STABILIZATION OF EXPANSIVE SOIL BY USING WASTE PAPER SLUDGE ASH

MSc. THESIS

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ADVISORS' APPROVAL SHEET

This is to certify that the thesis entitled "Stabilization of Expansive Soil by using waste paper sludge ash" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Geotechnical Engineering, the Graduate Program of the School of Civil Engineering, and has been carried out by Bethelhem molla melaku. Id. No PGGeo/ 011/08, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Dr Ing. Henok Fiker	___________________	_________________
Name of major advisor	Signature	Date

DECLARATION

I hereby declare that this MSc thesis entitled "Stabilizing Expansive Soil by Waste Paper Sludge Ash" has been carried out by me under the supervision of Dr.Henok Fikre and has not been presented for a degree in any other university.

BETHELHEM MOLLA

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LIST OF ABBREVIATIONS AND ACRONYMS

AASHTO….. …American Association of States Highways and Transport Officials

ASTM……… ...American Society for Testing of Materials

CBR………….. California Bearing Ratio

ERA………….. Ethiopian Roads Authority

FS…………….Free swell

LL……….….... Liquid Limit

MDD…………. Maximum Dry Density

OMC……….... Optimum Moisture Content

PI…………….. Plasticity Index

PL………..….. Plastic Limit

UCS…………. Unconfined Compressive Strength

USCS………… Unified Soil Classification System

WPSA ………..Waste Paper Sludge Ash

kPa …………….kilo Pascal

gm … …….. . . . Gram

Kg. ……………...Kilogram

Km ………………Kilometer

kN ……………….Kilo Newton

g/cm3 …………….Gram per centimeter cube

kN/m2…………….Kilo Newton per meter square

kPa……………….. Kilo Pascal

mm……………….. Millimeter

ºC ……………….Degree Centigrade

cc ………………. Centimeter cube

µm ………………..Micrometer

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ABSTRACT

Expansive soils occurring in arid and semi-arid climate regions of the world cause serious problems on civil engineering structures. Due to its expansive behavior, they need modification in engineering properties of soil. This study evaluates the suitability of waste paper sludge ash for stabilization of expansive soil. Material of waste paper sludge ash coming from paper factory sludge incinerated under controlled condition. To investigate the effect of adding waste paper sludge ash to an expansive soil, different laboratory experiments such as Atterberg's limit test, free swell index tests, compaction tests, California bearing ratio test and unconfined compressive strength tests were performed for different percentage of waste paper sludge ash. The preliminary investigation of the soil shows that it belongs to A-7-5 class of soil based on AASHTO soil classification system which is clay soil of poor engineering properties. The soil was stabilized with WPSA in stepped concentration of 4 %, 6 %, 8 %, 10 %, 12 % and 14 % by dry weight of the soil and also the effect of curing period was evaluated over a period of four and seven days for Atterberg's limits, compaction, UCS and CBR tests. The results from analysis show improvement of the geotechnical properties of expansive soil with waste paper sludge ash. The plasticity index, free swelling index and OMC reduce with increase in CBR, UCS and MDD value when using 10% waste paper sludge ash.

Keyword: Expansive soil, Waste paper sludge ash, Soil stabilization.

1. INTRODUCTION

1.1 Background of the study

Expansive soil is defined as plastic clay soil that exhibits volume change when its environmental conditions are altered from dry to wet. The degree of expansiveness depends on whether the soil mass contain active minerals or not. This soil type contains clay mineral mainly montomorillonite, that has basic structural unit consisting of an alumina sheet sandwiched between two silica sheets (Chen, 1988).

Expansive soil is difficult to use in the construction of highway, airfields and lightweight structure because such light structure cannot exert the necessary counter load to overcome the swelling. Substantial damage has been occurring in Ethiopia on building and road that are constructed on expansive soil with several economical consequence, physiological effect and loss of proper function of structures (Nebro, 2002). Soil properties have to be studied in detail and improvement of these properties using different chemical gives good result to solve problems encountered in many infrastructures due to the behavior of expansive soil. The researchers report admixtures such as molasses, fly ash, liquid enzymes, have been used to improve or stabilize soil properties. In this research one of the waste materials, waste paper sludge ash is used as stabilizing agent.

Waste paper sludge ash is obtained from paper industry by incineration from waste paper sludge and also formed during the recycling of paper by removing pin, sands and by delinking the paper. It contains kaolinite which on heating at high temperature becomes metakaoline. This metakaolinite helps to reduce swell and increases the engineering properties of soil (Norazlan, Mazidah, Faizahka, 2012).

Construction materials produced from natural resources have now become limited and are causes of air pollution and environmental problems. Waste paper sludge ash can be used as stabilizer of expansive soil. The researchers reported that stabilization of soils using construction materials like lime and cement is effective but the cost is high. For this reason researchers focus more on the cheap and locally available material such as waste paper sludge ash, sugarcane straw ash, fly ash, rice husk ash, etc. as stabilizing agents for the purpose of full or partial replacement of traditional stabilizers like cement and lime. So here in this research waste paper sludge ash is used as stabilizing material for expansive soils. Currently in Ethiopia there are a small number of paper factories and the amount of waste products found from these factories is insignificant to use for stabilization but in the near future there will be many paper factories in the country and use of wastepaper sludge ash as a stabilizing material will be consistent. This research is to establish the effects of waste paper sludge ash on expansive soils.

1.2 Statement of the problem

Large portion of Ethiopia is covered with expansive soil which is cause for many structural failures particularly light weight structures like Addis Ababa to Jimma road (Nebro, 2002). Due to the property of expansive soil that reduced service life and increased the maintenance cost. The particular area of the research Modjo and Ejere city in rapid development and fast population increment. This lead to construction of many infrastructures either by replacing expansive soil with selective material or deep foundation that lead to high construction and maintenance coast.to reduce this problem modify the properties of locally available soil with a cheaper stabilizer to the extent that it can be used in construction and make the best utilization of various industrial wastes like waste paper sludge ash as soil stabilizing agent.

1.3 Objective

1.3.1 General objectives

The main objective of this study is to evaluate the suitability of waste paper sludge ash as stabilizer material of expansive soil in the area from Modjo to Ejera road.

1.3.2 Specific Objectives

- To evaluate the effect of waste paper sludge ash on the properties of the expansive soil using, index properties, swelling capacity and strength of expansive soil by using CBR.
- To compare the changes in properties of expansive soil with respect to waste paper sludge ash stabilized soil.
- To determine the optimum concentration percentage of waste paper sludge ash as additives based on the compressive strength.
- To provide an economical solution for soil stabilization using WPSA.

1.4 Scope

This thesis emphasizes on the stabilization of expansive soil using waste paper sludge ash by conducting laboratory tests such as, water content, free swell, specific gravity, gradation, Atterberg's limits, compaction, unconfined compression and California bearing capacity.

In this study the chemical composition of the stabilizing material waste paper sludge ash is not conducted and the strength properties to be improved are California bearing ratio and unconfined compression strength. Mainly this is due to financial capacity.

1.5 Significance of the study

The problem of expansive soil is worldwide problem that affects the development of a country (Chen, 1988). To reduce the effect of expansive soils different mechanisms have been applied like replacing with selected material, designing good foundation systems that counter balance these effects and using different type of stabilizers on the expansive soil. This study helps to show new locally available material as a stabilizer of expansive soil by increase service life of the structure.

2. LITERATURE REVIEW

2.1 Genesis of Expansive Soils

The origin of expansive soils is related to a complex combination of condition and processes that result in the formation of clay minerals having a particular chemical makeup which, when in contact with water, will expand. Variations in the conditions and processes may also form other clay minerals, most of which are non-expansive. The condition and processes which determine the clay mineralogy include composition of the parent material and degree of physical and chemical weathering to which the materials are subjected (Chen, 1988).

Expansive soils contain clay mineral montmorillonite that formed from two separate origins. The product of weathering and erosion of rocks in the highlands were carried by streams to coastal plains. The fine grained soils eventually became shale accumulating in the ocean basin. Meanwhile volcanic eruptions, sending up clouds of ash, fell on the plains and seas. Finally, these ashes were altered to montmorillonite (Guyer, 2011).

Expansive soils mainly black cotton soils covers about 40% area of Ethiopia. Due to this foundation on expansive soils area subjected to differential movement and heave, also sub grade and sub base of roads are poor since they lay on this expansive soils and it affects the construction economy (ERA, 2002).

2.2 Parent material

The parent material associated with expansive soils may be classified in to two groups. The first group comprises the basic igneous rocks, which are low in silica, generally about 45% to 25%, such as basalt, dolerite sills and dykes, gabbros, where feldspar, amphiboles, biotitic, olivine and pyroxene minerals of the parent rock decomposes to form Montmorillonite. The second group includes sedimentary rocks like shale’s and claystone, and limestone and marls rich in magnesium that contain Montmorillonite, and break down physically to form expansive soils. (Chen, 1988).There are indications that confirm that the expansive soils of Ethiopia are derived from both groups (Teklu, 2001).

2.3 Identification and classification of expansive soil

A major concern in geotechnical engineering is identification of expansive soils, either in the field or laboratory, and estimation of their properties.

2.3.1 Filed identification

It is easy to recognize expansive soils in the field during either dry or wet seasons. Their color varies from dark grey to black. During dry seasons, shrinkage cracks are visible on the ground surface with wide or deep cracks reaching into the ground. A shiny surface is easily obtained when a partially dry piece of the soil is polished with a smooth object such as the top of a finger nail. During rainy seasons, these soils become very sticky and very difficult to traverse. Appearance of cracking in the nearby structures is also indicative (Chen, 1988).

2.3.2 Laboratory method of identification

The behavior of expansive soil can be best predicted by examining combination of physical, chemical, and mineralogical soil properties. Briefly studied on the properties of expansive soil under this method as stated in (Al-Rawas and Goosen, Bizualem, Teferra.).

2.4.2.1 Mineralogical identification

This helps for identifying the mineralogy of clay particles such as characteristic crystal dimensions, characteristic reaction to heat treatment, size and shape of clay particles and charge deficiency and surface activity of clay particle. The clay mineral in expansive soil can be identified by variety techniques like, X-ray diffraction, differential thermal analysis, dye adsorption, chemical analysis, and electron microscope resolution. But, the methods are not suitable for routine tests due to expansiveness and time consuming.

2.4.2.2 Indirect method

This helps to investigate the swelling potential of a soil by examining commonly used index property tests (consist of Grain size analysis, liquid limit, plastic limit, shrinkage limit, free swell and vertical swell). Also Cation Exchange Capacity and Potential Volume Change test can be used.

i. Atterberg's limit

Atterberg's limits is the moisture content boundaries between states of consistency of fine grained soils. The useful indices computed from the Atterberg's limits are plasticity index and liquidity index. The plasticity index used extensively for classifying expansive soils and should always be determined during preliminary investigation (Nelson and Miller, 1992).

Table 2. 1 Relation between swelling potential of clays and plasticity index (Chen.1988)

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

ii. Free Swell Test

Free Swell Index is the increase in volume of a soil, without any external constraints, on submergence in water. This test is carried out by taking two representative oven dried soil samples each of 10 grams passing through 425-micron sieve and Pour each soil sample in to each of the two glass graduated cylinders of 100ml capacity. Fill one cylinder with kerosene and the other with the distilled water up to the100ml mark and Remove the entrapped air in the cylinder by gentle shaking and stirring with a glass rod. Allow the samples to settle in both the cylinders. Sufficient time, not less than 24 hours shall be allowed for soil sample to attain equilibrium state of volume without any further change in the volume of the soils then record the final volume of the soils in each of the cylinders (ASTM).

Free swell (%) = $\frac{vd-vk}{vk} * 100$ (2.1)

Where:

Vd = Volume of the soil specimen read from the graduated cylinder containing distilled water.

Vk = Volume of the soil specimen read from the graduated cylinder containing kerosene.

2.2.4.3. Direct method

Here the actual measurement of volume change in an odometer-type testing apparatus is generally grouped into swell or swell pressure tests. These testing methods are necessary to obtain measurable properties for predicting or estimating the magnitude of volume change the material will experience in order to ascertain approximate treatment and/or design alternatives.

2.4.3. Classification of expansive soil

The classification system used in expansive soil can be grouped into two categories as follows,

2.4.3.1 General classification

I. AASHTO Classification

The classification depends on liquid limit and plastic index of the soil. Based on this group2. A-6 and A-7 are classified under clayey soil which is potentially expansive having the LL value as a limit of 40 maximum and 41 minimum and also the PI value as limit of 11 minimum .

II. Unified soil classification system

As per the USCS all clay and organic soils which undergo high volume change (CL, OL, CH, and OH) are expansive soils.

2.4 Waste paper sludge ash

Waste Paper sludge ash is incinerated from Waste paper sludge. The chemical composition of WPSA have been investigated using X-rays Fluorescence (XRF) test analysis (Norazlan.K,2012).The laboratory result for physical properties of WPSA has shown that the specific gravity of WPSA is about 1.65 and it can be considered as light materials. The result of particle size shows, about 0.08% of sand sizes and 99.92% of fine or silt size. It indicates that the WPSA considered a silt size. According to ASTM C618, the requirement for fly ash WPSA classified as Class-C fly ash because the total combination percentage composition for major constituent components such as silicon dioxide (SiO_2), Aluminum oxide (Al_2O_3) and Iron oxide (Fe_2O_3) more than 70 percent. Instead this Class-C of WPSA considered as higher of calcium fly ash of Calcium Carbonate or free Lime content (CaO) about 62.39%. Class-C fly ash provides an in expensive source of high quality soil stabilizing agent because of the self-cementing characteristics (RBarani, 2016).

2.4.1 Chemical Properties

The principal constituent present in waste paper sludge ash are lime and silica. The amount of the other major element were low (less than 2 %), except magnesium oxide. Therefore it contains also Aluminum trioxide, ferric trioxide, magnesium oxide, potassium oxide. The material of sludge change to sludge ash by dewatering at low temperature and incineration at high temperature (> 800 ºC).CaO, Al_2O_3, MgO and SiO_2 are the most abundant oxides in paper sludge ash that found the presence of CaO in WPSA has both negative and positive concerns for the use of WPSA as hydraulic binder (Shishir Kumar Sikder Amit, Mohammad Rafiqual Islam, 2016).

2.5 Soil Stabilization

Soil Stabilization is the alteration of one or more soil properties, by mechanical and chemical means, to create an improved soil material possessing the desired engineering properties. The process may include blending of soil to achieve a desired gradation or mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil (Teferra, 2011).

2.5.1 Types of soil stabilization

Classified soil stabilization in two: mechanical stabilization and chemical stabilization.

2.5.1.1 Mechanical stabilization

Mechanical stabilization can be defined as a process of improving the stability and shear strength characteristics of the soil without altering the chemical properties of the soil. The main methods of mechanical stabilization can be categorized into compaction, mixing or blending of two or more gradation, applying geo-reinforcement and mechanical remediation (Guyer, 2011).

2.5.1.2 Chemical stabilization

Soil stabilization using chemical admixtures is the oldest and most widespread method of ground improvement. Chemical stabilization is mixing of soil with one or a combination of admixtures of powder, slurry or liquid to improve or control its stability, strength, swelling, permeability and durability. Soil improvement by means of chemical stabilization can be grouped into three chemical reactions; cation exchange, flocculation-agglomeration and pozzolanic reactions (Nebro, 2002).

a) Cation Exchange

Clay minerals have the property of absorbing certain anions and cations and retaining them in an exchangeable state. The exchangeable 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. Negatively charged clay particles adsorb cations (positive ions) 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 the hydrated ion becomes 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 replace ability series is:

$Na^{+}<Li^{+}<K^{+}<Rb^{+}<Cs^{+}<Mg^{2+}< Ca^{2+}<Ba^{2+}<Cu^{2+}<Al^{3+}<Fe^{3+}< NH_4^{+}$

An example of the cation exchange;

$Ca^{2+} + Na^{+}\text{-Clay} \rightarrow Ca^{2+}\text{-Clay} + Na^{+}$

The thickness of the diffused double layer decreases as replacing the divalent ions (Ca^{2+}) from stabilizers with monovalent ions (Na^{+}) of clay. Thus, swelling potential decreases. The exchangeable cations may be present in the surrounding water or be gained from the stabilizers.

b) Flocculation and Agglomeration

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. Due to change in texture, significant reduction in the swelling of the soil occurs

c) Pozzolanic Reactions

Time dependent 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 hydrate (CAH).

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

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

The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystallizes to form an interlocking structure which increases the soil strength.

2.6 Previous studies on stabilization of expansive soil

Sharan Veer Singh and Mahabir Dixit (2017), studied stabilization of expansive soil using waste plastic material in India. The tests such as liquid limit, plastic limit, standard proctor compaction test, California bearing ratio test and unconfined compressive strength have been conducted to check the stability of expansive soil. The conclusions and findings drawn from the studied are;

- The plastic inclusions can improve the strength thus increasing the soil bearing capacity of the soil.
- One of the solutions is use of plastic waste in soil reinforcement and stabilization.
- The results are better and more durable with a higher strength and reduction of permeability of the soil.
- Sub-base thickness can be significantly reduced if waste plastic is used as soil stabilizing agent for sub grade material.
- UCS of black cotton soil increased on addition of plastic waste. When 4.5 % plastic waste was added, 287.32 KN/m2 soil strength of the soil was obtained which was more than untreated soil.

Akinyele, Salim, Oikelome, Olateju (2015), studied stabilization of expansive soil by using of rice husk ash in Gboko, Nigeria. Physical test such as particle size distribution, Atterberg's limits test, and density test were carried out on the mix material. The conclusions and findings drawn from the studied are;

- The addition of rice husk ash to lateritic clay improved the index property and particle size distribution of the soil and this qualifies the rice husk ash as a good stabilizing agent, for sub grade in road construction and for back filling in retaining wall, but the mix should be controlled not to exceed 10%. Also the various soils-ash mixes used in this study are suitable materials for hydraulic barriers.

Meron (2014), studied stabilization of expansive soil by addition of bagasse ash on expansive clay soil from Addis Ababa,Bole sub city around Medhanialem. The experiment study involved index properties, strength parameter and swelling pressure of soil with bagasse ash were determined using Atterberg's limit test, moisture-density relations, free swell, free swell index and California Bearing Ratio tests. The conclusions and findings drawn from the studied are;

- The plasticity index slightly reduced with increased in bagasse ash content and curing has also an insignificant effect on the plasticity of the expansive soil. The optimum moisture content increased while the maximum dry density values decreased with increment of bagasse ash content.
- Free swell, free swell index and free swell ratio of the stabilized samples decreased with increasing bagasse ash content.
- CBR values slightly increased with the addition of bagasse ash.
- The addition of bagasse ash in combination with lime improved the CBR value. The stability is more significant when the sample is cured. Hence, combination of bagasse ash and lime can strongly improve the strength of the expansive soil.

Bizualem (2015), studied stabilization of expansive soil by addition of sugar cane molasess and cement on expansive soil from Mojo-Ejere-Areti-Sembo Road project areas. Index properties and strength parameter of soil with sugar cane molasess and cement were determined using Atterberg's limit test, moisture-density relations, swell, California Bearing Ratio tests and unconfined compression strength. The conclusions and findings drawn from the study are;

- The engineering property of the studied expansive clay soil revealed that it is not suitable to use as a sub-grade and/or embankment fill material unless its undesirable properties are rectified.
- Soil treated with molasses showed substantial improvement. Soil treated with 8% molasses, gave CBR value of 10.4% from a value of 1.3% of the native soil and the CBR swell of 2.3% from 9.8% of the natural soil showed that strength of the expansive soil substantially improved and swelling potential decreased considerably.
- Soil treated with cement by 4%, 8% and 12% by dry weight of the soil showed significant improvement in strength and satisfactorily minimized swelling property of the native soil. Generally it was observed that with increasing cement content, strength improved and swelling potential decreased. Even though; addition of cement reduced PI and linear shrinkage values, shrinkage cracks were observed at all the three stabilizers contents.

· Tesfaye (2001), studied stabilization of expansive soil by addition of lime and cement on black cotton soil from different parts of Addis Ababa. Index properties, characteristics and swelling pressure of soil-cement and soil-lime were determined using Atterberg's limit test, moisture-density relations, free swell and swelling pressure tests. The conclusions and findings drawn from the study are;

- Expansive soil becomes moderately active to inactive based on the amount of lime and cement added.
- Swelling pressure of expansive soil decreases with increasing lime, cement and molding water content.
- 4-6% of lime and 9-12% of cement yielded significant improvement on plasticity and swelling properties of expansive soils.

Nebro (2002), evaluated lime and liquid stabilizer called Con-Aid for stabilization of potentially expansive subgrade soil on samples collected form Addis-Jimma road which had indicated different pavement damages exacerbated by the presence of expansive soils. The experimental study involved Atterberg limit test, moisture-density relation, UCS, CBR and CBR swell. The findings and conclusions of the study can be summarized as follows:

- Addition of lime reduced maximum dry density and increased the optimum moisture content.
- 4% of lime by dry weight of the soil was optimum lime content to stabilize the soil even though increased quantity of lime led to increased strength.
- Addition of lime reduces the swelling potential but no significant improvement in the engineering properties of the soil was attained by addition of Con-Aid.

In stabilizing soil by molasses to improve the properties of soil experimentation work is done by adding industrial waste is molasses in different percentage to the soil. The addition of 6.5% of molasses in soil, increased value of liquid limit, plastic limit and plasticity index of modified soil is reduced. In the same manner California bearing ratio increased due to increased density of soil which is gained by proper rearrangement of soil particles and also use of 8% molasses increased the California bearing ratio and reduced the swelling tendency of the soil (Bizualem, 2015).

The uncured CBR from a natural soil with a value ranging from 11.83% to 6.07%, lime, 15% bagasse ash and 3% lime plus 15% respectively. For 7 days curing period the CBR-swell decreased from the natural soil value of 11.83% to 0.95%, and to 0.26% with the addition of 3% lime, 15% bagasse ash respectively. This shows that the swelling capacity of the expansive soil decreased considerably with bagasse ash and lime treatment and curing has also a significant effect on the CBR-swell values (Meron.W, 2012).

This paper focuses on determining the stabilization of expansive soil by adding WPSA through laboratory tests. Addition of 10% WPSA is improves unconfined compressive strength and also increase the CBR value of unsoaked condition than soaked condition compared with untreated soil sample.

3. MATERIALS AND METHODS

3.1 General Description of the study area

The study area covers the road segment from Modjo to Ejere which falls dominantly in flat terrain based on the literature and the sample conducted on the end of mojo town. The road segment is located in the central part of the country and in Oromiya regional states, it has a latitude of 8º39'N 39º5'E with an elevation between 1788 and 1825 meters above sea level (Bizualem.T). Currently there is no road project but in Modjo road segment is placed as severely damaged sections because of expansive soils are predominant in the area and while taking the samples, same indication of cracks which were leading to complete failures of roads haven been considered.

Figure 3.1: Location of expansive soil sample

3.2 Materials used in the research

3.2.1 Expansive soil

Expansive soils are soils that show considerable volume change with change in moisture content. This is due to the swelling that takes place with increased moisture content and conversely shrinkage by decreased moisture content. The soil sample used for this study is a grayish black clay soil obtained from a single test pit in start of Modjo to Ejere road. A disturbed soil sample was collected from the single test pit at depth below 1.5 m in order to avoid the inclusion of organic matter.

3.2.2 Waste paper sludge ash

Waste paper sludge ash is the product that is formed during the recycling of paper by removing pins, sands and by delinking the paper using rotary screen. The paper sludge contains roseine mineral that have aluminum sulfate and waste paper sludge contains kaolinite mineral. The waste of this sludge which on heating at high temperature becomes metakaoline. This metakaolinite contain silica oxide, Calcium oxide and Aluminum oxide that helps to reduce swell as much as possible and increases the soil properties (RBarain,2016) .The stabilizer take from Anmol paper factory in Ginch town around 80 km to the waste of Addis Ababa. They have no disposal system and the waste paper sludge contains the chemical which affect the environment.

Figure 3.2: Waste paper sludge ash (left) and incineration of sludge (right)

3.3 Testing Procedure

3.3.1 Sample Preparation

Before treatment and testing, the sample was prepared in accordance with the method described in AASHTO T87-86 and ASTM. This method involves:

- Air drying of sample and/or oven drying the soil at 60 degree centigrade.

- Sieve analysis is performed to separate the dried soils into two groups. The first group is used in preparing uniform samples for Atterberg's limits, free swell ratio tests and the other for compaction, California bearing ratio and unconfined compression tests.
- The waste paper sludge incinerate at the temperature of 1000 Celsius in ferns. Then, soil and waste paper sludge ash is mixed manually to get uniform mix ratio for each test.

Figure 3.3: Manual mixing of Waste paper sludge ash and expansive soil

3.3.2 Particle Size Distribution

The test conducted in accordance with ASTM D 854-00 and AASHTO T88.500 gram of sample take for wet sieve soak more than an hour washing using No 200 it become clear. Then, measure the sample in the container showing the distribution of the soil particles in soil mass than classify the soil. And also 50 gram of dry soil passing in No 200 sieve is treated with a sodium hexameta phosphate dispersing agent for 18 hour. This analysis measures the amount of silt and clay size particle.

3.3.3 Specific Gravity

The test conducted in accordance with ASTM D 2216 and AASHTO T-100 Values for specific gravity of the soil solids were determined by placing a known weight of oven-dried soil in a flask, then filling the flask with water. The weight of displaced water was then calculated by comparing the weight of the soil and water in the flask with the weight of flask containing only water. The specific gravity was then calculated by dividing the weight of the dry soil by the weight of the displaced water

Figure 3.4: Specific gravity test

3.3.4 Water Content

The test is conducted in accordance with AASHTO T265 and ASTM D 4318. Small representative sample of the natural soil and soil-waste paper sludge ash mixture specimens are obtained and oven-dried at 105 ± 5°C for at least 16 hours. The samples were then reweighed, and the difference in weight was assumed to be the weight of the water driven off during drying. The difference in weight was divided by the weight of the dry soil, giving the water content of the soil a dry weight basis.

3.3.5 Atterberg's Limit Test

The test conducted in accordance with ASTM T-89 and ASTM D4318-95.The soil sample for liquid limit is air dried and 200 gram of the material passing through No. 425μm apparatus was obtained and thoroughly mixed with water to form a homogeneous paste on a flat glass plate. A portion of the soil water mixture is then placed in the cup of the Casagrande's apparatus, leveled off parallel to the base. The cup is then lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove. The values of the moisture content determined and the corresponding number of blows is then plotted on a semi-logarithmic graph and the liquid limit is determined as the moisture content corresponding to 25 blows.

The soil sample for plastic limit is air dried and material passing through No. 40 sieve (425μm aperture) each of the parts is rolled into a thread between the first finger and the thumb. The thread is then rolled between the tip of the fingers of one hand and the glass. This continued until the diameter of the thread is reduced to about 3mm.

The plasticity index of the natural soil and the soil–bagasse ash mixture is the difference between the liquid limits and their corresponding plastic limits. The plasticity indexes of the samples are calculated as:

$$PI = LL - PL \qquad (3.1)$$

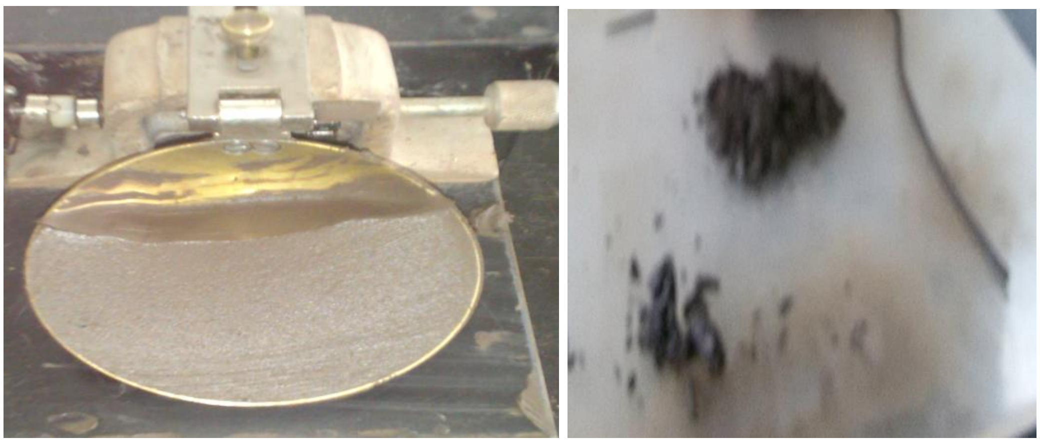


Figure 3.5: Liquid limit (left) and Plastic limit (right)

3.3.6 Compaction Test

The test conducted in accordance with ASTM T 99-94 and ASTM D698-91.The maximum dry density is conducted for both the natural and soil-waste paper sludge ash mixture of about 2.5kilogram, by varying the moisture content. The sample is then compacted into the 944 cubic centimeters in three layers of approximately equal mass with each layer receiving 25 blows. The blows are uniformly distributed over the surface of each layer. The collar is then removed and the compacted sample leveled off at the top of the mold with a straight edge. The mold containing the leveled sample. One small representative sample is then taken from the compacted soil for the determination of moisture content. Before done the compaction methods of mixing were followed, i.e. wets mixing and dry mixing based on the nature of the stabilizers so the nature of stabilizer was dry. Amount of stabilizers (WPSA) which are 4%, 6%, 8% and 12% by dry weight of the soil were measured and placed in air tight container to avoid the effect of carbonation and atmospheric moisture. For each proctor test five runs were conducted by increasing water content 4% of the preceding tests using 8% water content an initial run. This series of determinations was continued until there was either a decrease or no change in the wet unit mass (gram per centimeter cube) of the compacted soil-stabilizer mixture.

3.3.7 Free Swell Index Test

The test conducted in accordance with ASTM D 4829-95.Two samples of oven dried soil 10cc each, passing through 425 micron sieve are taken and the waste paper sludge ash take in soil percent started from 4% increment by 2% up to 12%. One is put in a 100cubic centimeters graduated glass cylinder containing kerosene. The other sample is put in a similar cylinder containing distilled water. The samples are left undisturbed for 24 hours and then their volumes are noted, then free swell index is determined.

3.3.8 California Bearing Ratio Test

The test conducted in accordance with AASTO T193 (1995).The specimen was prepared by compacting soil-stabilizer mixtures in 2124 cubic centimeters CBR mold. The mold height was divided into equal three thicknesses and soil-stabilizes mixtures for one mold were divided into equal three parts by mass. Each equal three layers were compacted into the molds by giving 56 blows for one point CBR tests for each prescribed stabilizers content. Each layer should occupy about or a little more than one-three-D of the height of the mold. Ensure that the blows are evenly distributed over the surface. The final level of the soil surface should be about 5-10 mm above the top of the mold body. The extension collar was removed, and using a straightedge, the compacted soil was trimmed even with the top of the mold. Surface irregularities were patched with small-sized material. The spacer disk was removed and a coarse filter paper was placed on the perforated base plate. The compacted specimen was ready for soaked in 96 hours in water bath to get the soaked CBR value and the CBR swell of the soil. The CBR swell of the soil is measured by placing the tripod with the dial indicator on the top of the soaked CBR mold.

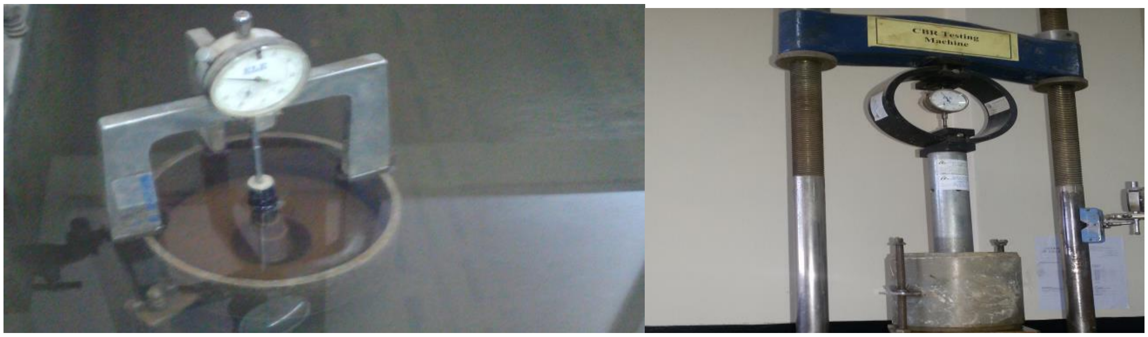


Figure 3.6: CBR Test Procedure: soaked CBR and CBR penetration.

3.3.9 Unconfined Compression Strength Test

The test conducted in accordance with AASTO T-208.the Samples were compacted in proctor compaction mold. The compaction procedure was using 2.5 kg rammer, applying 25 blows evenly distributed blows to each of the 3 equal thick layers. After the specimen was formed, it was extruded from the Shelby tube sampler and cut height-to-diameter ratio of 2. The mass of the specimen, the length of specimen, and diameter of the specimen at mid height were determined and recorded. Having determined the mass and dimension of the specimens, then it was placed in the loading device. A strain rate of 2 percent per minute was used with measurements taken every 10 divisions on deformation until the load values decreased with increasing strain. The specimen was removed from the compression device and a sample for water content determination was taken.

Figure 3.7: UCS Test: specimen with compression device.

3.4 Curing Time of Stabilization Expansive Soil

Curing times of 1, 4, and 7 days were used in this research. The samples for each curing time were prepared in order to provide sufficient data for accurate results. Additional curing times beyond this days for the test of soils treated with waste paper sludge ash was desired in some cases to see the changes in strength. The selecting curing day only show the effect of the result to be cured.

4. RESULTS AND DISCUSSIONS

This chapter presents the result of laboratory tests in stabilize of expansive soil with different percent of waste paper sludge ash at different curing time by varying percent of stabilizer from 4% to 14% by increments of 2%. Results are summarized and represented in graph and tables discussed below.

4.1. Properties of Natural Soil

The properties of the natural soil before applying waste paper sludge ash is presented in Table 4.1. The soil is grayish black in color. As shown the table, the particle size distribution analysis test results 92.38% soil is passing through 0.075 mm sieve; the liquid limit, plastic limit and plasticity index of the native soil are 87%, 36% and 51% respectively. Hence, this value indicates that the soil is highly plastic clay. According to AASHTO soil classification system the soil falls under A-7-5 group. The liquid limit and plasticity index values are very much greater than the Ethiopian roads authority's requirements, i.e., liquid limit less than 60% and plasticity index less than 30%. Results that are related to swelling characteristics of the soil also indicate that the soil is highly expansive clay with a free swell index of about 104%. It has a maximum dry density of 1.201 g/cm3, optimum moisture content of 33.6 %, soaked CBR value of 2.13%, CBR swell was 5.02 %. This value indicate that the soil has very low bearing capacity and high swelling potential when compared to Ethiopian road authorities specifications of CBR greater than five.

According to ERA design manual the laboratory results of the soil sample do not fulfill the requirement as layer of sub grade .Therefore, the layer of soil should be treated with appropriate improving methods before use as sub grade layer. This can be done by different soil improvement techniques including removal of the soil and replacement with suitable material, chemical stabilization, compaction, pre-wetting and making the appropriate pavement designs that considers the unsuitability of the soil. These results have been summarized in table 4.1.

Table 4. 1Geotechnical properties of the natural soil

Property	Quantity
Percentage Passing in 0.075 mm sieve,%	92.380
Liquid limit,%	87.000
Plastic limit,%	36.000
Plasticity index,%	51.000
AASTHO soil classification	A-7-5
Specific gravity	2.660
Free swell index,%	104.000
Maximum dry density/cm3	1.201
Optimum moisture content,%	33.600
Soaked CBR value,%	2.130
CBR swell,%	5.020

4.2. Effect of Stabilizer on Expansive Soil

4.2.1. Effect of Waste Paper Sludge Ash on Atterberg's Limits

The tests were performed to determine liquid limit, plastic limit and plastic index according to AASTHO T-89 and T-90. The soil samples where first air dried and prepared with soil passing 0.475mm sieve by increasing the percent by weight of stabilizer and varying its curing time to show the effect on stabilization.

Sample of soil mix with waste paper sludge ash showed highest reduction in PI when they are treated with 12% waste paper sludge ash which is 47.05% reduction compared to untreated soil. After the addition of 12% waste paper sludge ash it increases the plastic index to31%. So this indicates that 12% is optimum value for waste paper sludge ash. And also the result of liquid limit showed slight decrease and increase of plastic limit with increment of the stabilizer. The decrease and increase value of the LL and PL was small due to curing. So the time of curing affects the reaction of stabilizer with soil.

According to the results observed from the laboratory test, the behavior of soil sample was changed from very high plasticity soil to medium plasticity soil. These effects are due to the partial replacement with waste paper sludge ash which is non-plastic material and flocculation and agglomeration of clay particles caused by cation exchange may be the other. Generally the effect of stabilizer at different curing day improved the behavior of the soil to be used as layer of pavement by decreasing LL and PI of as the percent of stabilizer increasing up to 12%.

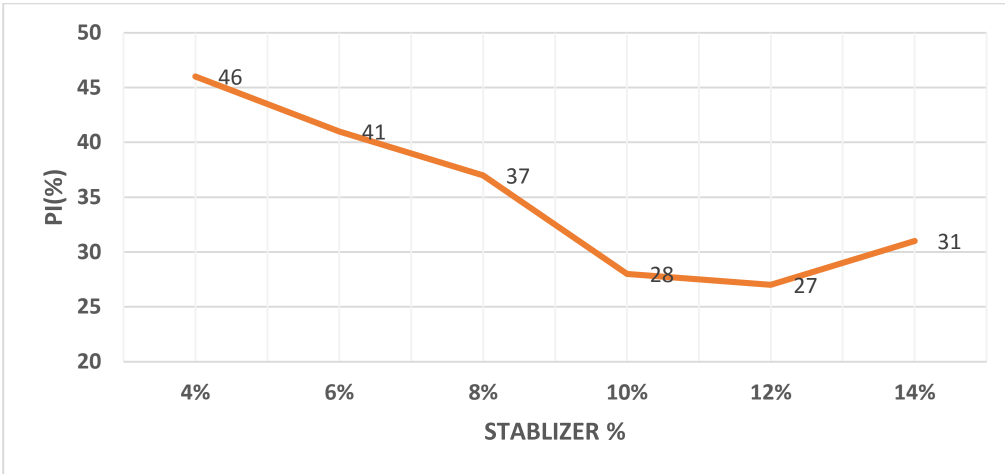


Figure 4.1: plastic index as percent of stabilizer increase

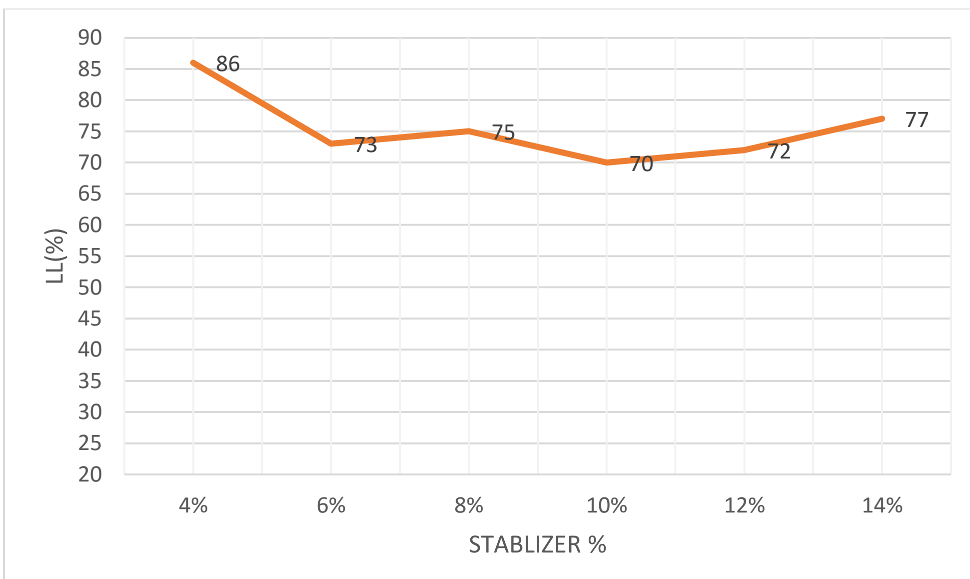


Figure 4.2: liquid limit with increment percent of stabilizer in four day curing

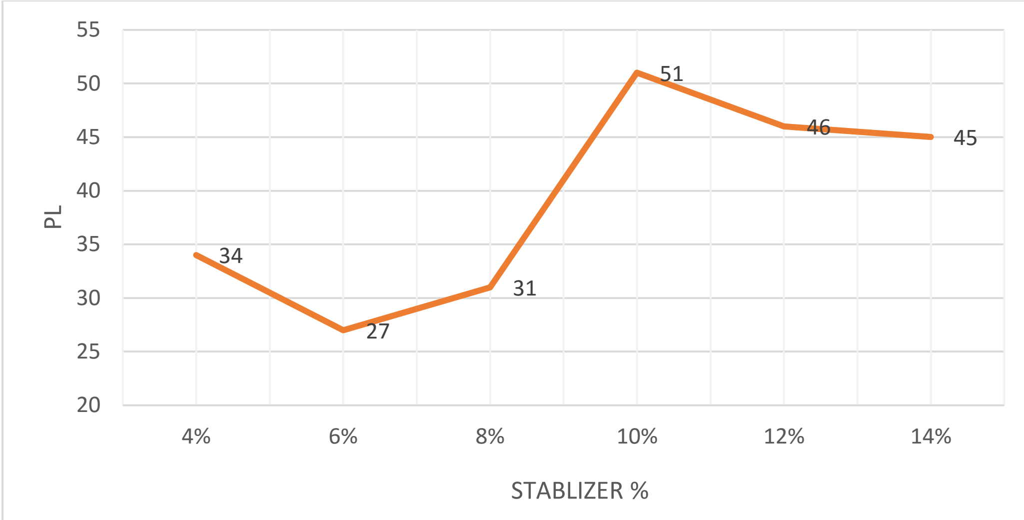


Figure 4.3: Plastic limit with increment percent of stabilizer

4.2.2. Effect of Waste Paper Sludge Ash on Free Swell Index

The free swell index test is performed on untreated and treated soil sample at different proportion by dry weight of soil sample. Addition of waste paper sludge ash on soil sample change on free swell index. The result of free swell index decreased from 104% to 30.77%.this result was achieved at 12% of waste paper sludge ash to proportion to the soil sample, which shows about 70.4% decrease in the free swell index. The result indicate highest reduction of free swell index. When using of more than 12% wpsa it increase the swell so, 12% of wpsa is the optimum value for decreasing of soil swelling.

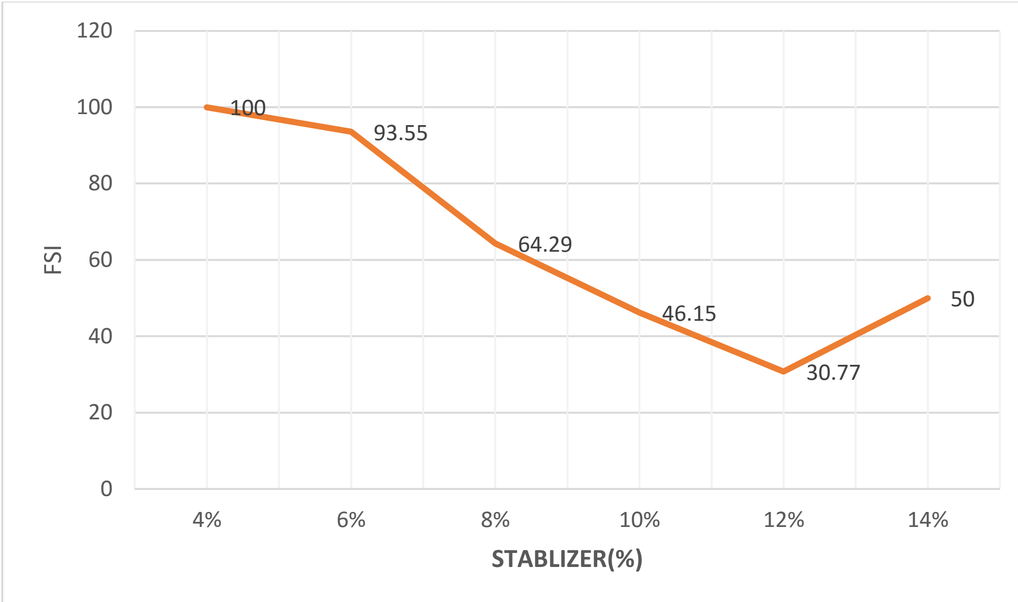


Figure 4.4: Free swell index with varying percentage of waste paper sludge ash

4.2.3. Effect of Waste Paper Sludge Ash on the Compaction of Characteristics

To determine optimum moisture content and maximum dry density of the expansive soil with stabilizer were performed according to ASTM D698 at different percentage of WPSA. The effect of waste paper sludge ash on the maximum dry density of expansive soil is shown in different cured time. Figure 4.5 and Figure 4.6 shows that increase density and decrease in moisture content up to 10%WPSA.

The addition of WPSA increase the maximum dry density of the natural soil from 1.201 g/cm3 to 1.33 g/cm3 at 10% of WPSA. The result indicate 9.7% of dry density of natural soil is increase after using of the stabilizer. And also optimum moisture content of the natural soil with waste paper sludge ash change from 33.6% to 27.5%.

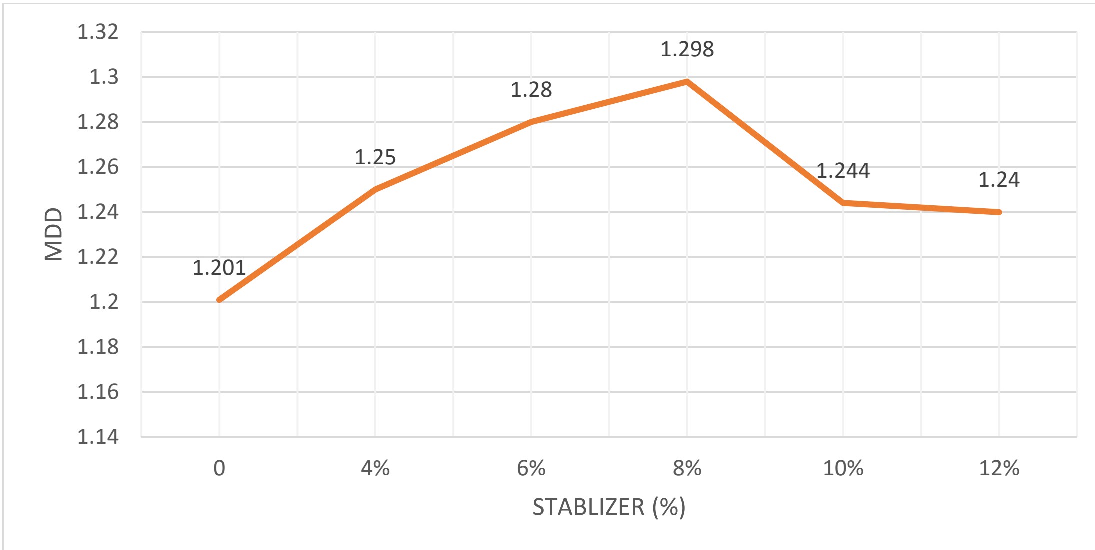


Figure 4.5: Variation of MDD with application of different percent of WPSA in 4 day cured

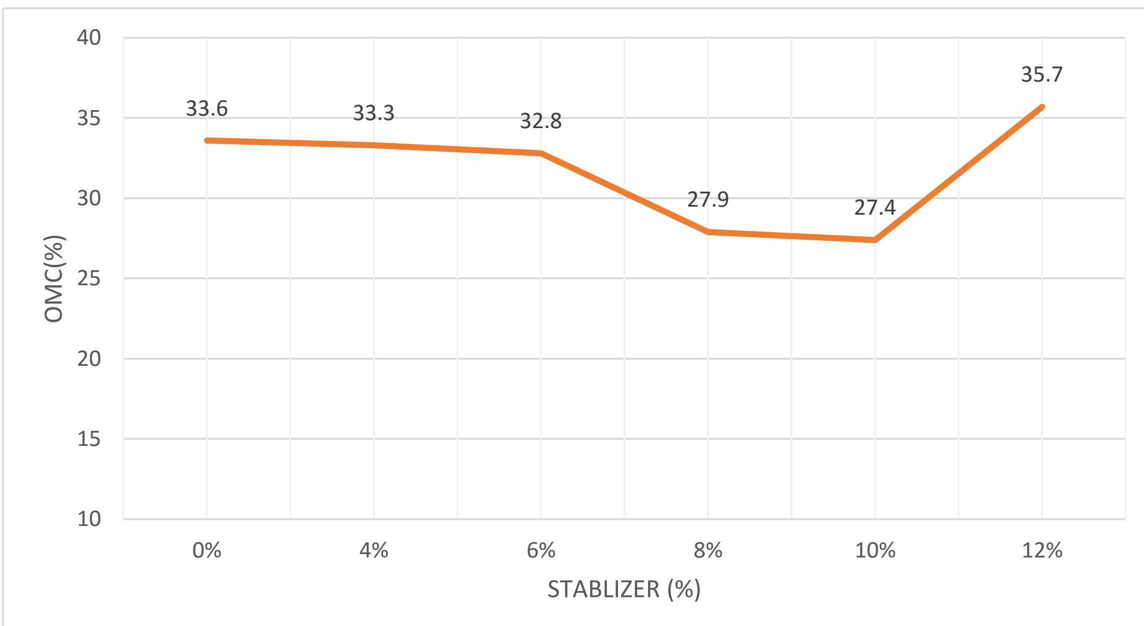


Figure 4.6: Variation of OMC with application of different percent of WPSA in 4 day cured

Generally natural soil MDD increased and OMC decreased up to 10% WPSA. This increase in density may be associated with rearrangement of the flocculated and agglomerated clay particles in smaller space due to the presence of more plastic paste in soil –waste paper sludge ash mixtures. The increased OMC is obtained from the effect of the increased size of clay particles that turned the fine soil to coarse soil because the stabilizer coated the soil particle so change the fine particle to course soil.

4.2.4. Effect of Waste Paper Sludge Ash on UCS Values

Unconfined compression test is quick and simple testing to determine the compressive strength. The samples were mixed and compacted at maximum dry density and at optimum moisture content. And also Tests performed on remolded, untreated specimens and remolded specimen treated with different waste paper sludge ash contents and curing periods. The curing time has a significant effect on unconfined compressive strength and to allow the reaction between soil and additive WPSA to take place to strengthen the expansive soil particles.

Figure 4.12 shows the laboratory result graph of stress versus axial strain from unconfined compression test for expansive soil stabilized with various percentages (2%, 4%, 6%, 8%, 10%, and 12%) of WPSA. From the laboratory results, the optimum concentration percentages of WPSA to stabilize clay soil were determined and a summary of laboratory results was presented in Figure 4.13 shows the compressive strength of expansive soil stabilized with WPSA.

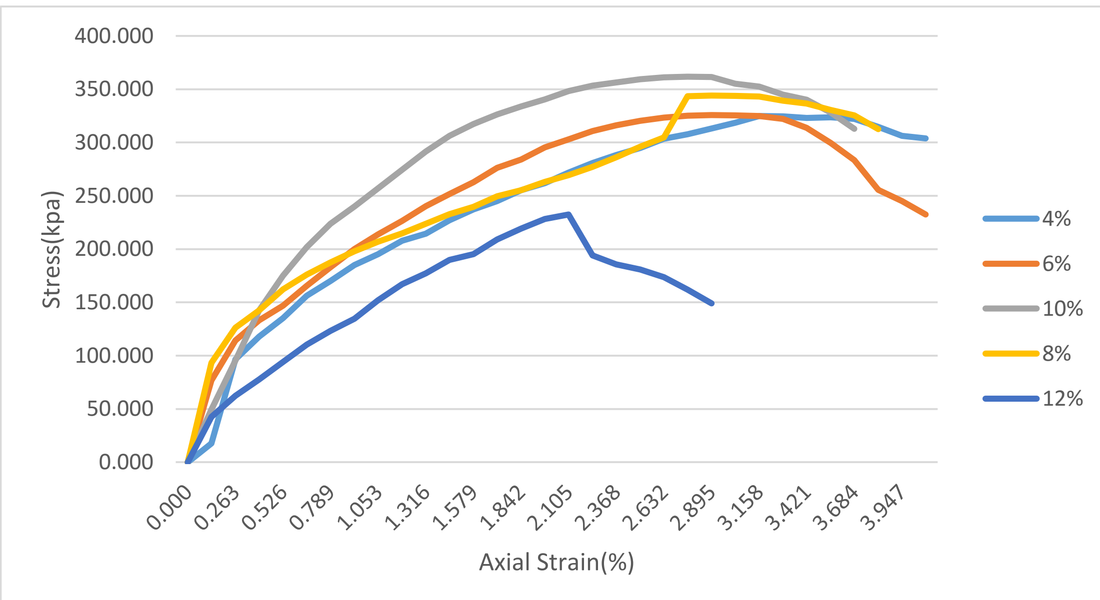


Figure 4.12: The graph of stress versus axial strain for the samples

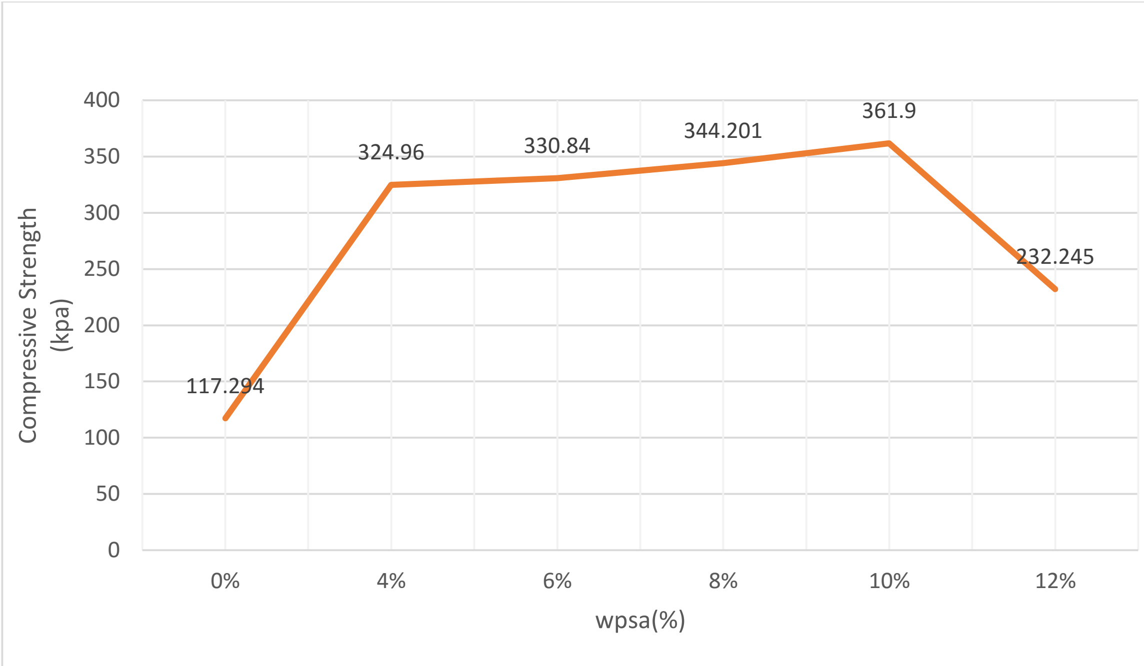


Figure 4.13 Optimum percentage of WPSA on compressive strength

Generally, it can be seen the compressive strength of the expansive soil stabilized with WPSA was improved. Instead the pattern from the graph shows the compressive strength is increase from 117.294 kPa to 361.9 kPa with the increment of WPSA from 4% to 10% of WPSA. However, it shows the decreasing of compressive strength value from 361.9 kPa to 232.489 kPa with the increment of WPSA from 10% to 12% of WPSA. From the results found that the optimum concentration percentage of WPSA is about 10% to stabilize the expansive soil at the maximum strength about 361.9 kPa of compressive strength were determined. The UCS result indicate may be due to cation exchange takes place due to behavior of waste paper sludge ash with the effect of pozollanic behavior.

4.2.5. Effect of Waste Paper Sludge Ash on CBR Values

California Bearing Ratio test is conducted to determine the CBR value of the sample and to evaluate the effective of expansive soil sample stabilized using WPSA. The CBR tests were carried out based on the standard procedure given in ASTM D 1883.Than the tests conducted after the sample was soaked for 96 hrs for uncured condition. The CBR value take at 2.5 or 5.0 mm penetration to the load and the samples were prepared with its optimum moisture content and were compacted at their maximum dry density using static compaction machine. The result show increase of soaked CBR from 2.13 % to 5.04% with the addition of 10% WPSA in seven day curing. So it can be accomplished that the maximum CBR were obtained at 10% of WPSA and further addition of WPSA, decreases the CBR of the expansive Soil. It is observed that the CBR increase as the curing period increases.

However according to Ethiopian Roads Authority pavement design manual specification WPSA treated soil satisfied a minimum CBR value not less than 5%. Hence, 10% of WPSA additives can potentially stabilize expansive soil from problematic poor layer to fair conation of layer. Detail test results are given in Appendix

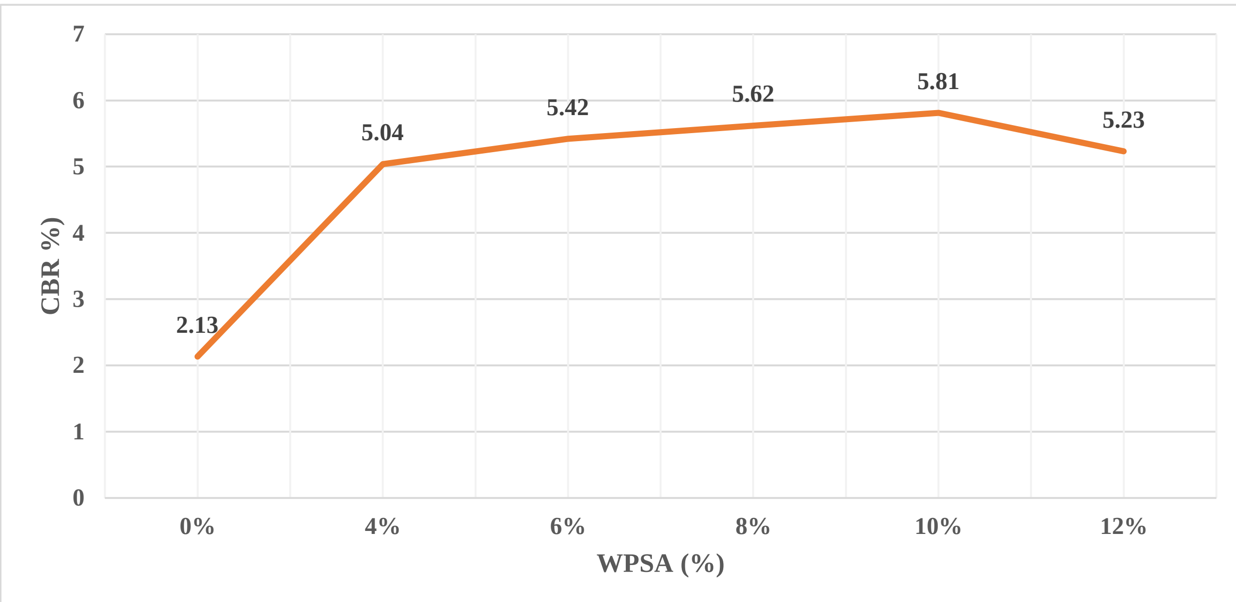


Figure 4.6: Variation of CBR values of Expansive soils with various proportion of WPSA in 7 days cured

4.2.5.1 Effect of Waste Paper Sludge Ash on CBR Swell Values

The mixture of expansive soil and CBR sample soaked for 96 hours in water bath to get swelling capacity. After that measure the CBR swell in using tripod by placing in soaked CBR mold. The result shows decrease the CBR swell from 5.02% to 3.07% with the addition of 10% WPSA in seven day curing. So it can be accomplished that the minimum CBR swell were obtained at 10% of WPSA and further addition of WPSA, increase the CBR swell of the expansive Soil.

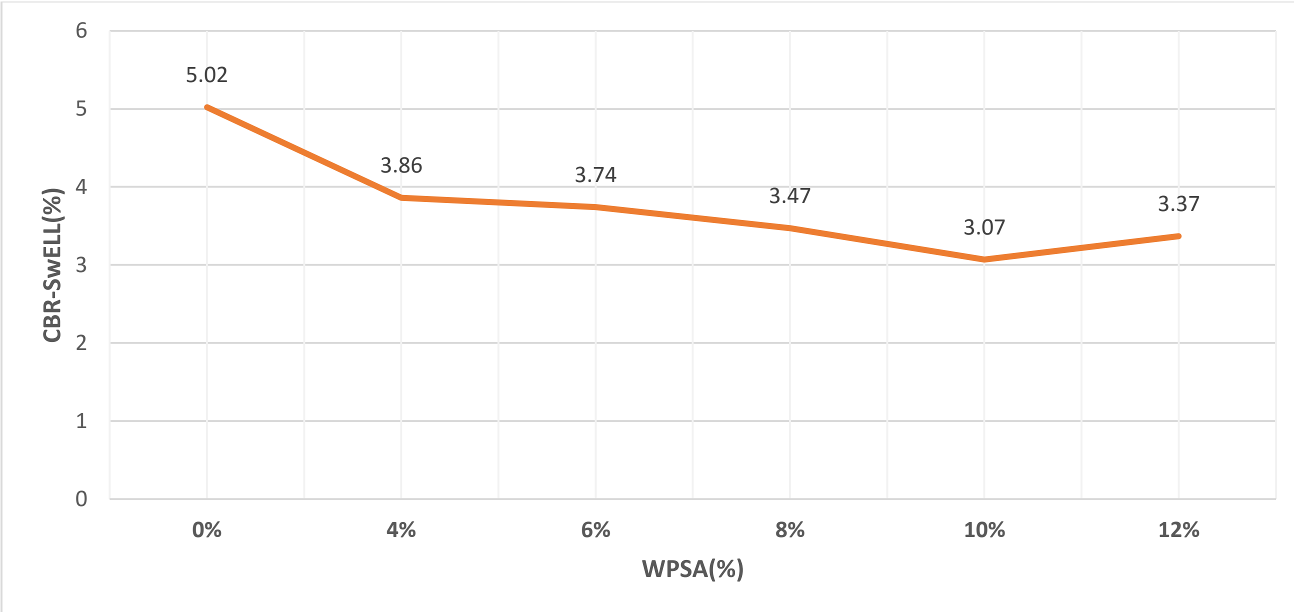


Figure 4.14: Variation of Soaked CBR –Swell with different percentage waste paper sludge ash

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Based on the experimental results on this study, conclusion can be made as below.

- The addition different proportion of WPSA on soil samples shows slightly reduced plasticity index. But increasing of waste paper sludge ash in mixture of expansive soil more than 12% the value of plasticity index is increased from 27% to 31%.
- The maximum dry density and optimum moisture content increased and decreased respectively up to 10% of WPSA. After the addition of 10%of WPSA content with the soil it increase the optimum moisture content from 27.5% to 39.2% and decrease the maximum density from 1.33% to 1.23%.
- When using of waste paper sludge ash on the expansive soil sample shows significant change on free swell index tests up to 12% of WPSA. After using of 12%WPSA increase the swelling potential of the soil sample.
- The addition of 10% WPSA were increased the unconfined compressive strength of the expansive soil in seven day curing. The maximum value of unconfined compressive strength attended at 10% WPSA in soil mixture is 361.9 kPa. After that decrease unconfined compressive strength when increase the amount of waste paper sludge ash.
- Using the standard effort, the CBR values of soaked sample increased with 10%WPSA in seven day curing period. The result changed the CBR value from 2.13% to 5.81%.This increment changed behavior of natural soils from poor to fair standard as stated in ERA (2013). And also the CBR swell potential of the sample results shows decreased in 10% WPSA that change from 5.04% to 3.07%.
- The addition of waste paper sludge ash to expansive soil stabilize it. Furthermore, 10% waste paper sludge ash was found to be optimum stabilizer content for subgrade stabilization and meet all ERA specification requirement to be stabilized.

5.2. Recommendation

Based on the findings of the research the following are the main recommendation;

- The stabilizing potential of waste paper sludge ash from different source like wonji paper factory and coming new paper factories should be studied.
- The result of this research indicate the waste paper sludge ash change the soil property from highly plastic to medium plastic so further investigation using other material in addition to waste paper sludge ash to change low plastic.
- Studies should be made to check the secondary reaction of the waste paper sludge ash using more advanced methods like X-ray Diffraction analysis.
- Studies should be made using controlled burning of the waste paper sludge ash at different temperature.

6. REFERENCE

AASHTO. (1995) “Standard specification for transportation materials and methods of sampling and testing,” America.

Al-Rawas, A.A. and Goosen, M.F. (2006). Expansive soils: Recent advances in characterization and treatment. Taylor & Francis Group, London, UK.

ASTM – American Society for Testing and Materials.

Bizualem, T.May (2015) “stabilization of expansive clay soil with sugar cane molasess”.

C.Subhacini, M. Ranjitha, S.D Harapal, K. Arunprakash, K .Uma Shankars April 2015, “Expansive soil stabilization using waste from sugarcane industries” IJR Vol 1 Issue 03.

Chen, F.H. (1988), Foundation on Expansive Soils. Elsevier scientific publishing company.

DilipKumar.T (2015), “A study of paper sludge is mill lime sludge for stabilization of village road sub-base”, IJETAE, Vol No. 5, Issue 2.

ERA (2002). Ethiopian Roads Authority. Site Investigation Manual. Addis Ababa, Ethiopia.

Guyer, J. P (2011),”Introduction to Soil Stabilization in Pavements,” New York.

Akinyele, Salim, Oikelome, O. T. Olateju, 2015,” the use of rice husk ash as a stabilizing agent in lateritic clay soil”.

Julius K. M’Ndegwa, (2011), the Effect of Cane Molasses on Strength of Expansive Clay Soil.

Makusa, G.P, (2012), “Soil Stabilization Methods and Materials in Engineering Practice,”Department of Civil, Environmental and Natural resources engineering, Luleå University of Technology, Luleå, Sweden.

Meron, W., 2014, “improvement of expansive soil by addition of bagasse ash on expansive clay soil”.

Nebro, D., 2002, “Stabilization of Potentially Expansive Subgrade Soil Using Lime and Con-Aid,” MSc. Thesis, Addis Ababa University, Addis Ababa.

Nelson, D., and Miller, J., "Expansive Soils: Problems and Practices in Foundation and Pavement Engineering," New York, 1992.

Norazlan.K, Mazidah.M, Faizahka.M, 2012, "Clay soil stabilized using waste paper sludge ash (wpsa) mixtures".

RBarani. D, 2016 "Effect of Waste Paper Sludge Ash on Engineering Behaviors of Black Cotton Soils", ISSN 0974-5904, Volume 09, No. 03.

S.S.Shirsavkar.S and Prof. S.S. Koranne.M, 2010, Innovation in Road Construction Using Natural Polymer. 1V. Surya.T, 2K. Sindhuja.A, 3G. Sai.K 1Assistant

Shishir Kumar Sikder Amit, Mohammad Rafiqual Islam, 2016 "Application of paper sludge ash in construction industry".

Sachin N. and Ankit J.Pater (2014) "Behavior of black cotton soil after stabilizing with marble powder" IJSR Vol 3 Issue 12.

Sharan Veer Singh[1], Mahabir Dixit[2], 2017," stabilization of soil by using waste plastic material".

Surya.T, 2K. Sindhuja.A, 3G. Sai.K [1]Assistant Professor, 2, 3,4Under Graduate Students

Teferra. A, (2009), Principles of Foundation Engineering. 2nd ed. Addis Ababa University Press, Addis Ababa.

Teklu. D, (2003), examines the swelling pressure of Addis Ababa Expansive soil. Msc Thesis, Addis Ababa University Technology Faculty, Addis Ababa, Ethiopia.

Tesfaye, A., 2001, "Chemical Treatment of "Black Cotton" Soil to make it Usable as Foundation Material," MSc. Thesis, Addis Ababa University, Addis Ababa, October.

Ulusay.R, (2002), a simple test and predictive models for assessing swell potential of Ankara (Turkey) Clay. Elsevier scientific publishing company.

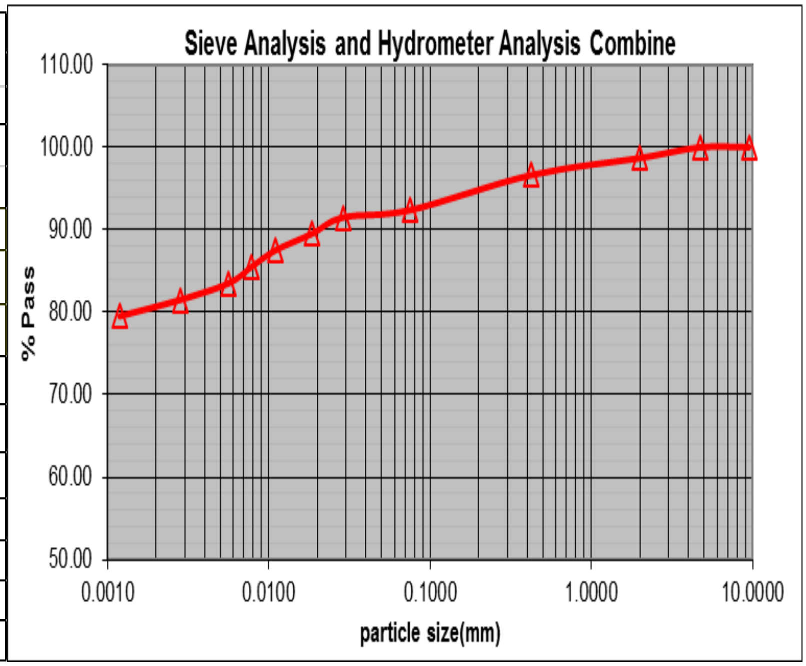
APPENDIX

Appendix 1

Table A-1. 1Hydrometer analysis data

Hydrometer analysis Data						Specific Gravity=	2.66		
Time (minutes)	Hydrometer Reading	Temp.	Corrected H.Reading		Correction factor(a)	Effe. Depth of Hydrometer(L)	Values of K	Diameter of soil Particle(mm)	% finer,P
			R'	R"					
2	50	19	51.85	45.85	0.9977	8.70	0.01377	0.0287	91.49
5	49	19	50.85	44.85	0.9977	8.90	0.01377	0.0184	89.49
15	48	19	49.85	43.85	0.9977	9.45	0.01377	0.0109	87.49
30	47	19	48.85	42.85	0.9977	9.62	0.01377	0.0078	85.50
60	46	19	47.85	41.85	0.9977	9.95	0.01377	0.0056	83.50
250	45	20	46.85	40.85	0.9977	10.46	0.01377	0.0028	81.51
1440	44	19	45.85	39.85	0.9977	10.62	0.01377	0.0012	79.51

	Diameter of soil Particle (mm)	% Pass
	9.50	100.00
	4.75	100.00
	2.0	98.70
	0.425	96.64
	0.075	92.38
Hydrometer Analysis	**0.029**	91.49
	0.018	89.49
	0.011	87.49
	0.008	85.50
	0.006	83.50
	0.003	81.51
	0.001	79.51



1.Particles larger than 2mm =		1.3%
2.Coarse Sand 2mm - 0.425mm =		2.1%
3.Fine Sand 0.425mm - 0.075mm =		4%
4.Silt 0.075-0.002mm =		11%
5.Clay smaller than 0.002mm =		82%

Appendix 2

Table A-2. 1 Specific gravity of soil

TEST DATA OF SPECIFIC GRAVITY OF SOIL				
Testing Standard:	ASTM D854		Oven Dried Speciemen	
Test No.			**1**	**2**
Pycnometre No.			A5	B7
Mass of Pycnometer, M_p (g)			48.91	46.02
Mass of Soil Sample, M_s (g)			25.08	25.01
Calibrated Volume of Pycnometer, V_p (ml)			99.927	99.927
Testing Temprature, T (^{0}C)			18.6	18.5
Density of Water at Testing Temprature, ρ_w (g/cm^3)			0.99848	0.99850
Calibrated Mass of Pycnometer + Water, M_{pw} (g)			148.685	145.797
Mass of Pycnometer + Water + Soil, M_{pws} (g)			164.33	161.42
G (at Testing Temprature)			2.658	2.664
Correction Factor			1.00028	1.00030
G (at 20 ^{0}C)			2.659	2.665
G_{avg} (at 20 ^{0}C)			2.66	

Table A-2. 2 Free swell index

FREE SWELL INDEX

WPSA (%)	**Vk**	**Vd**	**FS (%)**
0%	12.5	25.5	104.00
4%	13	26	100.00
6%	15.5	30	93.55
8%	14	23	64.29
10%	13	19	46.15
12%	13	17	30.77
14%	12	18	50.00

Table A-2. 3 Atterberg's Limit Test

TEST DATA FOR NATURAL SOIL						
Testing Standard	ASTM D4318	**Sample Preparation Method**			**Liquid Limit Test Method**	
		Dry			THERR-Point Method	
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	28	26	20			
Container Number	106	185	120		128	149
Mass of Empty Container, M_c	33.0	33.0	33.2		33.2	33.0
Mass of Container + Wet Soil, M_{csw} (g)	54.3	55.5	54.0		39.3	38.7
Mass of Container + Dry Soil, M_{cs} (g)	44.6	45.1	44.0		37.7	37.2
Mass of Dry Soil, M_s (g)	11.60	12.10	10.80		4.50	4.20
Mass of Water, M_w (g)	9.70	10.40	10.00		1.60	1.50
Water Content, *w* (%)	83.62	85.95	92.59		35.56	35.71
Liquid Limit,LL (%)	87					
Plastic Limit, PL (%)	36					

Plastic Idex,PI(%)	51					

TEST DATA FOR 4% IN 1 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**			**Liquid Limit Test Method**	
		Dry			Three-Point Method	
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	35	27	19			
Container Number	75	92	52		105	149
Mass of Empty Container, M_c	30.9	30.2	30.8		30.5	30.5
Mass of Container + Wet Soil, M_{csw} (g)	49.8	56.3	58.0		38.7	38.9
Mass of Container + Dry Soil, M_{cs} (g)	41.4	44.2	45.0		36.4	36.6
Mass of Dry Soil, M_s (g)	10.50	14.00	14.20		5.90	6.10
Mass of Water, M_w (g)	8.40	12.10	13.00		2.30	2.30
Water Content, *w* (%)	80.00	86.43	91.55		38.98	37.70
Liquid Limit,LL(%)	87					
Plastic Limit, PL (%)	38					
Plasticity Index,PI(%)	49					

TEST DATA FOR 6% IN 1 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**			**Liquid Limit Test Method**	
		Dry			Three-Point Method	
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	29	23	22			
Container Number	106	185	120		128	149
Mass of Empty Container, M_c	32.8	33.6	33.0		33.2	33.3
Mass of Container + Wet Soil, M_{csw} (g)	61.5	59.2	65.0		42.1	46.3
Mass of Container + Dry Soil, M_{cs} (g)	48.7	47.3	50.0		39.6	42.6
Mass of Dry Soil, M_s (g)	15.90	13.70	17.00		6.40	9.30
Mass of Water, M_w (g)	12.80	11.90	15.00		2.50	3.70
Water Content, *w* (%)	80.50	86.86	88.24		39.06	39.78
Liquid Limit,LL(%)	85					
Plastic Limit,PL(%)	39					
Plasticity Index,PI(%)	46					

TEST DATA FOR 8% IN 1 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Three-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	31	20	16			
Container Number	106	185	120		128	149
Mass of Empty Container, M_c	33.6	33.7	33.5		33.4	33.0
Mass of Container + Wet Soil, M_{csw} (g)	51.5	55.7	58.2		36.7	35.7
Mass of Container + Dry Soil, M_{cs} (g)	43.9	46.2	47.4		35.9	35.0
Mass of Dry Soil, M_s (g)	10.30	12.50	13.90		2.50	2.00
Mass of Water, M_w (g)	7.60	9.50	10.80		0.80	0.70
Water Content, *w* (%)	73.79	76.00	77.70		32.00	35.00
Liquid Limit,LL(%)	75					
Plasticity Index,PI(%)	34					
Plasticity Index,PI(%)	41					

TEST DATA FOR 10% IN 1 DAYS CURING					
Testing Standard	ASTM D4318	**Sample Preparation Method**			**Liquid Li**
		Dry			Three-Poi
Type of Test	**Liquid Limit**				
Number of Blows	30	27	23		
Container Number	106	185	120		
Mass of Empty Container, M_c	32.9	33.1	33.2		
Mass of Container + Wet Soil, M_{csw} (g)	53.5	56.5	59.5		
Mass of Container + Dry Soil, M_{cs} (g)	44.9	46.5	48.0		
Mass of Dry Soil, M_s (g)	12.00	13.40	14.80		
Mass of Water, M_w (g)	8.60	10.00	11.50		
Water Content, *w* (%)	71.67	74.63	77.70		
Liquid Limit,LL(%)	776				
Plastic Limit,PL(%)	337				
Plasticity Index,PI(%)	339				

TEST DATA FOR 12% IN 1 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**			**Liquid Limit Test Method**	
		Dry			Four-Point Method	
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	34	27	19			
Container Number	106	185	120		128	149
Mass of Empty Container, M_c	19.9	20.8	22.3		31.1	30.9
Mass of Container + Wet Soil, M_{csw} (g)	36.9	36.9	40.5		36.9	36.3
Mass of Container + Dry Soil, M_{cs} (g)	30.5	29.9	32.5		35.2	34.8
Mass of Dry Soil, M_s (g)	10.60	9.10	10.20		4.10	3.90
Mass of Water, M_w (g)	6.40	7.00	8.00		1.70	1.50
Water Content, *w* (%)	60.38	76.92	78.43		41.46	38.46
Liquid Limit,LL(%)	73					
Plastic Limit,PL(%)	40					
Plasticity Index,PI(%)	33					

TEST DATA FOR 14% IN 1 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**			**Liquid Limit Test Method**	
		Dry			Three-Point Method	
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	30	27	23			
Container Number	106	185	120		128	149
Mass of Empty Container, M_c	32.7	33.1	33.2		32.7	33.0
Mass of Container + Wet Soil, M_{csw} (g)	50.2	52.9	53.8		42.6	41.1
Mass of Container + Dry Soil, M_{cs} (g)	43.8	45.4	45.8		40.3	39.4
Mass of Dry Soil, M_s (g)	11.10	12.30	12.60		7.60	6.40
Mass of Water, M_w (g)	6.40	7.50	8.00		2.30	
Water Content, *w* (%)	57.66	60.98	63.49		30.26	0.00
Liquid Limit,LL(%)	62					
Plastic Limit,PL(%)	28					
Plasticity Index,PI(%)	34					

TEST DATA FOR 4% IN 4 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Three-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	34	27	19			
Container Number	106	185	120		128	149
Mass of Empty Container, M_c	19.9	20.8	22.3		21.1	20.4
Mass of Container + Wet Soil, M_{csw} (g)	38.8	46.9	49.5		29.3	28.8
Mass of Container + Dry Soil, M_{cs} (g)	30.4	34.8	36.6		27.0	26.3
Mass of Dry Soil, M_s (g)	10.50	14.00	14.30		5.90	5.90
Mass of Water, M_w (g)	8.40	12.10	12.90		2.30	2.50
Water Content, *w* (%)	80.00	86.43	90.21		38.98	42.37
Liquid Limit,LL(%)	86					
Plastic Limit,PL(%)	41					
Plasticity Index,PI(%)	45					

TEST DATA FOR 6% IN 4 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Three-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	29	23	22			
Container Number	106	185	120		128	149
Mass of Empty Container, M_c	32.8	33.6	33.0		33.2	33.2
Mass of Container + Wet Soil, M_{csw} (g)	52.1	56.8	51.9		37.4	36.7
Mass of Container + Dry Soil, M_{cs} (g)	44.1	46.9	43.8		36.4	
Mass of Dry Soil, M_s (g)	11.30	13.30	10.80		3.20	33.20
Mass of Water, M_w (g)	8.00	9.90	8.10		1.00	36.70
Water Content, *w* (%)	70.80	74.44	75.00		31.25	110.54
Liquid Limit, LL (%)	73					
Plastic Limit, PL (%)	30					
Plasticity Index, PI (%)	43					

TEST DATA FOR 8% IN 4 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Three-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	32	22	19			
Container Number	92	185	120		125	149
Mass of Empty Container, M_c	33.0	32.9	33.9		33.5	33.2
Mass of Container + Wet Soil, M_{csw} (g)	56.8	60.6	56.4		36.1	35.8
Mass of Container + Dry Soil, M_{cs} (g)	46.9	48.6	46.5		35.4	35.1
Mass of Dry Soil, M_s (g)	13.90	15.70	12.60		1.90	1.90
Mass of Water, M_w (g)	9.90	12.00	9.90		0.70	0.70
Water Content, *w* (%)	71.22	76.43	78.57		36.84	36.84
Liquid Limit, LL (%)	75					
Plastic Limit, PL (%)	37					
Plasticity Index, PI (%)	38					

TEST DATA FOR 10% IN 4 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Three-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	28	27	19			
Container Number	111	11	141		163	106
Mass of Empty Container, M_c	33.0	33.4	33.4		33.7	33.5
Mass of Container + Wet Soil, M_{csw} (g)	57.4	58.4	67.9		38.5	38.4
Mass of Container + Dry Soil, M_{cs} (g)	47.5	48.2	53.4		37.2	37.0
Mass of Dry Soil, M_s (g)	14.50	14.80	20.00		3.50	3.50
Mass of Water, M_w (g)	9.90	10.20	14.50		1.30	1.40
Water Content, *w* (%)	68.28	68.92	72.50		37.14	40.00
Liquid Limit, LL (%)	70					
Plastic Limit, PL (%)	39					
Plasticity Index, PI (%)	31					

TEST DATA FOR 12% IN 4 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Three-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	30	25	20			
Container Number	119	76	155		163	106
Mass of Empty Container, M_c	33.3	32.6	33.2		32.9	32.0
Mass of Container + Wet Soil, M_{csw} (g)	57.7	57.7	64.3		36.0	36.2
Mass of Container + Dry Soil, M_{cs} (g)	47.9	47.2	50.6		35.1	34.9
Mass of Dry Soil, M_s (g)	14.60	14.60	17.40		2.20	2.90
Mass of Water, M_w (g)	9.80	10.50	13.70		0.90	1.30
Water Content, *w* (%)	67.12	71.92	78.74		40.91	44.83
Liquid Limit, LL (%)	72					
Plastic Limit, PL (%)	43					
Plasticity Index, PI (%)	29					

TEST DATA FOR 14% IN 4 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Four-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	31	28	24			
Container Number	106	185	120		128	149
Mass of Empty Container, M_c	32.4	33.1	33.2		32.9	34.0
Mass of Container + Wet Soil, M_{csw} (g)	53.5	56.5	59.5		37.2	37.9
Mass of Container + Dry Soil, M_{cs} (g)	44.8	46.5	48.0		35.9	36.7
Mass of Dry Soil, M_s (g)	12.40	13.40	14.80		3.00	2.70
Mass of Water, M_w (g)	8.70	10.00	11.50		1.30	1.20
Water Content, *w* (%)	70.16	74.63	77.70		43.33	44.44
Liquid Limit, LL (%)	77					
Plastic Limit, PL (%)	44					
Plasticity Index, PI (%)	33					

TEST DATA FOR 4% IN 7AYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Three-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	28	26	20			
Container Number	123	102	23		130	149
Mass of Empty Container, M_c	33.0	33.0	33.2		33.0	32.8
Mass of Container + Wet Soil, M_{csw} (g)	50.0	52.3	53.4		35.1	35.0
Mass of Container + Dry Soil, M_{cs} (g)	42.6	43.8	44.1		34.6	34.4
Mass of Dry Soil, M_s (g)	9.60	10.80	10.90		1.60	1.62
Mass of Water, M_w (g)	7.40	8.50	9.30		0.50	0.58
Water Content, *w* (%)	77.08	78.70	85.32		31.25	35.80
Liquid Limit, LL (%)	80					
Plastic Limit, PL (%)	34					
Plasticity Index, PI (%)	46					

TEST DATA FOR 6% IN 7DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Three-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	27	24	16			
Container Number	106	185	120		128	149
Mass of Empty Container, M_c	33.7	32.0	32.7		33.2	33.3
Mass of Container + Wet Soil, M_{csw} (g)	55.0	57.3	60.6		36.7	36.8
Mass of Container + Dry Soil, M_{cs} (g)	46.5	47.0	48.6		35.9	36.1
Mass of Dry Soil, M_s (g)	12.80	15.00	15.90		2.70	2.80
Mass of Water, M_w (g)	8.50	10.30	12.00		0.80	0.70
Water Content, *w* (%)	66.41	68.67	75.47		29.63	25.00
Liquid Limit, LL (%)	68					
Plastic Limit, PL (%)	27					
Plasticity Index, PI (%)	41					

TEST DATA FOR 8% IN 7DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**			**Liquid Limit Test Method**	
		Dry			Three -Point Method	
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	30	25	19			
Container Number	181	165	147		105	139
Mass of Empty Container, M_c	33.9	32.9	32.8		33.3	32.9
Mass of Container + Wet Soil, M_{csw} (g)	60.9	59.6	60.0		36.9	37.5
Mass of Container + Dry Soil, M_{cs} (g)	50.3	48.7	48.5		36.0	36.5
Mass of Dry Soil, M_s (g)	16.40	15.80	15.70		2.70	3.60
Mass of Water, M_w (g)	10.60	10.90	11.50		0.90	1.00
Water Content, *w* (%)	64.63	68.99	73.25		33.33	27.78
Liquid Limit, LL (%)	68					
Plastic Limit, PL (%)	31					
Plasticity Index, PI (%)	37					

TEST DATA FOR 10% IN 7 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**			**Liquid Limit Test Method**	
		Dry			Three-Point Method	
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	32	20	18			
Container Number	111	11	141		163	106
Mass of Empty Container, M_c	33.6	33.0	33.3		33.3	33.6
Mass of Container + Wet Soil, M_{csw} (g)	64.8	66.1	62.3		35.7	35.1
Mass of Container + Dry Soil, M_{cs} (g)	51.1	51.4	49.4		34.9	34.0
Mass of Dry Soil, M_s (g)	17.50	18.40	16.10		1.60	0.40
Mass of Water, M_w (g)	13.70	14.70	12.90		0.80	1.10
Water Content, *w* (%)	78.29	79.89	80.12		50.00	52.21
Liquid Limit, LL (%)	79					
Plastic Limit, PL (%)	51					
Plasticity Index, PI (%)	28					

TEST DATA FOR 12% IN 7 DAYS CURING			
Testing Standard	ASTM D4318	**Sample Preparation Method**	**Liquid Limit Test Method**
		Dry	Three-Point Method

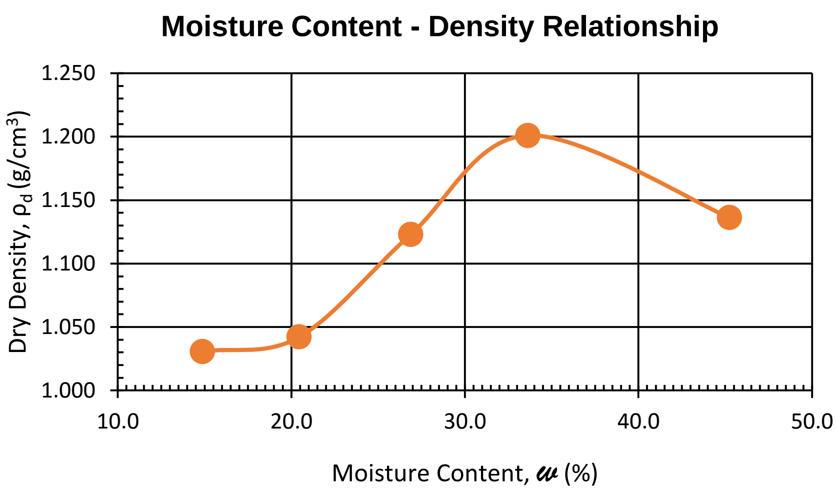
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	33	22	16			
Container Number	119	76	155		163	106
Mass of Empty Container, M_c	32.9	32.8	33.4		33.2	33.4
Mass of Container + Wet Soil, M_{csw} (g)	61.2	65.5	64.1		35.8	36.4
Mass of Container + Dry Soil, M_{cs} (g)	49.6	51.5	50.7		34.9	35.4
Mass of Dry Soil, M_s (g)	16.70	18.70	17.30		1.70	2.00
Mass of Water, M_w (g)	11.60	14.00	13.40		0.90	1.00
Water Content, *w* (%)	69.46	74.87	77.46		42.20	50.00
Liquid Limit, LL (%)	73					
Plastic Limit, PL (%)	46					
Plasticity Index, PI (%)	27					

TEST DATA FOR 14% IN 7 DAYS CURING						
Testing Standard	ASTM D4318	**Sample Preparation Method**		**Liquid Limit Test Method**		
		Dry		Three-Point Method		
Type of Test	**Liquid Limit**				**Plastic Limit**	
Number of Blows	33	22	16			
Container Number	119	76	155		163	106
Mass of Empty Container, M_c	32.9	32.8	33.4		33.5	33.4
Mass of Container + Wet Soil, M_{csw} (g)	62.2	65.5	64.1		36.9	36.5
Mass of Container + Dry Soil, M_{cs} (g)	49.6	51.3	50.7		35.9	35.5
Mass of Dry Soil, M_s (g)	16.70	18.50	17.30		2.40	2.10
Mass of Water, M_w (g)	12.60	14.20	13.40		1.00	1.00
Water Content, *w* (%)	75.45	76.76	77.46		41.67	47.62
Liquid Limit, LL (%)	76					
Plastic Limit PL (%)	45					
Plasticity Index, PI (%)	31					

Appendix 3

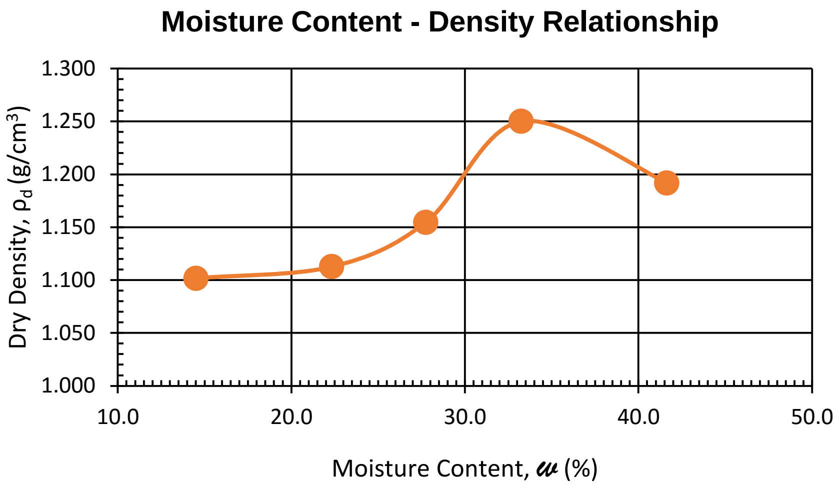
PROCTOR TEST RESULTS FOR NATURAL SOIL

Table A-3. 1 Proctor test result



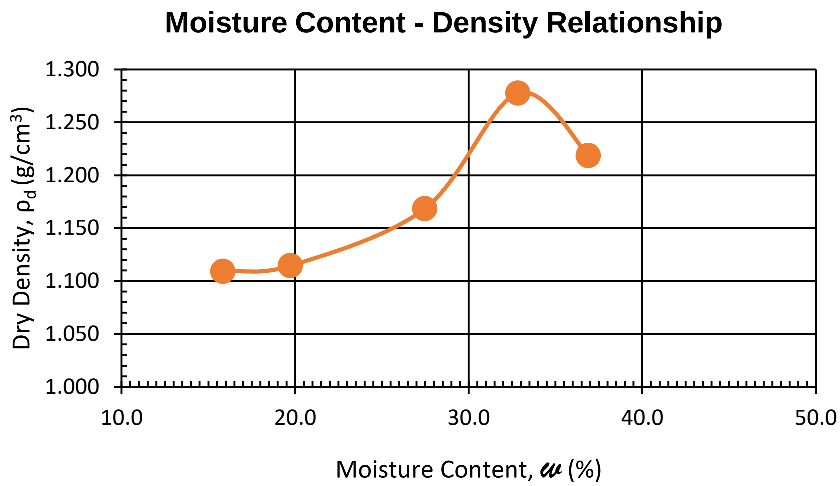
OMC (%)	33.6
MDD(g/cm3)	1.201

PROCTOR TEST FOR 4% WPSA



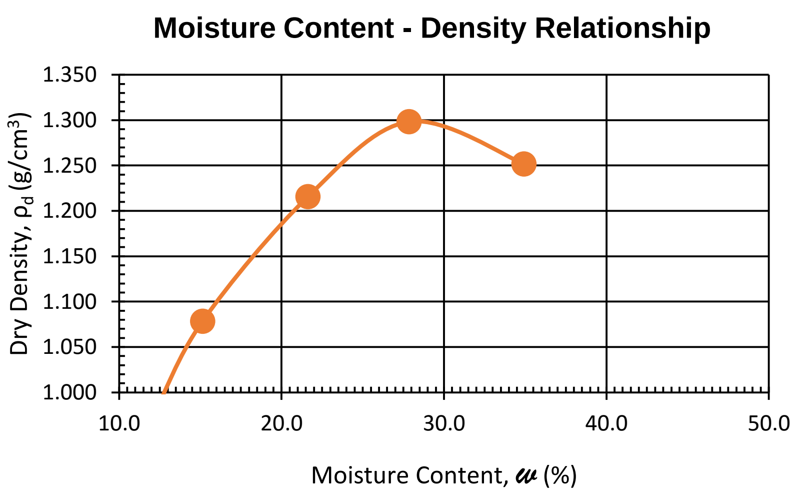
OMC (%)	33.3
MDD(g/cm3)	1.25

PROCTOR TEST FOR 6% WPSA



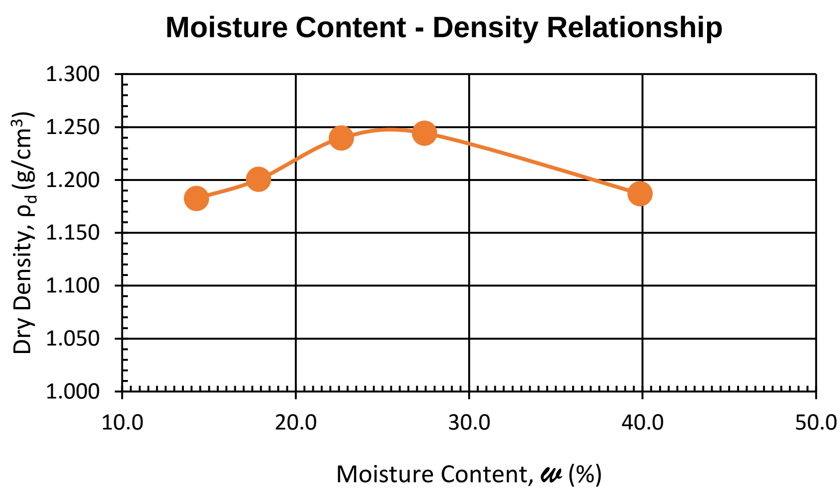
OMC (%)	32.8
MDD(g/cm3)	1.28

PROCTOR TEST FOR 8% WPSA



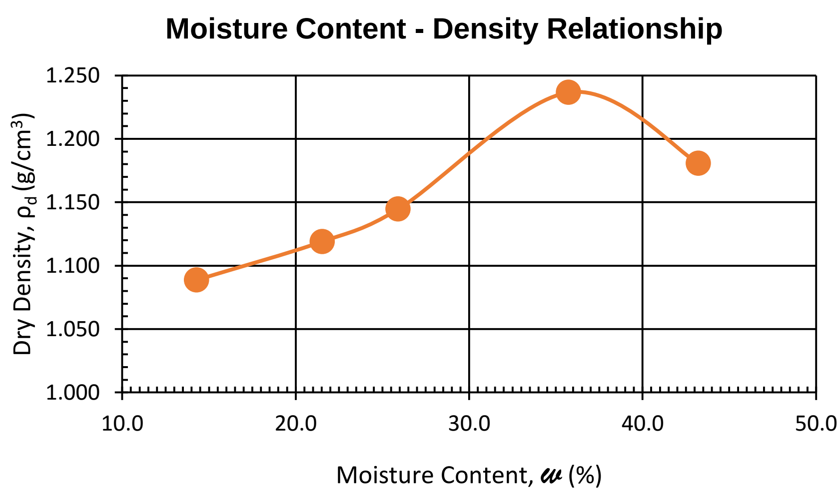
OMC (%)	27.9
MDD(g/cm3)	1.298

PROCTOR TEST FOR 10% WPSA



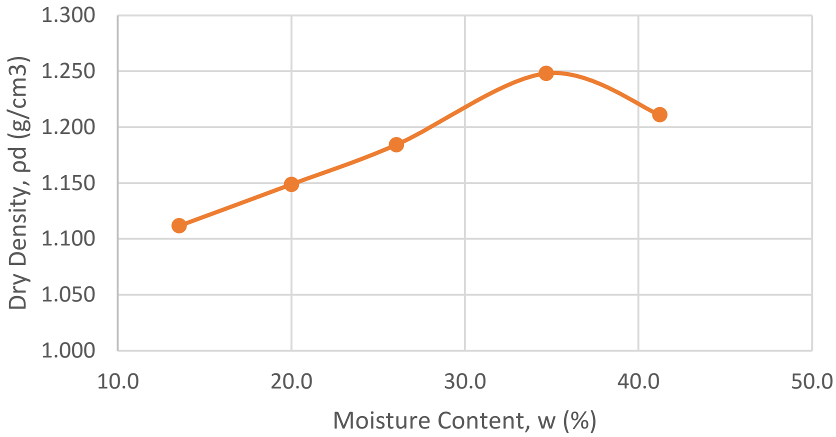
OMC (%)	27.4
MDD(g/cm3)	1.244

PROCTOR TEST FOR 12% WPSA



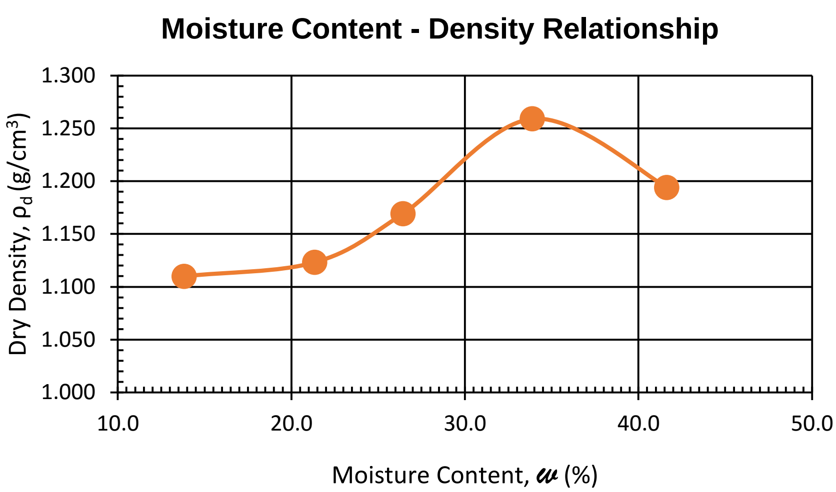
OMC (%)	35.7
MDD(g/cm3)	1.24

PROCTOR TESTS FOR 4% IN SEVEN DAY CURED



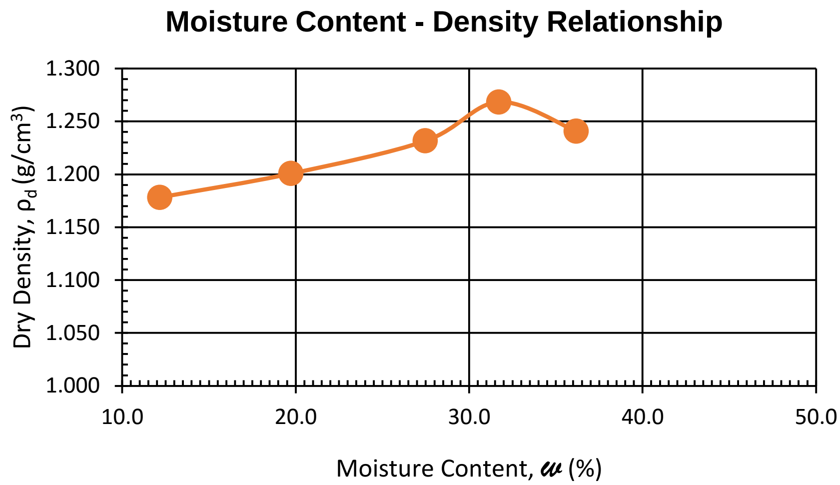
OMC (%)	33.9
MDD(g/cm3)	1.248

PROCTOR TESTS FOR 6% IN SEVEN DAY CURED



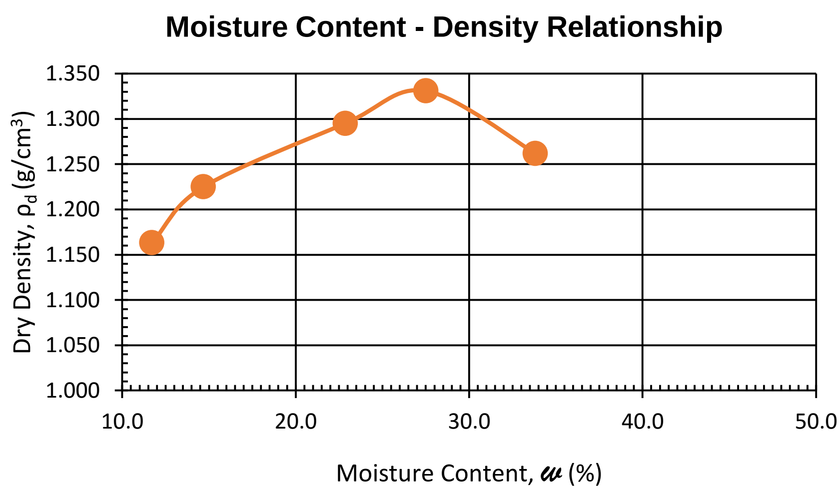
OMC (%)	33.7
MDD(g/cm3)	1.259

PROCTOR TESTS FOR 8% IN SEVEN DAY CURED



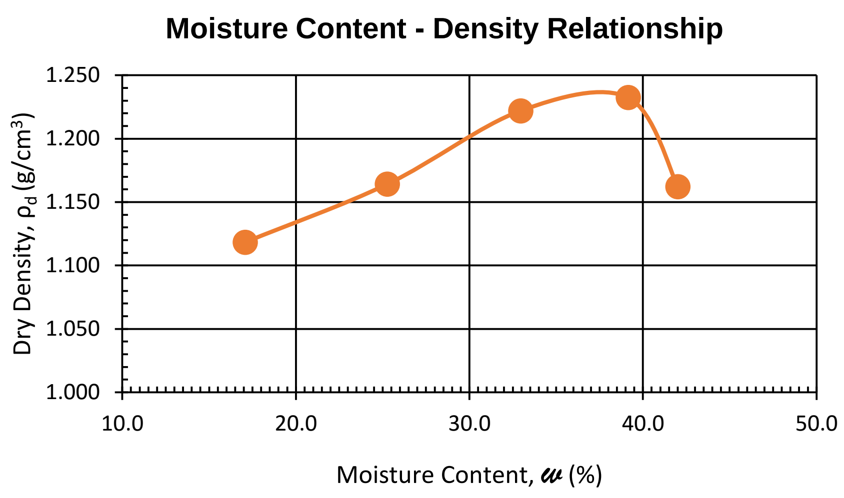
OMC (%)	31.7
MDD(g/cm3)	1.268

PROCTOR TESTS FOR 10% IN SEVEN DAY CURED



OMC (%)	27.5
MDD(g/cm3)	1.33

PROCTOR TESTS FOR 12% IN SEVEN DAY CURED

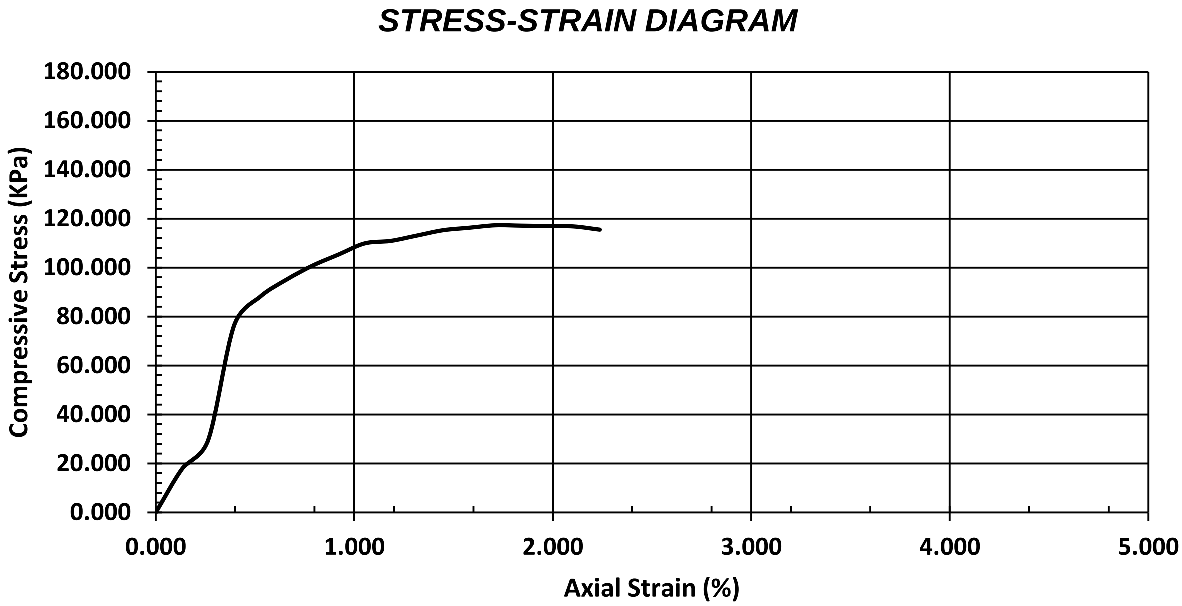


OMC (%)	39.2
MDD(g/cm3)	1.23

Appendix 4

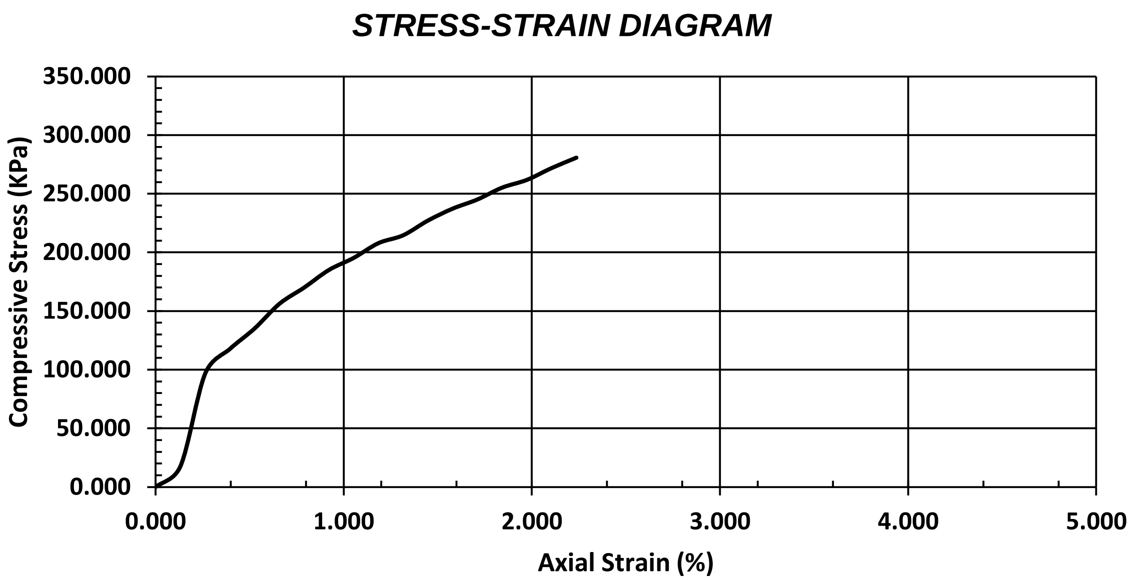
UNCONFINED COMPRESSION TEST RESLUT FOR NATURAL SOIL ONLY

Table A-4. 1 Unconfined compression test result



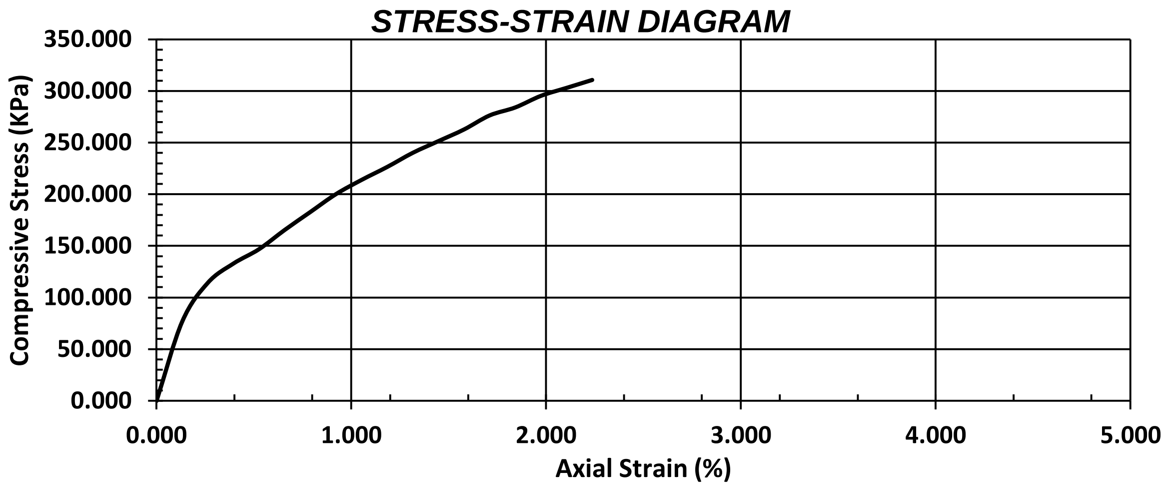
Unconfined Compressive Strength, q_u (KPa)	117.294
Undrained Shear Strength, S_u (KPa)	58.647
Failure Strain, E_f (%)	1.579
Wet Density, ρ (g/cm^3)	1.790
Dry Density, ρ_d (g/cm^3)	1.616
Natural Moisture Content, *w (%)*	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 4% WPSA IN SEVEN DAY CURED



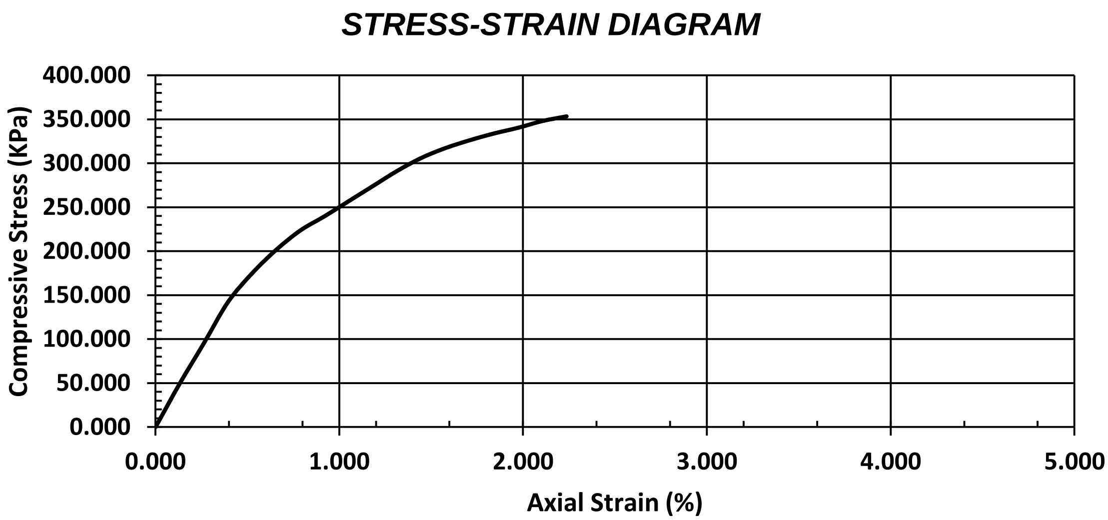
Unconfined Compressive Strength, q_u (KPa)	324.960
Undrained Shear Strength, S_u (KPa)	162.480
Failure Strain, E_f (%)	1.974
Wet Density, ρ (g/cm^3)	2.284
Dry Density, ρ_d (g/cm^3)	2.062
Natural Moisture Content, *w (%)*	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 6% WPSA IN SEVEN DAY CURED



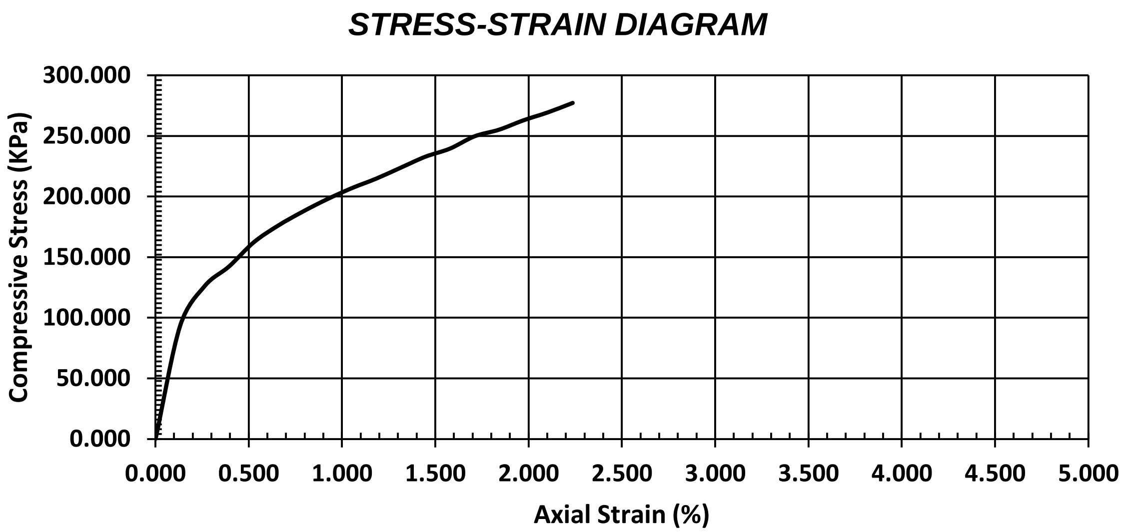
Unconfined Compressive Strength, q_u (KPa)	325.843
Undrained Shear Strength, S_u (KPa)	162.922
Faliure Strain, E_f (%)	2.895
Wet Density, ρ (g/cm^3)	1.667
Dry Density, ρ_d (g/cm^3)	1.505
Natural Moisture Content, *w (%)*	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 10% WPSA IN SEVEN DAY CURED



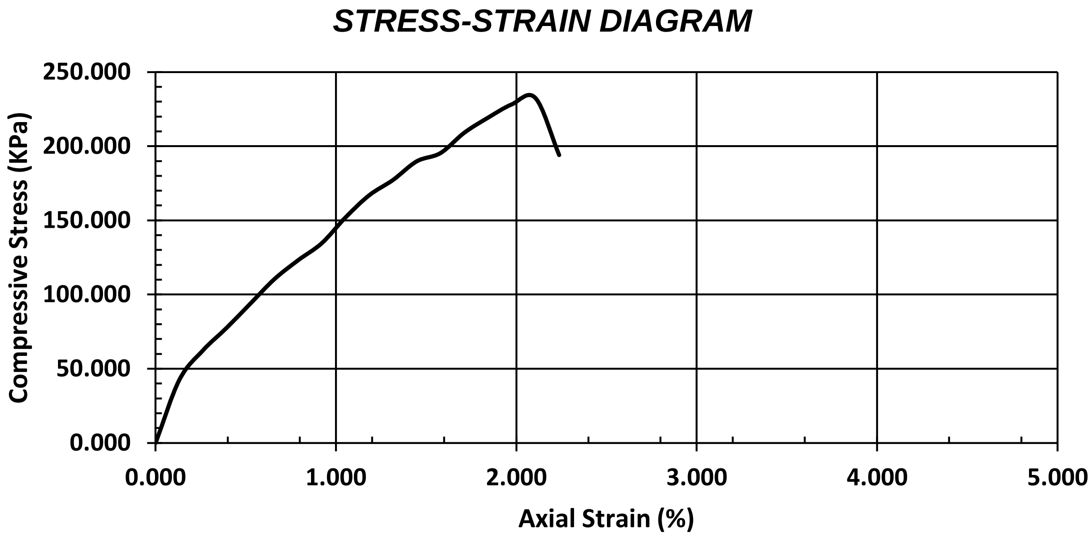
Unconfined Compressive Strength, q_u (KPa)	361.900
Undrained Shear Strength, S_u (KPa)	180.950
Faliure Strain, E_f (%)	2.763
Wet Density, ρ (g/cm^3)	1.704
Dry Density, ρ_d (g/cm^3)	1.538
Natural Moisture Content, *w (%)*	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 8% WPSA IN SEVEN DAY CURED



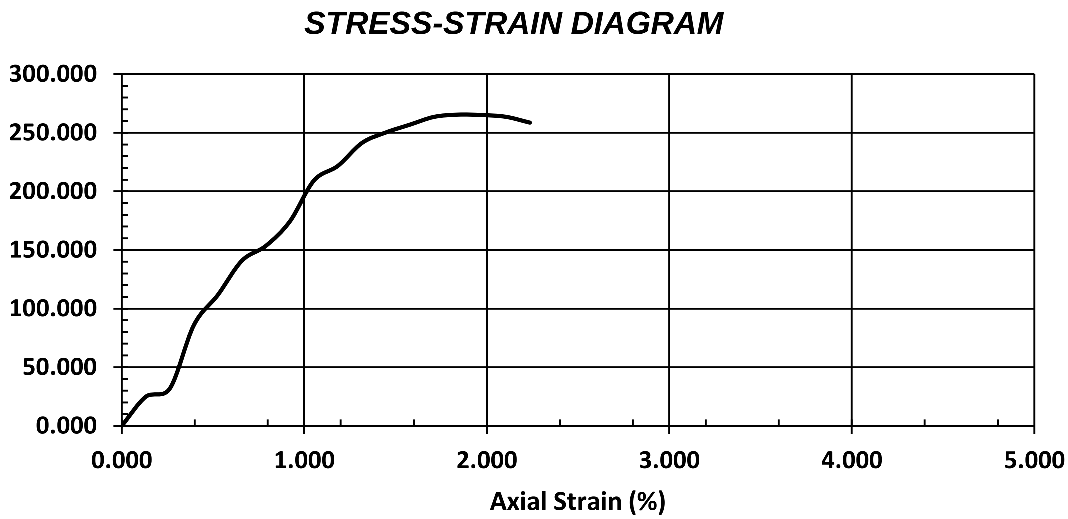
Unconfined Compressive Strength, q_u (KPa)	344.201
Undrained Shear Strength, S_u (KPa)	172.100
Faliure Strain, E_f (%)	2.895
Wet Density, ρ (g/cm^3)	1.790
Dry Density, $ρ_d$ (g/cm^3)	1.616
Natural Moisture Content, *w (%)*	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 12% WPSA IN SEVEN DAY CURED



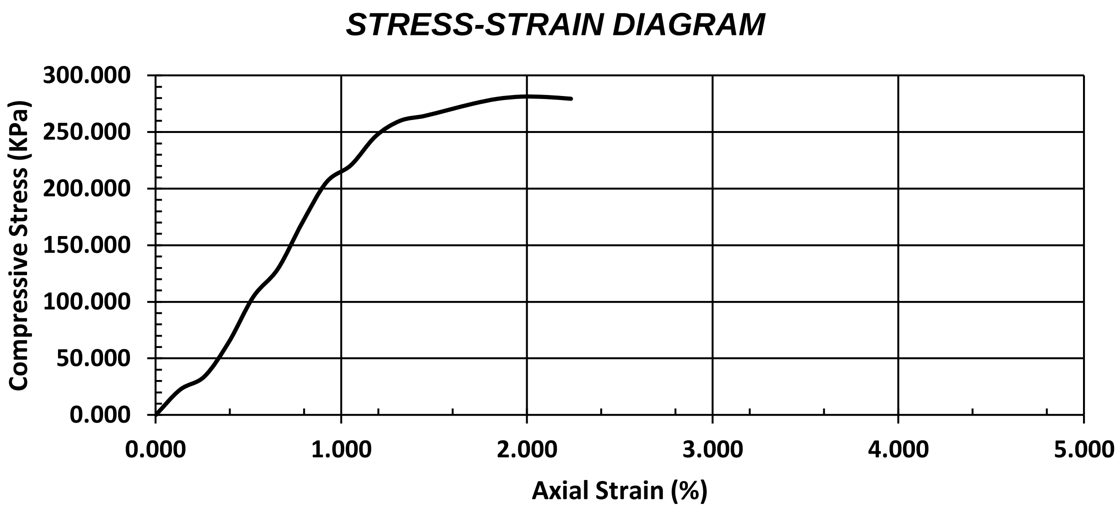
Unconfined Compressive Strength, q_u (KPa)	232.489
Undrained Shear Strength, S_u (KPa)	116.245
Failure Strain, E_f (%)	2.105
Wet Density, ρ (g/cm^3)	1.627
Dry Density, ρ_d (g/cm^3)	1.468
Natural Moisture Content, ***w (%)***	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 4% WPSA IN FOUR DAY CURED



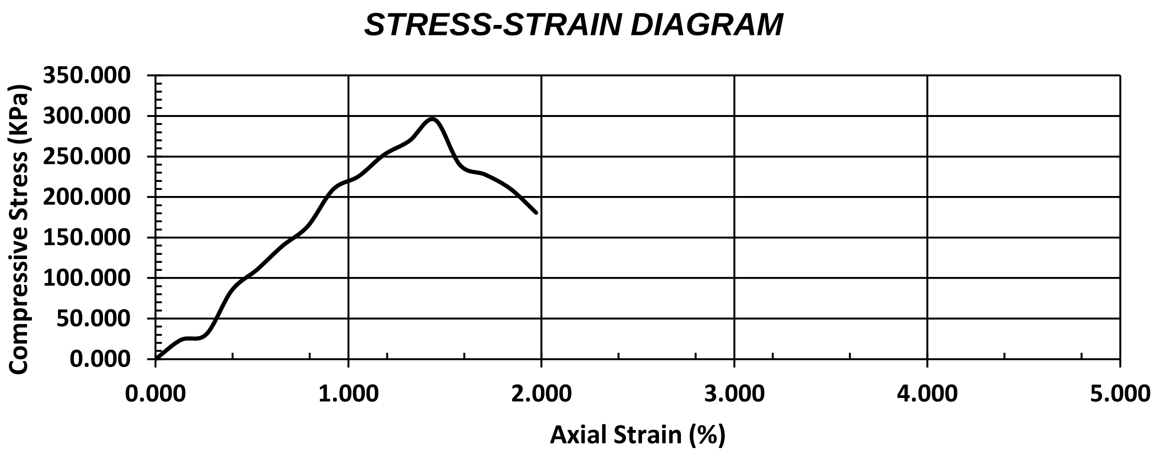
Unconfined Compressive Strength, q_u (KPa)	265.588
Undrained Shear Strength, S_u (KPa)	132.794
Faliure Strain, E_f (%)	1.974
Wet Density, ρ (g/cm^3)	1.591
Dry Density, ρ_d (g/cm^3)	1.435
Natural Moisture Content, *w (%)*	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 6% WPSA IN FOUR DAY CURED



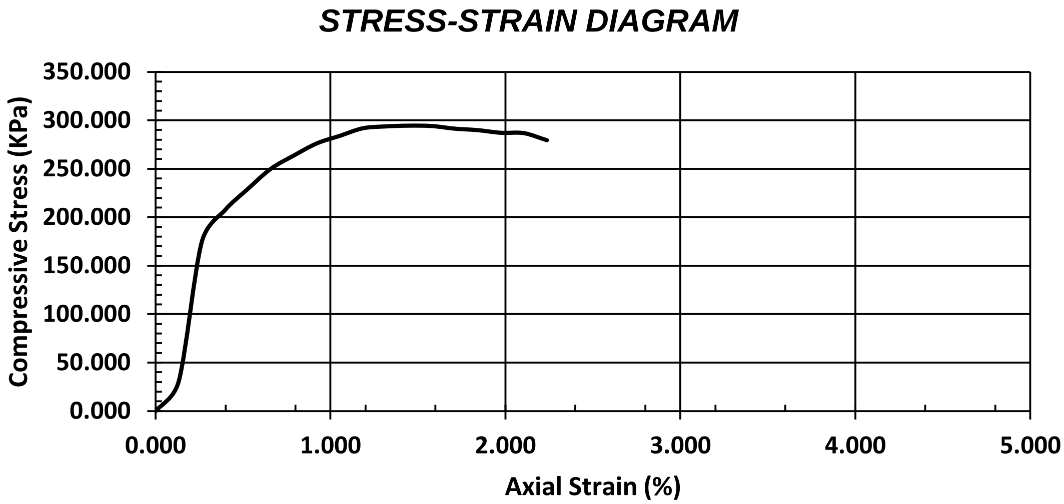
Unconfined Compressive Strength, q_u (KPa)	281.447
Undrained Shear Strength, S_u (KPa)	140.724
Failure Strain, E_f (%)	1.974
Wet Density, ρ (g/cm^3)	1.630
Dry Density, ρ_d (g/cm^3)	1.471
Natural Moisture Content, *w (%)*	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 10% WPSA IN FOUR DAY CURED



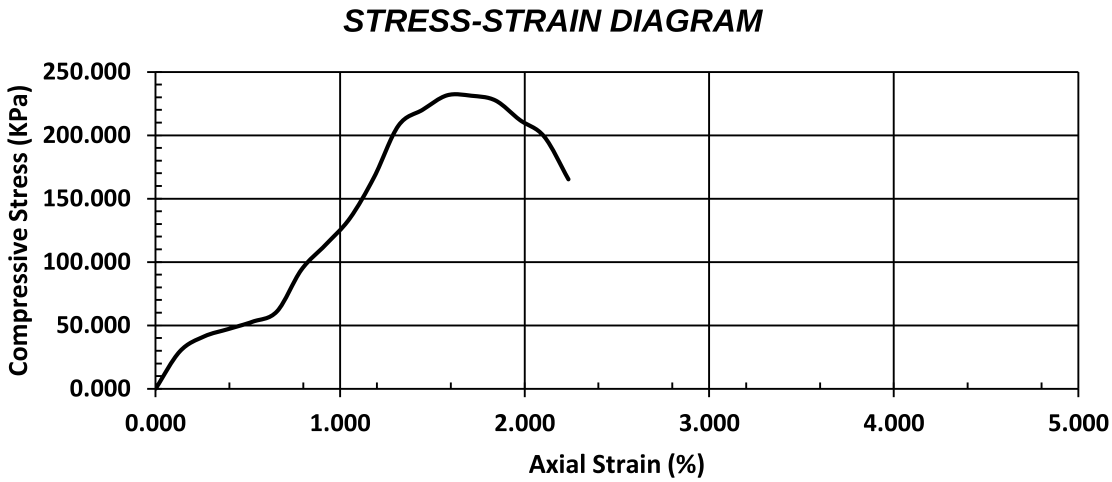
Unconfined Compressive Strength, q_u (KPa)	295.767
Undrained Shear Strength, S_u (KPa)	147.883
Faliure Strain, E_f (%)	1.447
Wet Density, ρ (g/cm^3)	1.718
Dry Density, ρ_d (g/cm^3)	1.551
Natural Moisture Content, *w (%)*	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 8% WPSA IN FOUR DAY CURED



Unconfined Compressive Strength, q_u (KPa)	294.603
Undrained Shear Strength, S_u (KPa)	147.301
Failure Strain, E_f (%)	1.447
Wet Density, ρ (g/cm^3)	1.618
Dry Density, ρ_d (g/cm^3)	1.461
Natural Moisture Content, *w (%)*	10.81

UNCONFIED COMPRESSION TEST RESLUT FOR 12% WPSA IN FOUR DAY CURED



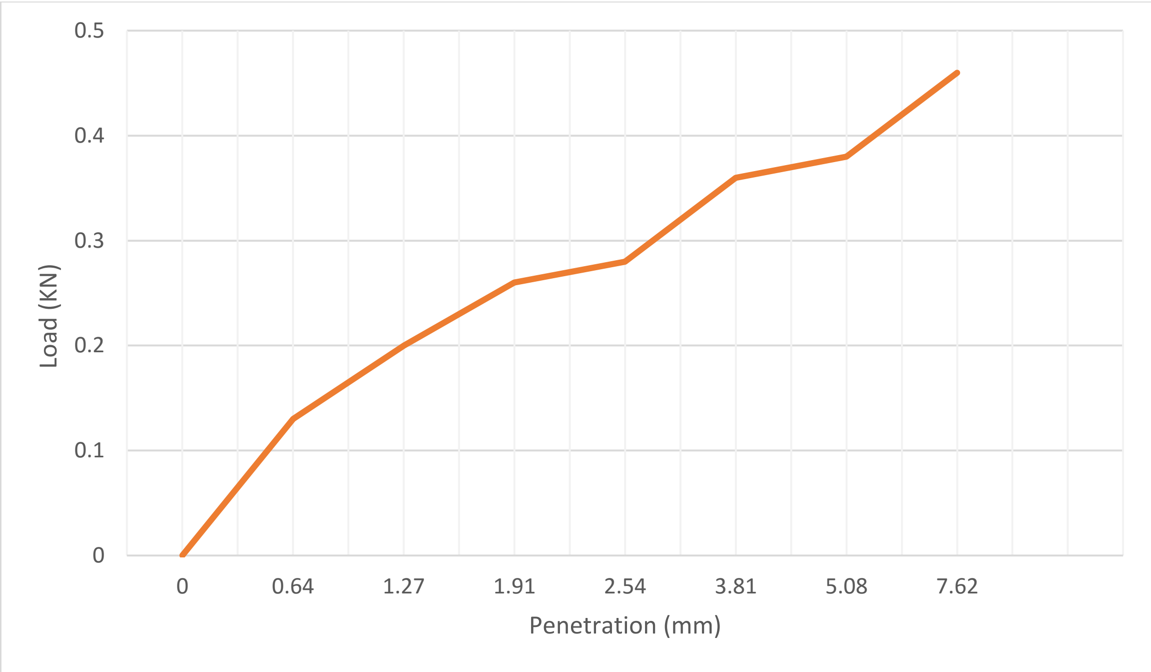
Unconfined Compressive Strength, q_u (KPa)	231.414
Undrained Shear Strength, S_u (KPa)	115.707
Failure Strain, E_f (%)	1.579
Wet Density, ρ (g/cm^3)	1.521
Dry Density, ρ_d (g/cm^3)	1.373
Natural Moisture Content, *w (%)*	10.81

Appendix 5

CALINFORINA BEARING REATIO TEST RESULT FOR NATURAL SOIL

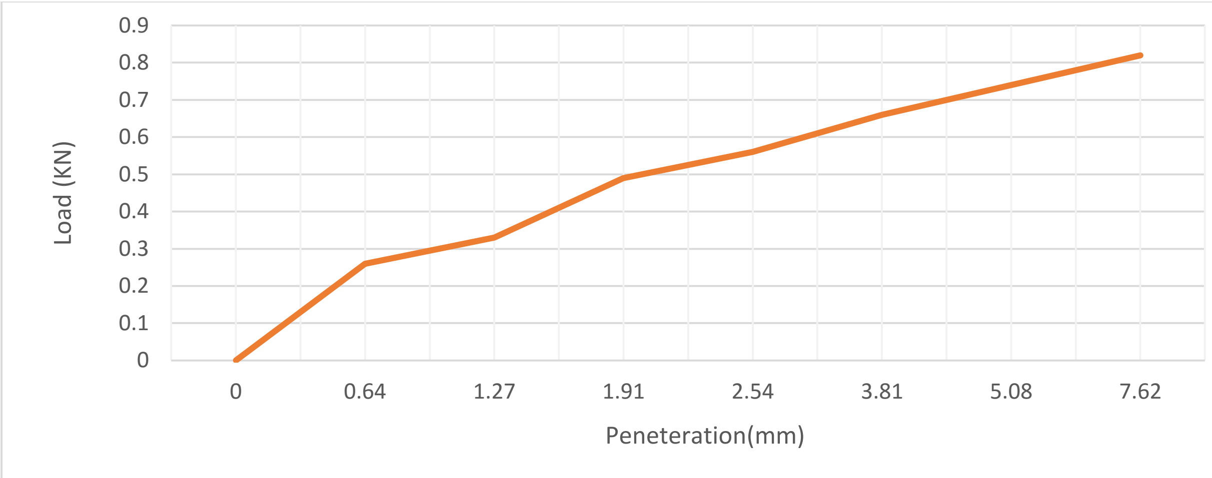
Table A-5. 1 Calinforina bearing ratio test result

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	5.02
13.2	20	0.28	0.38	2.13	1.92	



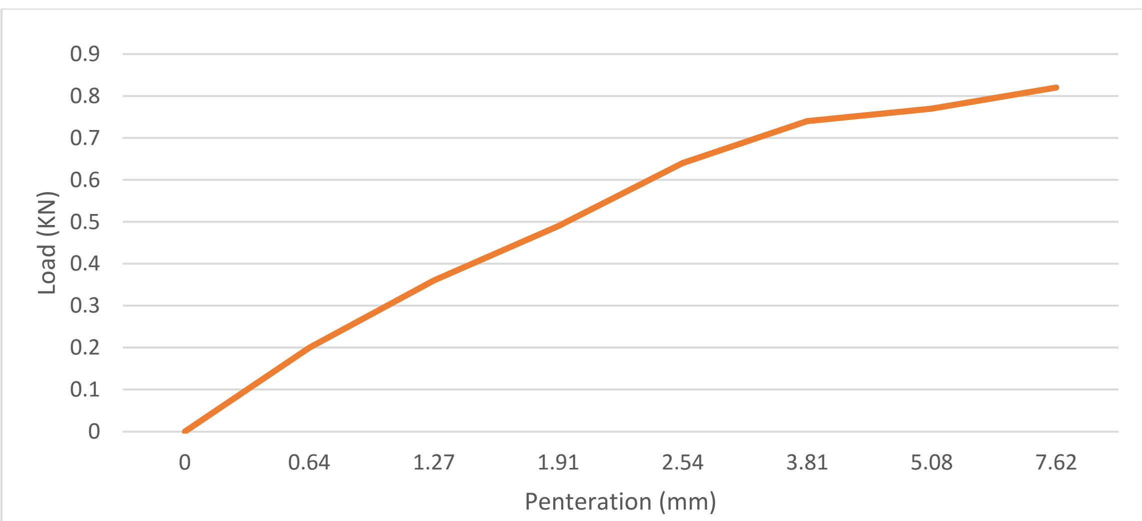
CALINFORINA BEARING REATIO TEST RESULT FOR 4%WPSA

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	3.98
13.2	20	0.28	0.38	4.26	3.71	



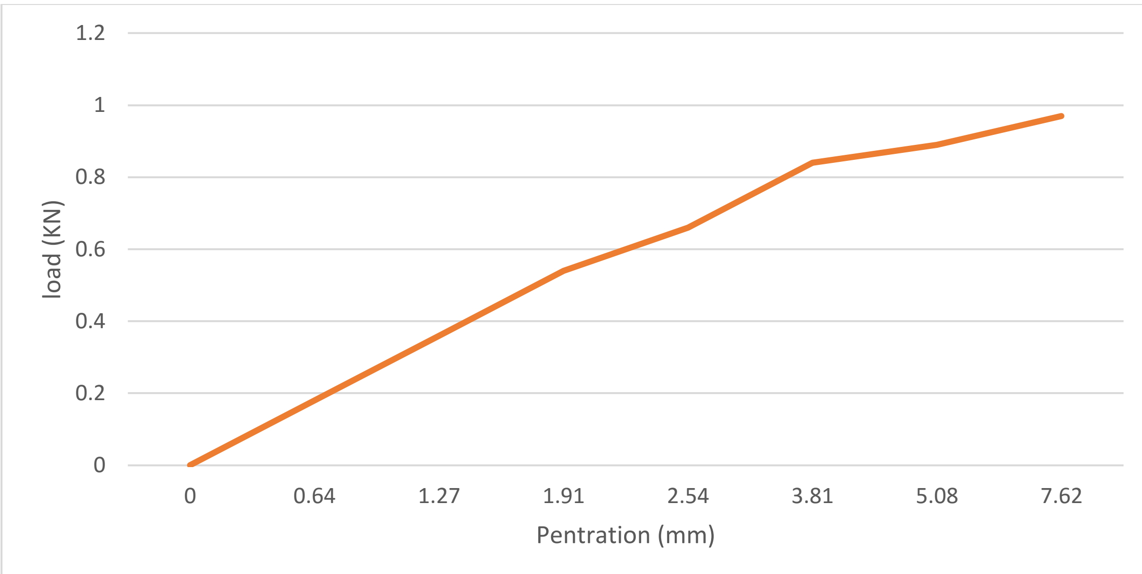
CALINFORINA BEARING REATIO TEST RESULT FOR 6%WPSA

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
13.2	20	0.64	0.77	4.84	3.84	3.85



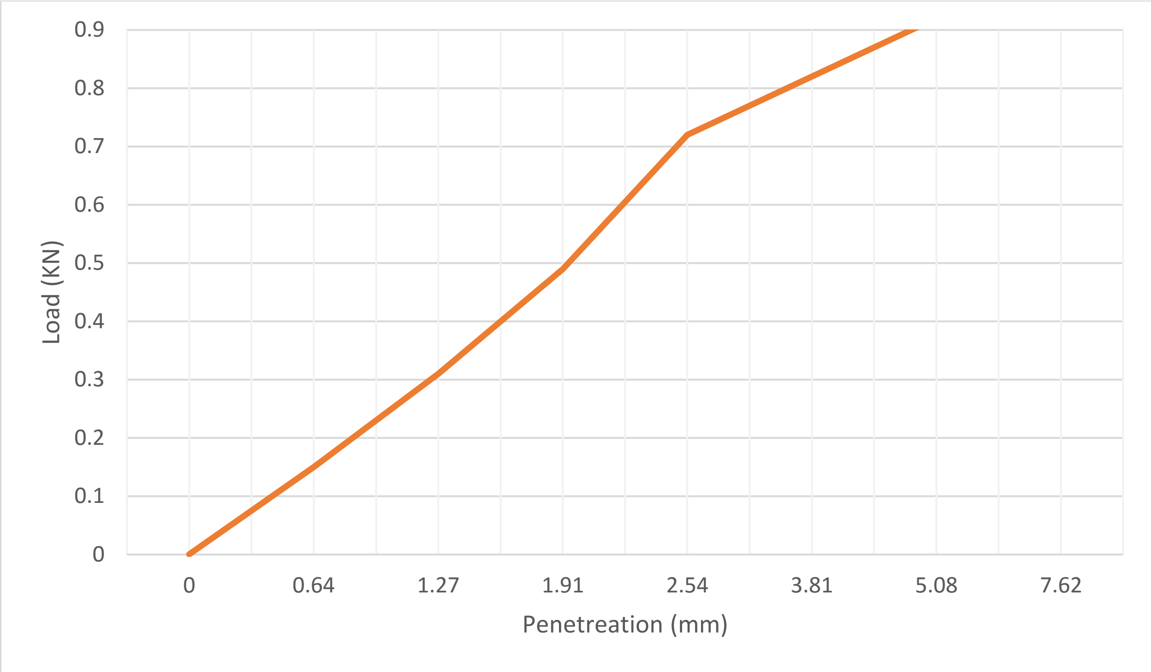
CALINFORINA BEARING REATIO TEST RESULT FOR 8%WPSA

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
13.2	20	0.66	0.89	5.04	4.47	3.62



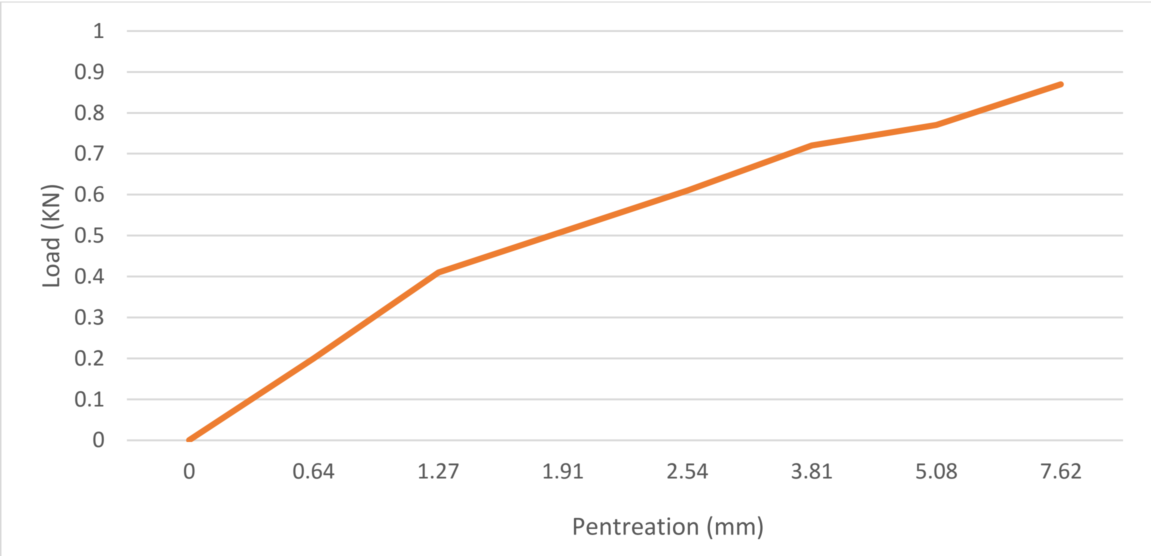
CALINFORINA BEARING REATIO TEST RESULT FOR 10%WPSA

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
13.2	20	0.72	0.92	5.42	4.6	3.26



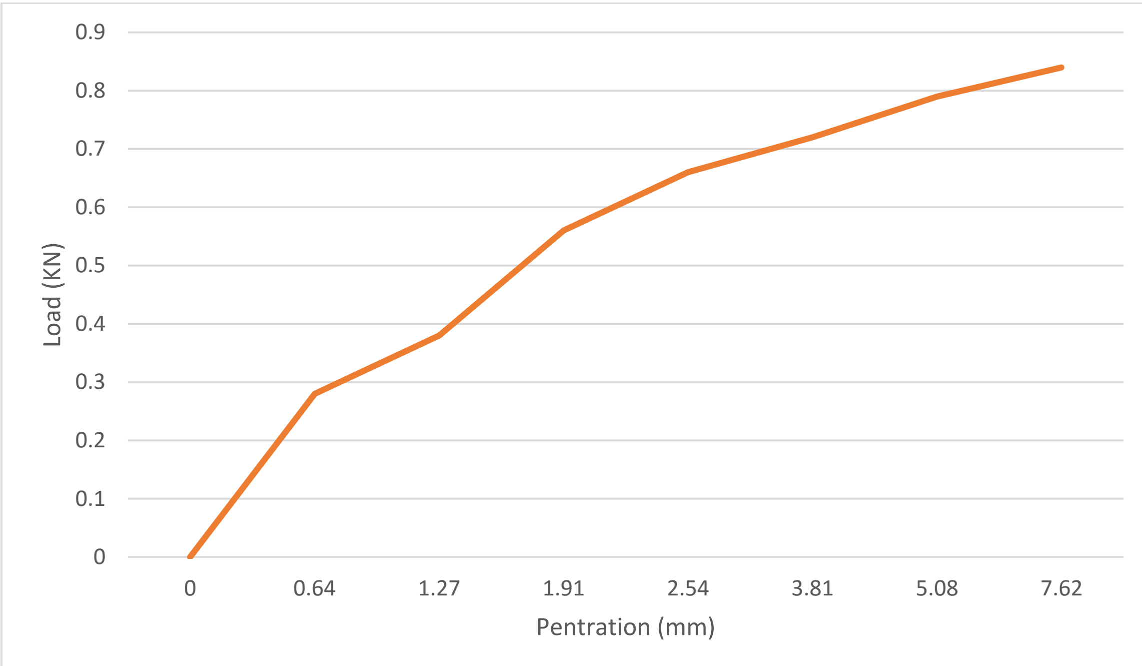
CALINFORINA BEARING REATIO TEST RESULT FOR 12%WPSA

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
13.2	20	0.61	0.77	4.65	3.84	3.31



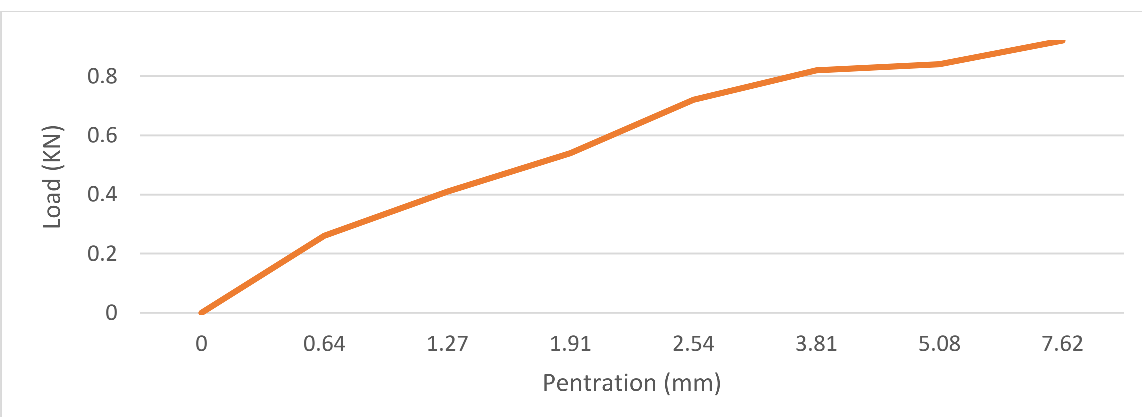
CALINFORINA BEARING REATIO TEST RESULT FOR 4%WPSA IN SEVEN DAY CURED

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
13.2	20	0.66	0.79	5.04	3.96	3.86



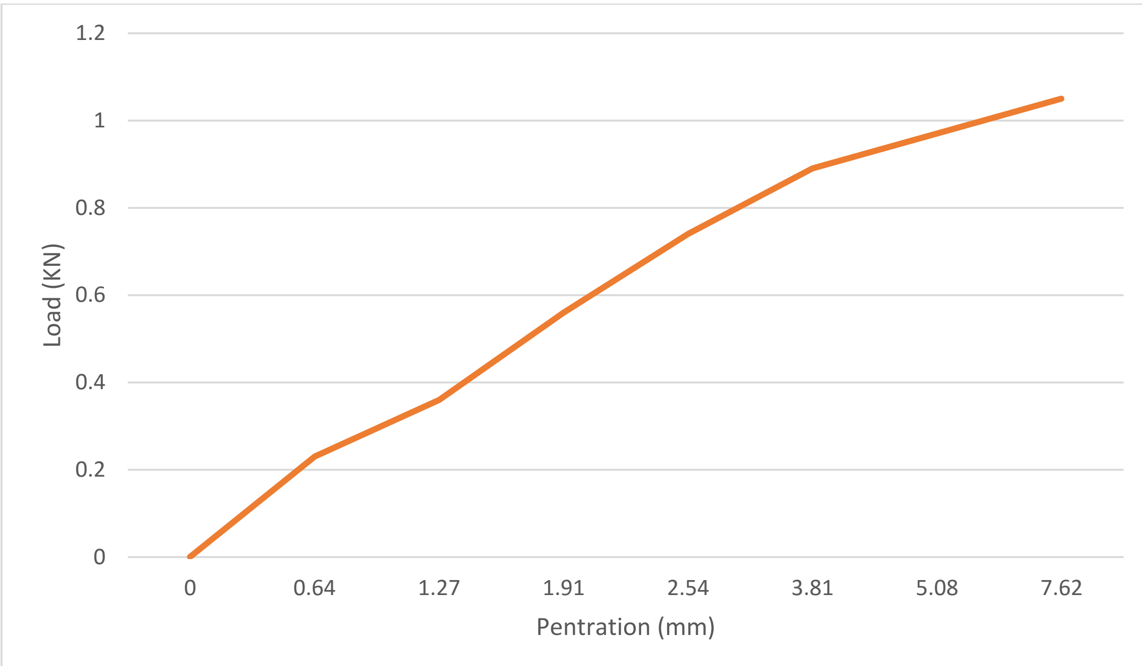
CALINFORINA BEARING REATIO TEST RESULT FOR 6%WPSA IN 7 DAY CURED

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
13.2	20	0.72	0.84	5.42	4.22	3.74



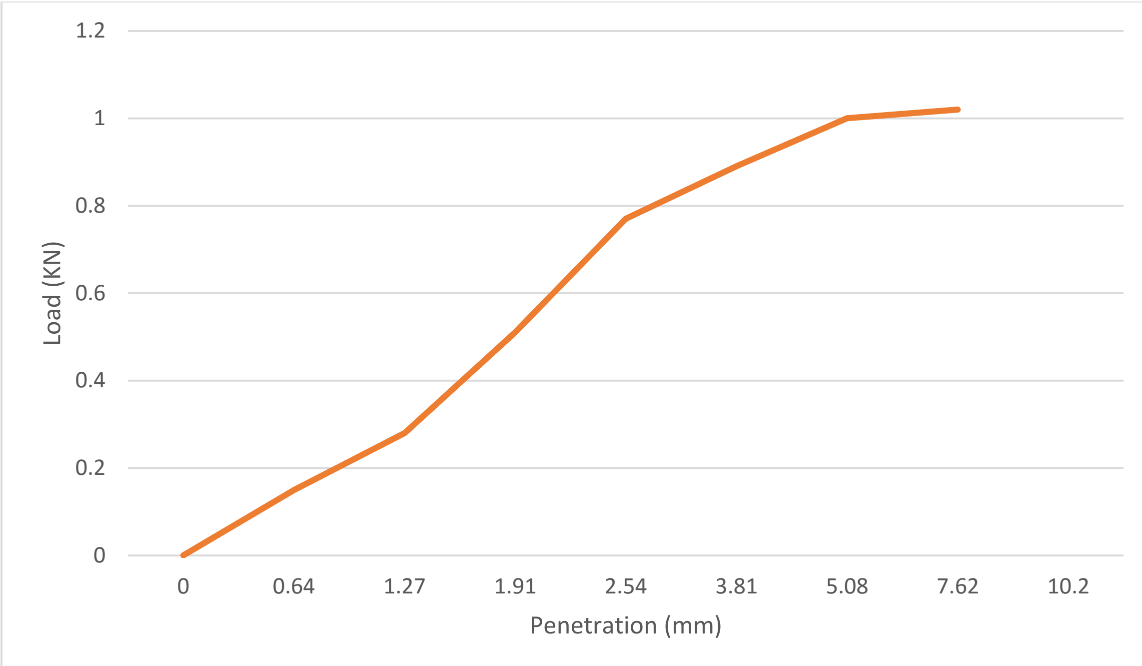
CALINFORINA BEARING REATIO TEST RESULT FOR 8%WPSA IN 7 DAY CURED

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
13.2	20	0.74	0.97	5.62	4.86	3.47



CALINFORINA BEARING REATIO TEST RESULT FOR 10%WPSA IN 7 DAY CURED

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
13.2	20	0.77	1	5.81	4.99	3.07



CALINFORINA BEARING REATIO TEST RESULT FOR 12%WPSA IN 7 DAY CURED

Standard Load (KN)		Load (KN)		CBR (%)		CBR-Swell (%)
2.54 mm	5.08 mm	2.54 mm	5.08 mm	2.54 mm	5.08 mm	
13.2	20	0.69	0.95	5.23	4.73	3.24