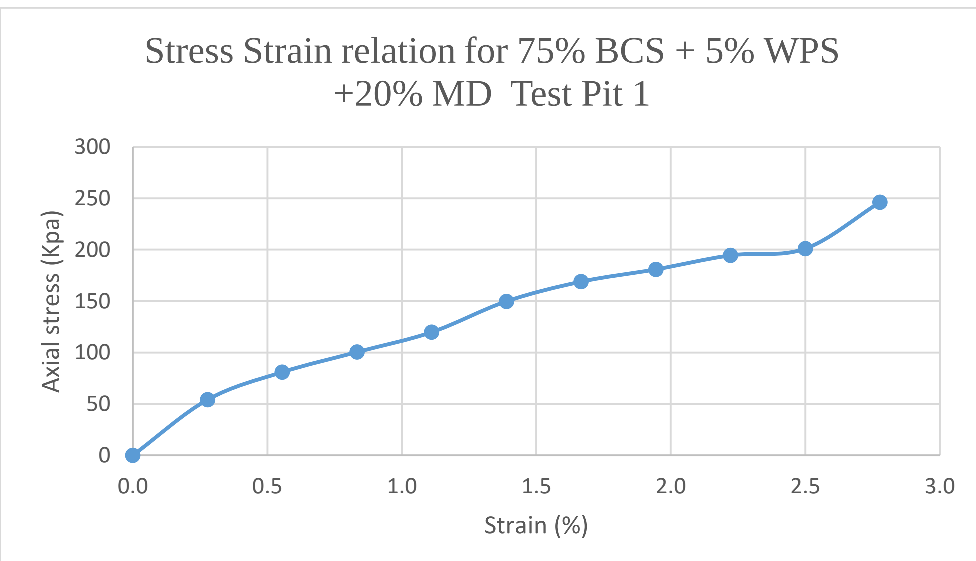
TP 1 ..Effect of Addition of 5% and 10% marble dust Waste paper sludge on Unconfined Compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	30	0.2	0.003	0.278	1134.26	1137.41	0.062	54.070
40	48	0.4	0.006	0.556	1134.26	1140.56	0.098	86.273
60	57	0.6	0.008	0.833	1134.26	1143.71	0.117	102.167
80	70	0.8	0.011	1.111	1134.26	1146.86	0.144	125.124
100	90	1	0.014	1.389	1134.26	1150.01	0.185	160.433
120	105	1.2	0.017	1.667	1134.26	1153.16	0.215	186.660
140	118	1.4	0.019	1.944	1134.26	1156.32	0.242	209.199
160	127	1.6	0.022	2.222	1134.26	1159.47	0.260	224.543
180	135	1.8	0.025	2.500	1134.26	1162.62	0.277	238.041
200	138	2	0.028	2.778	1134.26	1165.77	0.283	242.673



10. **Effect of Addition of 5% and 20% marble dust Waste paper sludge on Unconfined Compressive strength for Test Pit 1**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	149.8	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	115.6	Length (mm)	76
Weight of Water (gm)	34.2	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	115.6	Bulk Density (gm/cm^3)	1.738
Water content	29.58	Dry Density (gm/cm^3)	1.341
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

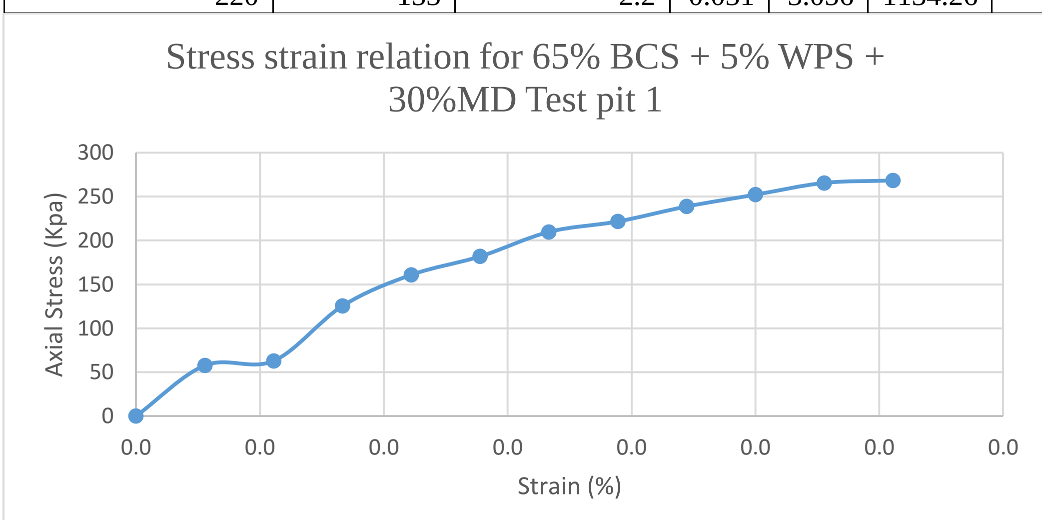
Effect of Addition of 5% and 20% marble dust Waste paper sludge on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	30	0.2	0.003	0.278	1134.26	1137.41	0.062	54.070
40	45	0.4	0.006	0.556	1134.26	1140.56	0.092	80.881
60	56	0.6	0.008	0.833	1134.26	1143.71	0.115	100.375
80	67	0.8	0.011	1.111	1134.26	1146.86	0.137	119.761
100	84	1	0.014	1.389	1134.26	1150.01	0.172	149.737
120	95	1.2	0.017	1.667	1134.26	1153.16	0.195	168.883
140	102	1.4	0.019	1.944	1134.26	1156.32	0.209	180.833
160	110	1.6	0.022	2.222	1134.26	1159.47	0.226	194.486
180	114	1.8	0.025	2.500	1134.26	1162.62	0.234	201.012
200	140	2	0.028	2.778	1134.26	1165.77	0.287	246.190



11. **Effect of Addition of 5% Waste paper sludge and 30% marble dust on Unconfined Compressive strength for Test Pit 1**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	158.4	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	120.7	Length (mm)	76
Weight of Water (gm)	37.7	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	120.7	Bulk Density (gm/cm^3)	1.838
Water content	31.23	Dry Density (gm/cm^3)	1.4
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

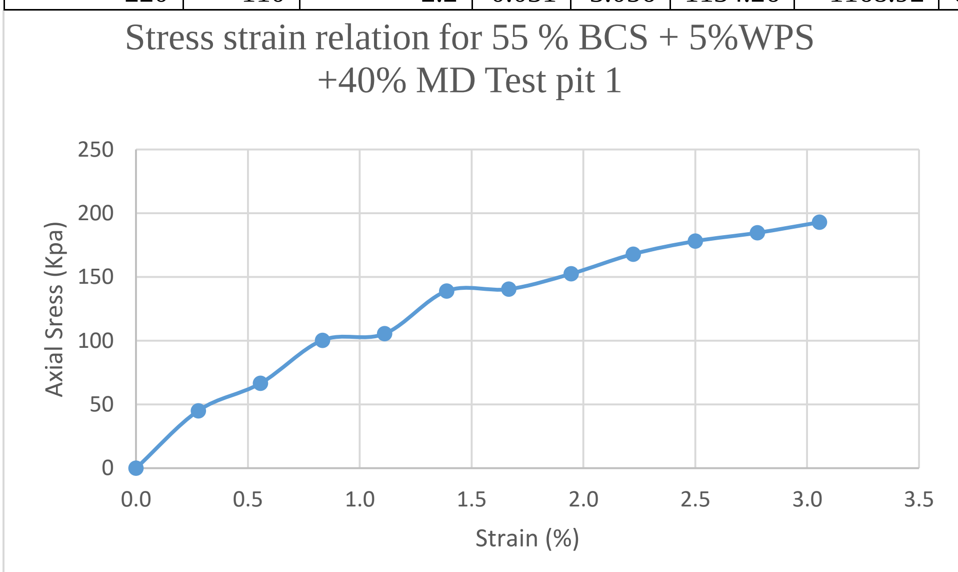
Effect of Addition of 5% Waste paper sludge and 30% marble dust on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	32	0.2	0.003	0.278	1134.26	1137.41	0.066	57.675
40	35	0.4	0.006	0.556	1134.26	1140.56	0.072	62.908
60	70	0.6	0.008	0.833	1134.26	1143.71	0.144	125.469
80	90	0.8	0.011	1.111	1134.26	1146.86	0.185	160.874
100	102	1	0.014	1.389	1134.26	1150.01	0.209	181.824
120	118	1.2	0.017	1.667	1134.26	1153.16	0.242	209.771
140	125	1.4	0.019	1.944	1134.26	1156.32	0.256	221.609
160	135	1.6	0.022	2.222	1134.26	1159.47	0.277	238.688
180	143	1.8	0.025	2.500	1134.26	1162.62	0.293	252.147
200	151	2	0.028	2.778	1134.26	1165.77	0.310	265.533
220	153	2.2	0.031	3.056	1134.26	1168.92	0.314	268.325



12. **Effect of Addition of 5% Waste paper sludge and 40% marble dust on Unconfined Compressive strength for Test Pit 1**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	157	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	124	Length (mm)	76
Weight of Water (gm)	33.17	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	124	Bulk Density (gm/cm^3)	1.823
Water content	26.75	Dry Density (gm/cm^3)	1.438
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

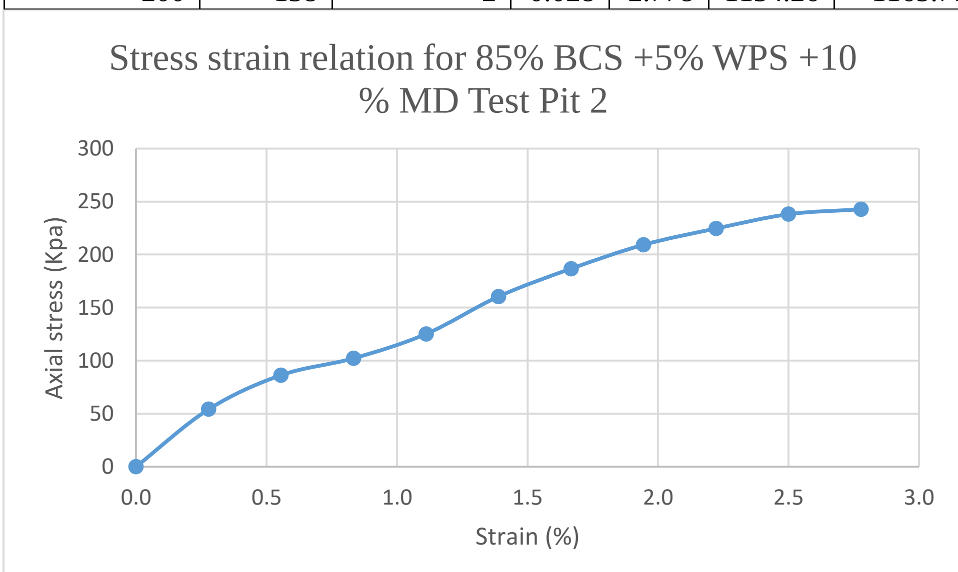
Effect of Addition of 5% Waste paper sludge and 40% marble dust on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	25	0.2	0.003	0.278	1134.26	1137.41	0.051	45.058
40	37	0.4	0.006	0.556	1134.26	1140.56	0.076	66.502
60	56	0.6	0.008	0.833	1134.26	1143.71	0.115	100.375
80	59	0.8	0.011	1.111	1134.26	1146.86	0.121	105.462
100	78	1	0.014	1.389	1134.26	1150.01	0.160	139.042
120	79	1.2	0.017	1.667	1134.26	1153.16	0.162	140.440
140	86	1.4	0.019	1.944	1134.26	1156.32	0.176	152.467
160	95	1.6	0.022	2.222	1134.26	1159.47	0.195	167.965
180	101	1.8	0.025	2.500	1134.26	1162.62	0.207	178.090
200	105	2	0.028	2.778	1134.26	1165.77	0.215	184.642
220	110	2.2	0.031	3.056	1134.26	1168.92	0.226	192.913



13. **Effect of Addition of 5% Waste paper sludge and 10% MD on Unconfined compressive strength for Test Pit 2**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	153	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	113.2	Length (mm)	76
Weight of Water (gm)	39.8	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	113.2	Bulk Density (gm/cm^3)	1.775
Water content	35.16	Dry Density (gm/cm^3)	1.313
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

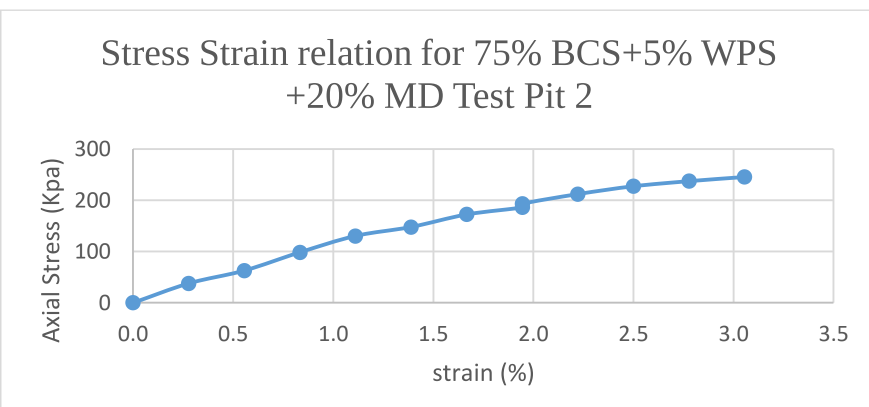
Effect of Addition of 5% Waste paper sludge and 10% MD on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	30	0.2	0.003	0.278	1134.26	1137.41	0.062	54.070
40	48	0.4	0.006	0.556	1134.26	1140.56	0.098	86.273
60	57	0.6	0.008	0.833	1134.26	1143.71	0.117	102.167
80	70	0.8	0.011	1.111	1134.26	1146.86	0.144	125.124
100	90	1	0.014	1.389	1134.26	1150.01	0.185	160.433
120	105	1.2	0.017	1.667	1134.26	1153.16	0.215	186.660
140	118	1.4	0.019	1.944	1134.26	1156.32	0.242	209.199
160	127	1.6	0.022	2.222	1134.26	1159.47	0.260	224.543
180	135	1.8	0.025	2.500	1134.26	1162.62	0.277	238.041
200	138	2	0.028	2.778	1134.26	1165.77	0.283	242.673



14. **Effect of Addition of 5% Waste paper sludge and 20% marble dust on Unconfined Compressive strength for test Pit 2**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	147.2	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	116	Length (mm)	76
Weight of Water (gm)	31.2	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	116	Bulk Density (gm/cm^3)	1.708
Water content	26.9	Dry Density (gm/cm^3)	1.346
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

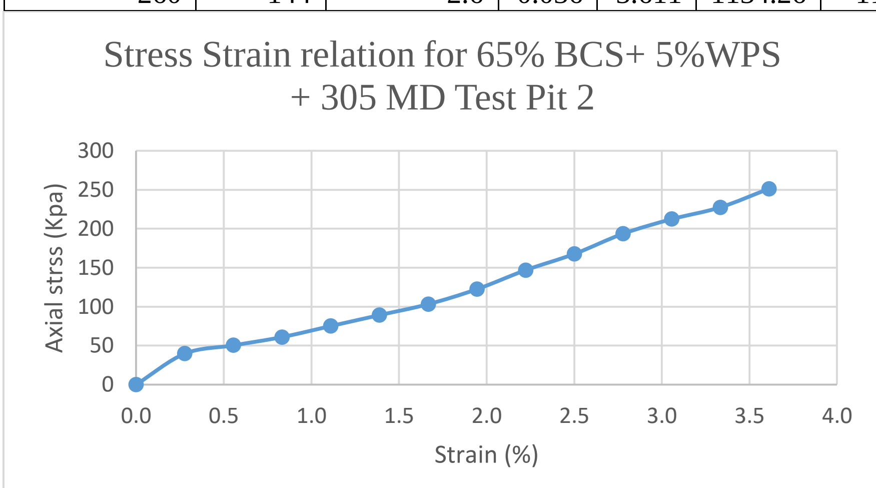
Effect of Addition of 5% Waste paper sludge and 20% marble dust on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	21	0.2	0.003	0.278	1134.26	1137.41	0.043	37.849
40	35	0.4	0.006	0.556	1134.26	1140.56	0.072	62.908
60	55	0.6	0.008	0.833	1134.26	1143.71	0.113	98.582
80	73	0.8	0.011	1.111	1134.26	1146.86	0.150	130.486
100	83	1	0.014	1.389	1134.26	1150.01	0.170	147.955
120	97	1.2	0.017	1.667	1134.26	1153.16	0.199	172.439
140	105	1.4	0.019	1.944	1134.26	1156.32	0.215	186.152
140	109	1.4	0.019	1.944	1134.26	1156.32	0.223	193.243
160	120	1.6	0.022	2.222	1134.26	1159.47	0.246	212.167
180	129	1.8	0.025	2.500	1134.26	1162.62	0.264	227.461
200	135	2	0.028	2.778	1134.26	1165.77	0.277	237.397
220	140	2.2	0.031	3.056	1134.26	1168.92	0.287	245.526



15. **Effect of Addition of 5% Waste paper sludge and 30% Marble dust on Unconfined compressive strength for Test Pit 2**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	148.2	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	118.2	Length (mm)	76
Weight of Water (gm)	30.1	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	118.2	Bulk Density (gm/cm^3)	1.721
Water content	25.55	Dry Density (gm/cm^3)	1.371
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

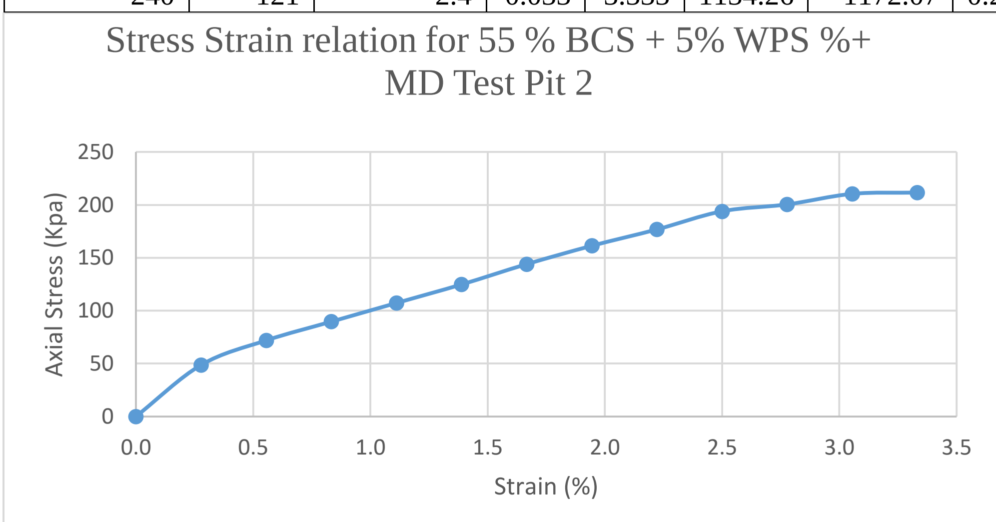
Effect of Addition of 5% Waste paper sludge and 30% Marble dust on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	22	0.2	0.003	0.278	1134.26	1137.41	0.045	39.651
40	28	0.4	0.006	0.556	1134.26	1140.56	0.057	50.326
60	34	0.6	0.008	0.833	1134.26	1143.71	0.070	60.942
80	42	0.8	0.011	1.111	1134.26	1146.86	0.086	75.074
100	50	1	0.014	1.389	1134.26	1150.01	0.103	89.129
120	58	1.2	0.017	1.667	1134.26	1153.16	0.119	103.108
140	69	1.4	0.019	1.944	1134.26	1156.32	0.141	122.328
160	83	1.6	0.022	2.222	1134.26	1159.47	0.170	146.749
180	95	1.8	0.025	2.500	1134.26	1162.62	0.195	167.510
200	110	2	0.028	2.778	1134.26	1165.77	0.226	193.435
220	121	2.2	0.031	3.056	1134.26	1168.92	0.248	212.205
240	130	2.4	0.033	3.333	1134.26	1172.07	0.267	227.376
260	144	2.6	0.036	3.611	1134.26	1175.22	0.295	251.187



16. **Effect of Addition of 5% Waste paper sludge and 40% on Unconfined compressive strength for Test Pit 2**

Moisture Content Determination		Specimen Data	
Weight of Wet Sample + Container (gm)	155.04	Diameter (mm)	38
Weight of Dry Sample + Container (gm)	124.8	Length (mm)	76
Weight of Water (gm)	30.24	Area ,Ao (mm^2)	1134.26
Weight of Container (gm)	0.00	Volume (mm^3)	86203.91
Weight of Dry Sample (gm)	124.8	Bulk Density (gm/cm^3)	1.799
Water content	24.23	Dry Density (gm/cm^3)	1.448
		Rate (mm/mm)	1.5
Sample Type	Remolded	Machine correction (KN/div)	0.00205

Effect of Addition of 5% Waste paper sludge and 40% on Unconfined compressive strength								
Deformation deal reading	Load Dial reading	Sample deformation	Strain	% Strain	Area	Corrected Area	Load	Stress
0	0	0	0.000	0.000	1134.26	1134.26	0.000	0.000
20	27	0.2	0.003	0.278	1134.26	1137.41	0.055	48.663
40	40	0.4	0.006	0.556	1134.26	1140.56	0.082	71.894
60	50	0.6	0.008	0.833	1134.26	1143.71	0.103	89.620
80	60	0.8	0.011	1.111	1134.26	1146.86	0.123	107.249
100	70	1	0.014	1.389	1134.26	1150.01	0.144	124.781
120	81	1.2	0.017	1.667	1134.26	1153.16	0.166	143.995
140	91	1.4	0.019	1.944	1134.26	1156.32	0.187	161.331
160	100	1.6	0.022	2.222	1134.26	1159.47	0.205	176.806
180	110	1.8	0.025	2.500	1134.26	1162.62	0.226	193.959
200	114	2	0.028	2.778	1134.26	1165.77	0.234	200.469
220	120	2.2	0.031	3.056	1134.26	1168.92	0.246	210.451
240	121	2.4	0.033	3.333	1134.26	1172.07	0.248	211.634



Appendix 6: Summary of Consolidation Tests

1. Consolidation test for natural Black Cotton Soil Test Pit 1

Increment Nº			1	2	3	4	5	-	-
Load		Kg	2.5	5	10	20	40	20	5
Pressure		Kpa	55	111	222	444	888	444	111
Elapsed time			Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm
	t (min)	Sqrt t	DH	DH	DH	DH	DH	DH	DH
	0	0.00	0.000	0.760	1.631	3.212	4.458	4.999	4.992
	0.25	0.50	0.214	1.060	2.080	3.482	4.580	-	-
	1	1.00	0.232	1.122	2.104	3.500	4.599	-	-
	2.25	1.50	0.250	1.150	2.142	3.518	4.624	-	-
	4	2.00	0.268	1.174	2.167	3.542	4.642	-	-
	6.25	2.50	0.284	1.194	2.194	3.568	4.662	-	-
	9	3.00	0.308	1.218	2.228	3.584	4.684	-	-
	12.50	3.54	0.328	1.232	2.238	3.592	4.708	-	-
	16	4.00	0.350	1.254	2.286	3.624	4.226	-	-
	25	5.00	0.400	1.302	2.354	3.626	4.774	-	-
	36	6.00	0.438	1.330	2.388	3.654	4.826	-	-
	49	7.00	0.480	1.368	2.468	3.712	4.879	-	-
	64	8.00	0.514	1.400	2.522	3.770	4.934	-	-
	81	9.00	0.642	1.446	2.598	3.804	4.971	-	-
	100	10.00	0.674	1.464	2.642	3.884	4.976	-	-
	121	11.00	0.688	1.562	2.682	3.918	4.978	-	-
	225	15.00	0.692	1.588	2.846	4.119	4.980	-	-
	400	20.00	0.700	1.604	3.112	4.278	4.996	-	-
	1440	37.95	0.760	1.631	3.212	4.418	4.999	4.992	4.732
Net cumulative compression (DH)			0.760	1.631	3.212	4.418	4.999	4.992	4.732
Corrected cumulative compression DH			0.760	1.631	3.212	4.418	4.999	4.992	4.732

Specimen Data	
Before Test	
Weight of sample and Ring (gm)	223.8
Weight of ring (gm)	108.2
Weight of sample(gm)	115.6
Weight of Dry Sample (gm)	84.6
Weight of initial moisture (gm)	31
Initial moisture content (%)	36
initial void ratio: eo=(Gs/ϒd)-1	1.496
height of solids: Hs=Ho(1+eo) mm	8.011
Initial saturation: So=(Mo*Gs)/eo	58.52

Specific Gravity (Gs)	2.39
Sample Diameter (D) (mm)	75
Sample thickness (Ho) (mm)	20
Area (A) (cm2)	44.18
Volume (V) cm	88.37
Bulk Density (ϒb) (gm/cm3)	1.308
Dry Density (ϒb) (gm/cm3)	0.957

After Test	
Weight of sample + Ring + Can (gm)	230.2
weight of Dry sample +Ring +Can (gm)	192.8
weight of Ring +Can (gm)	108.2
weight of wet sample (gm)	122
Weight of Dry sample (gm)	84.36
Final moisture content	44.21

Over all settlement (mm)	4.732
Volume change (cm3)	20.91
Final volume (cm3)	67.46
Final bulk density (gm/cm3)	1.808
Final dry density (gm/cm3)	1.254

sample diameter (D)	75.00 mm	Height Ho	20 mm
Height of solids	8.011	Initial void ratio (eo)	1.5

void ratio				Compressibility			Coefficient of consolidation		
Pressure (Kpa)	Commutative compression	consolidated height	Void Ratio	Height change	Pressure change	Mv	t90	H	Cv
0	0	20	1.496						
				0.76	99.88	0.38			
100	0.76	19.24	1.402				184.14	19.62	1.45
				0.871	99.88	0.453			
200	1.631	18.369	1.293				190.44	18.805	1.35
				1.581	199.76	0.431			
400	3.212	16.788	1.096				338.56	17.579	0.77
				1.246	399.52	0.186			
799	4.458	15.542	0.94				681.47	16.165	0.33
				0.541	799.04	0.044			
1598	4.999	15.001	0.872				107.12	15.272	1.85
400	4.992	15.008	0.873						
100	4.732	15.268	0.906						

2. **Consolidation test for Black Cotton Soil + 5% Waste Paper Sludge + 30% Marble Dust For Test Pit 1**

Increment Nº			1	2	3	4	5	-	-
Load		Kg	2.5	5	10	20	40	20	5
Pressure		Kpa	55	111	222	444	888	444	111
Elapsed time			Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm
	t (min)	√τ	ΔH	ΔH	ΔH	ΔH	ΔH	ΔH	ΔH
	0	0.00	0.000	0.572	1.152	2.072	3.024	4.180	3.834
	0.25	0.50	0.142	0.732	1.428	2.310	3.674	-	-
	1	1.00	0.184	0.786	1.486	2.384	3.714	-	-
	2.25	1.50	0.248	0.818	1.552	2.442	3.728	-	-
	4	2.00	0.292	0.868	1.588	2.470	3.744	-	-
	6.25	2.50	0.324	0.882	1.624	2.488	3.760	-	-
	9	3.00	0.348	0.898	1.638	2.518	3.774	-	-
	12.50	3.54	0.382	0.934	1.652	2.532	3.790	-	-
	16	4.00	0.400	0.952	1.674	2.548	3.804	-	-
	25	5.00	0.408	0.994	1.694	2.562	3.834	-	-
	36	6.00	0.428	1.002	1.712	2.584	3.862	-	-
	49	7.00	0.452	1.010	1.728	2.616	3.888	-	-
	64	8.00	0.468	1.024	1.840	2.628	3.918	-	-
	81	9.00	0.478	1.028	1.878	2.638	3.938	-	-
	100	10.00	0.488	1.032	1.934	2.692	3.962	-	-
	121	11.00	0.492	1.082	1.978	2.748	3.980	-	-
	225	15.00	0.518	1.102	2.000	2.818	4.008	-	-
	400	20.00	0.528	1.114	2.038	2.896	4.064	-	-
	1440	37.95	0.572	1.152	2.072	3.024	4.180	3.834	3.410
Net cumulative compression (DH)			0.572	1.152	2.072	3.024	4.180	3.834	3.410
Correction			0.000	0.000	0.000	0.000	0.000	0.000	0.000
Corrected cumulative compression DH			0.572	1.152	2.072	3.024	4.180	3.834	3.410

Specimen Data	
Before Test	
Weight of sample and Ring (gm)	243.2
Weight of ring (gm)	109
Weight of sample(gm)	134.2
Weight of Dry Sample (gm)	103.2
Weight of initial moisture (gm)	30.9
Initial moisture content (%)	29.91
initial void ratio: eo=(Gs/ϒd)-1	1.062
height of solids: Hs=Ho(1+eo) mm	9.701
Initial saturation: So=(Mo*Gs)/eo	67.9

Specific Gravity (Gs)	2.41
Sample Diameter (D) (mm)	75
Sample thickness (Ho) (mm)	20
Area (A) (cm2)	44.18
Volume (V) cm	88.37
Bulk Density (ϒb) (gm/cm3)	1.519
Dry Density (ϒb) (gm/cm3)	1.169

After Test	
Weight of sample + Ring + Can (gm)	246.1
weight of Dry sample +Ring +Can (gm)	212.3
weight of Ring +Can (gm)	109
weight of wet sample (gm)	137.1
Weight of Dry sample (gm)	103.3
Final moisture content	32.72

Over all settlement (mm)	3.41
Volume change (cm3)	15.07
Final volume (cm3)	73.3
Final bulk density (gm/cm3)	1.87
Final dry density (gm/cm3)	1.409

sample diameter (D)	75.00 mm	Height Ho	20 mm
Height of solids	9.701	Initial void ratio (eo)	1.06

void ratio				Compressibility			Coefficient of consolidation		
Pressure (Kpa)	Commutative compression	consolidated height	Void Ratio	Height change	Pressure change	Mv	t90	H	Cv
0	0	20	1.062						
				0.572	49.94	0.573			
50	0.572	19.248	1.003				33.06	19.714	9.97
				0.58	49.94	0.598			
100	1.152	18.848	0.943				47.61	19.138	6.52
				0.92	99.88	0.489			
200	2.072	17.928	0.848				55.88	18.388	5.13
				0.952	199.76	0.266			
400	3.024	16.976	0.75				64.8	17.452	3.99
				1.156	399.52	0.17			
799	4.18	15.82	0.631				259.21	16.398	0.88
400	3.834	16.166	0.666						
100	3.41	16.590	0.71						

3. Consolidation test for natural Black Cotton Soil Test Pit 2

Increment Nº			1	2	3	4	5	-	-
Load	Kg		2.5	5	10	20	40	20	5
Pressure	Kpa		55	111	222	444	888	444	111
Elapsed time			Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm
	t (min)	√ι	ΔH	ΔH	ΔH	ΔH	ΔH	ΔH	ΔH
	0	0.00	0.000	0.644	1.340	2.716	3.904	4.999	4.992
	0.25	0.50	0.122	0.724	1.654	2.864	4.014	-	-
	1	1.00	0.128	0.752	1.682	2.876	4.026	-	-
	2.25	1.50	0.136	0.770	1.712	2.882	4.046	-	-
	4	2.00	0.146	0.792	1.730	2.902	4.071	-	-
	6.25	2.50	0.160	0.804	1.748	2.922	4.099	-	-
	9	3.00	0.174	0.820	1.767	2.952	4.110	-	-
	12.50	3.54	0.192	0.830	1.782	2.974	4.150	-	-
	16	4.00	0.204	0.846	1.798	2.982	4.168	-	-
	25	5.00	0.214	0.870	1.835	2.992	4.228	-	-
	36	6.00	0.228	0.892	1.866	3.002	4.301	-	-
	49	7.00	0.282	0.918	1.902	3.064	4.348	-	-
	64	8.00	0.302	0.938	1.936	3.128	4.418	-	-
	81	9.00	0.330	0.972	1.988	3.162	4.462	-	-
	100	10.00	0.346	0.984	2.018	3.260	4.468	-	-
	121	11.00	0.382	1.012	2.047	3.289	4.473	-	-
	225	15.00	0.446	1.242	2.184	3.314	4.540	-	-
	400	20.00	0.582	1.260	2.684	3.700	4.536	-	-
	1440	37.95	0.644	1.340	2.716	3.904	5.011	4.644	4.136
Net cumulative compression (DH)			0.644	1.340	2.716	3.904	5.011	4.644	4.136
Correction			0.000	0.000	0.000	0.000	0.000	0.000	0.000
Corrected cumulative compression DH			0.644	1.340	2.716	3.904	5.011	4.644	4.136

Specimen Data	
Before Test	
Weight of sample and Ring (gm)	232
Weight of ring (gm)	107.7
Weight of sample(gm)	124.3
Weight of Dry Sample (gm)	85.6
Weight of initial moisture (gm)	38.7
Initial moisture content (%)	45.21
initial void ratio: eo=(Gs/ϒd)-1	1.498
height of solids: Hs=Ho(1+eo) mm	8.006
Initial saturation: So=(Mo*Gs)/eo	73.2

Specific Gravity (Gs)	2.42
Sample Diameter (D) (mm)	75
Sample thickness (Ho) (mm)	20
Area (A) (cm2)	44.18
Volume (V) cm	88.37
Bulk Density (ϒb) (gm/cm3)	1.407
Dry Density (ϒb) (gm/cm3)	0.969

After Test	
Weight of sample + Ring + Can (gm)	228.3
weight of Dry sample +Ring +Can (gm)	193.3
weight of Ring +Can (gm)	107.7
weight of wet sample (gm)	120.6
Weight of Dry sample (gm)	85.6
Final moisture content	40.89

Over all settlement (mm)	4.136
Volume change (cm3)	18.27
Final volume (cm3)	70.09
Final bulk density (gm/cm3)	1.721
Final dry density (gm/cm3)	1.221

sample diameter (D)	75.00 mm	Height Ho	20 mm
Height of solids	8.006	Initial void ratio (eo)	1.5

void ratio				Compressibility			Coefficient of consolidation		
Pressure (Kpa)	Commutative compression	consolidated height	Void Ratio	Height change	Pressure change	Mv	t90	H	Cv
0	0	20	1.498						
				0.644	99.88	0.322			
100	0.644	19.356	1.418				611.33	19.678	1.46
				0.696	99.88	0.36			
200	1.34	18.66	1.293				338.56	19.008	1.37
				1.376	199.76	0.369			
400	2.716	17.284	1.096				428.49	17.972	0.64
				1.188	399.52	0.172			
799	3.904	16.096	0.94				806.84	16.690	0.29
				1.107	799.04	0.086			
1598	5.011	14.989	0.872				428.49	15.543	0.48
400	4.644	15.356	0.873						
100	4.136	15.864	0.906						

4. Consolidation test for Black Cotton Soil + 5% Waste Paper Sludge + 30% Marble Dust For Test Pit 2

Increment Nº			1	2	3	4	5	-	-
Load Kg			2.5	5	10	20	40	20	5
Pressure Kpa			55	111	222	444	888	444	111
Elapsed time			Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm	Cumulative compression mm
	0	0.00	0.000	0.654	1.462	2.510	3.630	4.750	4.330
	0.25	0.50	0.158	0.926	1.826	2.822	3.970	-	-
	1	1.00	0.182	0.952	1.888	2.886	4.032	-	-
	2.25	1.50	0.260	0.982	1.972	2.946	4.078	-	-
	4	2.00	0.282	1.072	2.028	2.992	4.138	-	-
	6.25	2.50	0.318	1.100	2.046	3.048	4.186	-	-
	9	3.00	0.324	1.120	2.068	3.064	4.244	-	-
	12.50	3.54	0.352	1.178	2.090	3.088	4.294	-	-
	16	4.00	0.376	1.248	2.102	3.098	4.384	-	-
	25	5.00	0.388	1.264	2.118	3.142	4.410	-	-
	36	6.00	0.408	1.290	2.148	3.170	4.462	-	-
	49	7.00	0.442	1.328	2.176	3.192	4.510	-	-
	64	8.00	0.478	1.354	2.238	3.242	4.548	-	-
	81	9.00	0.502	1.362	2.284	3.286	4.580	-	-
	100	10.00	0.546	1.372	2.362	3.340	4.604	-	-
	121	11.00	0.576	1.392	2.388	3.372	4.622	-	-
	225	15.00	0.600	1.400	2.448	3.472	4.640	-	-
	400	20.00	0.616	1.414	2.498	3.532	4.694	-	-
	1440	37.95	0.654	1.462	2.510	3.630	4.750	4.330	3.818
Net cumulative compression (DH)			0.654	1.462	2.510	3.630	4.750	4.330	3.818
Corrected cumulative compression DH			0.654	1.462	2.510	3.630	4.750	4.330	3.818

Specimen Data	
Before Test	
Weight of sample and Ring (gm)	240.1
Weight of ring (gm)	108.4
Weight of sample(gm)	131.7
Weight of Dry Sample (gm)	103.4
Weight of initial moisture (gm)	28.3
Initial moisture content (%)	27.37
initial void ratio: eo=(Gs/ϒd)-1	1.162
height of solids: Hs=Ho(1+eo) mm	9.25
Initial saturation: So=(Mo*Gs)/eo	59.68

Specific Gravity (Gs)	2.53
Sample Diameter (D) (mm)	75
Sample thickness (Ho) (mm)	20
Area (A) (cm2)	44.18
Volume (V) cm	88.37
Bulk Density (ϒb) (gm/cm3)	1.49
Dry Density (ϒb) (gm/cm3)	1.17

After Test	
Weight of sample + Ring + Can (gm)	241.6
weight of Dry sample +Ring +Can (gm)	211.8
weight of Ring +Can (gm)	108.4
weight of wet sample (gm)	133.2
Weight of Dry sample (gm)	103.4
Final moisture content	28.82

Over all settlement (mm)	3.818
Volume change (cm3)	16.87
Final volume (cm3)	71.5
Final bulk density (gm/cm3)	1.863
Final dry density (gm/cm3)	1.446

sample diameter (D)	75.00 mm	Height Ho	20 mm
Height of solids	9.25	Initial void ratio (eo)	1.16

void ratio				Compressibility			Coefficient of consolidation		
Pressure (Kpa)	Commutative compression	consolidated height	Void Ratio	Height change	Pressure change	Mv	t90	H	Cv
0	0	20	1.062						
				0.654	99.88	0.327			
100	0.654	19.346	1.092				26.78	19.673	1.13
				0.808	99.88	0.418			
200	1.462	18.538	1.004				40.01	18.942	1.05
				1.048	199.76	0.283			
400	2.51	17.49	0.891				40.01	18.014	6.88
				1.12	399.52	0.16			
799	3.63	16.37	0.77				84.64	16.930	2.87
				1.12	799.04	0.086			
1598	4.75	15.25	0.649				64.8	15.810	3.27
400	4.33	16.67	0.694						
100	3.818	16.182	0.749						