STRENGTH CHARACTERISTICS OF STATICALLY AND DYNAMICALLY COMPACTED SOILS AT DIFFERENT MOLDING WATER CONTENTS

A dissertation

submitted in the partial fulfillment of the requirement for the Award of the Degree of

MASTER OF TECHNOLOGY

In
CIVIL ENGINEERING
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DECLARATION

I hereby declare that the work presented in this report entitled "**STRENGTH CHARACTERISTICS OF STATICALLY AND DYNAMICALLY COMPACTED SOILS AT DIFFERENT MOLDING WATER CONTENTS**" in the partial fulfilment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13 under Assam Science and Technology University, is a real record of my work carried out in the said college under the supervision of Dr. (Mrs.) Binu Sharma, Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13, Assam.

Do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

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ABSTRACT

In this study, the strength characteristics of statically and dynamically compacted soils were investigated. Six soil samples with different physical properties from different sites of Guwahati were examined. Two methods of compaction—the static mode and the dynamic mode—were used to compact the soil samples. Standard Proctor compaction test was adopted as dynamic mode of compaction and to achieve static compaction the static compaction test set up according to Sharma et al. (2016) was used. To investigate the strength characteristics of soil samples of different category (CH, CI and CL) that has been statically and dynamically compacted, soil specimens were prepared at different molding water contents. The molding water contents at which the soil specimens were compacted are optimum moisture content (OMC) to achieve maximum dry density (obtained from standard Proctor compaction test), optimum moisture content minus three percent (OMC-3%) and optimum moisture content plus three percent (OMC+3%) for five soil samples and it was optimum moisture content, optimum moisture content minus five percent (OMC-5%) and optimum moisture content plus five percent (OMC+5%) for one soil sample.

To investigate the strength characteristics of statically and dynamically compacted soil, unsoaked CBR test and unconfined compressive strength test were conducted on the soil specimens. From the test results it was observed that for all the six soil samples, static compaction yielded higher unsoaked CBR values than soil samples compacted dynamically. In case of unconfined compressive strength three samples yielded higher unconfined compressive strength while statically compacted and the other three gave higher value in dynamic compaction. This could be because of the three dynamically compacted soils developing the suction phenomenon, which caused the temporary rise in unconfined compressive strengths that was seen. Nevertheless, long-term strength tests must be performed in order to comprehend the overall strength behaviour.

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CHAPTER 1

INTRODUCTION

Compaction of soil refers to the process of increasing the density of soil by reducing the volume of air within its pores. The process of compaction involves mechanically rearranging and packing the soil particles into a closer state of contact in order to reduce the porosity (or void ratio) of soil and consequently increase its dry density. Compaction is the term used to describe a relatively rapid decrease in the air voids under a loading of short duration. This is typically achieved through the application of mechanical energy, such as rolling, tamping, or vibrating to the soil.

The mechanical energy needed for compaction of soil can be provided dynamically or by static means. Dynamic compaction methods involve the application of repeated dynamic loads to the ground surface using heavy machinery, such as a dropping weight or a vibrating compactor. The energy imparted by the dynamic loads helps rearrange soil particles, reduces voids, and increases soil density. Another common method used in geotechnical engineering to enhance the engineering qualities of soil is static compaction. Unlike dynamic compaction, which involves the application of dynamic (impact) loads, static compaction relies on the application of a static (steady) load to compress and densify the soil. This process is typically achieved using heavy machinery, such as rollers or compactors.

The compaction characteristics of soil are first determined in laboratory. The standard laboratory compaction test which was derived by R.R Proctor for the construction of earth fill dams in the state of California is commonly used in the laboratory to find out compaction characteristics i.e. maximum dry density (MDD) and optimum moisture content (OMC). As a tribute to Proctor, this method is called as the Standard Proctor Test. This method is used in the laboratory to find out MDD and OMC in the laboratory to decide for the MDD and OMC of subgrade, but static roller machines are mainly employed in the field. So, to bridge the gap between laboratory and field data and to approximate actual field conditions as much as possible, many researchers have been working on developing static compaction method for determination of equivalent compaction characteristics.

Analyzing the effects of applying various compaction procedures on soil compaction is essential; because compaction is basically a process that modifies soil structure. Increasing the strength and stiffness of soil by reducing the compressibility is the main objective of the compaction process and it could be possible that the method of compaction used, i.e., whether a static or dynamic method of compaction has been used, will affect the soil strength. So, the assessment of the impact of various compaction techniques on the compaction curve of soil and, in turn, its mechanical strength is of great importance. An attempt has been made in this study to draw a comparison between the strength of soil samples compacted at the same moisture content to the same bulk densities by using both static and dynamic methods of compaction. The soil samples have been compacted both statically and dynamically at the dry of optimum, at optimum moisture content and at wet of optimum moisture content.

The study of compacted clay holds immense significance in geotechnical engineering and construction practices. The primary goal of this study is to investigate the strength characteristics of statically and dynamically compacted soils at different molding water content. A comparison between the unsoaked CBR values of a statically and dynamically compacted soil specimen has been attempted. Likewise, the unconfined compressive strength of clayey soil that has been statically and dynamically compacted is examined. A comprehensive analysis of the experimental procedures, description of the apparatus and the analysis of the test results obtained are discussed further in the work.

CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

Various research workers conducted static compaction and standard Proctor test to predict the compaction properties of soil and also to bring a comparison between these two methods of compaction. This chapter provides a brief discussion of the work done by various researchers to know the compaction properties of soil by these two approaches.

2.2 REVIEW OF LITERATURE

Laboratory compaction is an important test to obtain maximum dry density and optimum moisture content values. Different research workers like Reddy and Jagadish (1993); Hafez M.A., Doris Asmani M. and Nurbaya S. (2010), Talukdar and Sharma (2014), Sharma et al. (2016) etc discussed about static compaction method in their work which are discussed briefly below.

Hogentogler (1937) is thought to be the first researcher to describe the idea of static pressure, which is comparable to Proctor's compacting pressure. His results indicate that the equivalent static pressure of 896 KN/m^2 must be applied to the soil in order to achieve Proctor's compaction at its maximum dry density.

Beredhard and Kryine (1952) had compared the static and dynamic compaction efficiencies.

In order to perform static compaction**, Kenneth & Steven (1968)** used a metal plunger with a 1.4-inch diameter to force the soil into the mould, contrasting the outcomes of static compaction and kneading compaction. It was determined that the kneading compaction method yielded a lower maximum dry density than the static compaction method.

A newly developed static compaction test for soils was introduced by **Reddy and Jagadish** in **1993**. This test is intended to be employed in the production of compacted soil blocks. A continuous relationship between compaction energy and OMC can be obtained by using the static compaction test that they described in their work. OMC becomes a function of the energy input for a given maximum dry density in such a test since the energy input per unit volume might be readily changed. Two approaches of static compaction were developed in the laboratory by Reddy and Jagadish (1993): constant peak stress-variable stroke compaction and variable peak stress-constant stroke compaction.

In the constant peak stress-variable stroke compaction concept the applied stress is varied gradually at a definite rate until a specific peak stress is reached. The moisture content affects the compressed specimen's thickness. Olivier & Mesbah (1987) and Turnbull (1950) have conducted such testing. Similar to the Proctor curves, compaction curves were produced in these tests, but the energy input to the soil changed according to the moisture content. In contrast, a static force is gradually applied to a soil mass in variable peak stress-constant stroke compaction until a particular final thickness (volume) is reached. Depending on the soil's moisture level, this force at the end of compaction can change.

In their work, Reddy and Jagadish (1993) used static compaction of soil in small cubes at varying moisture contents while monitoring the energy input to the cube to determine the link between compaction energy, dry density, and OMC. This relationship gave precise information on the OMC to be applied when the compaction energy available in the static compaction process was known in order to reach a specified dry density.

Reddy and Jagadish (1993) also compared the results of static compaction and Proctor compaction by superimposing the curves obtained from both the methods as shown in Figure below. Upon comparison, it was discovered that the static compaction curves only showed the Proctor compaction curve's "rising" section; the "droping" portion that is often observed in the Proctor curve was absent. The graphs also demonstrated that the static compaction results in a substantially higher dry density for the same input energy and OMC value.

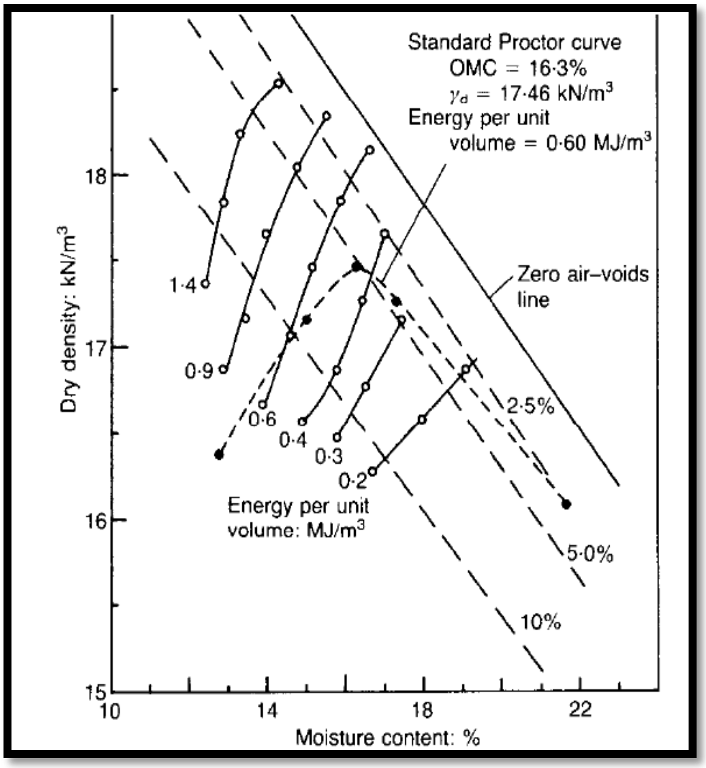

Fig. 2.1: Comparison between static compaction method and the stadard Protor compaction method by Reddy and Jagadish (1993).

Delage et.al (1996) in their work presented a qualitative and quantitative study of the microstructure of compacted silt. The samples were compacted statically at three water contents, on the dry side of standard Proctor optimum water content, optimum water content and on the wet side. The approach used is Diamond's (1970) methodology, which combines two complimentary techniques: qualitative observations and scanning electron microscopy (SEM) and a quantitative assessment of the morphology of the porous medium using measurements of the mercury intrusion pore size distribution (PSD).

It was discovered that the pore size distributions derived from the compacted silt corresponded to those of prior research on pure clays (kaolinite and illite). This increases the general validity of the results of this study on compacted fine-grained soils and makes it possible to draw some broad conclusions about the microstructures of compacted soils.

1. **1.** Visible interaggregate porosity in porosimetry is a characteristic of the soil structure at low water contents. The clay fraction is only visible as an infill material or as a coating on the grains due to its incomplete development.
2. **2.** The structure is less defined and more cohesive at the optimum water content, with a clay coating similar to that observed on the dry side. Because the aggregates are less resistant to deformation and break down more readily, resulting in a reduction of interaggregate porosities, a greater density can be reached with the same compactive effort as on dry soil.
3. **3.** The well-developed wet clay that makes up the wet side of the structure surrounds the silt grains and fills in the spaces between them in the form of a matrix. In this instance, the only voids identified by porosimetry are those of the clay matrix, whose radii are closely clustered around a value of 0.44 µm.

As the findings of this study and those of Ahmed et al. (1974) on a variety of clays are comparable, the same conclusion should be applicable to clays. In this instance, a microstructure made up of clayey aggregates would represent the solid state, and they would behave like very stiff grains.

Hafez et.al (2010) developed a new laboratory compaction technique which is suitable for measurement of degree of compaction for Malaysian cohesive soils. In their study two main methods of compaction were used which are Static Packing Pressure and Standard Proctor Test. The majority of Malaysia's road infrastructure is built on cohesive soils, and in order to meet the necessary MDD, static road roller machines are mostly employed in the field. But Standard Proctor Test is done in the laboratory to determine MDD of soil. So, in order to bridge the gap between laboratory and field data, a new technique employing static compaction efforts has been developed for determining the MDD and OMC values. In their study they also drew a comparison between the static packing pressure method and the standard Proctor method to determine MDD and OMC of soil.

The Packing Pressure Test was designed as static compaction technique in the laboratory. In this study, static packing pressure test imparts a constant compression force to the soil using a new static mould design with a certain amount of energy. The amount of energy is dependent on the characteristic and the conditions of each type of soils. As a result, according to the results of the static compaction test, every soil has a different amount of energy per unit volume than when using the Proctor compaction standard, which uses the same energy for all soil categories.

The compaction technique uses a hydraulic pump to apply a gradually increasing static force to the soil, while the static packing pressure machine measures the force values using a load cell attached to a data logger. A new static mould was created to ensure that the soil inside it has a high degree of freedom to plunge out under excessive static compaction. The static compaction was carried out in a single homogenous layer.

For dynamic compaction Standard Proctor Test was used according to BS 1377: Part 4, 1990. After that the test results were compared between static and dynamic compaction methods. The static method yields higher OMC and MDD values than the dynamic method, according to a comparison of the compaction test conducted using both static and dynamic methods. In order to correlate laboratory compaction values with field data from the static compaction technique, the static compaction test can be used to measure the degree of compaction value. In comparison to the dynamic concept, static compaction can also be characterized as a quicker, simpler, and easier method that can be completed in a lab setting.

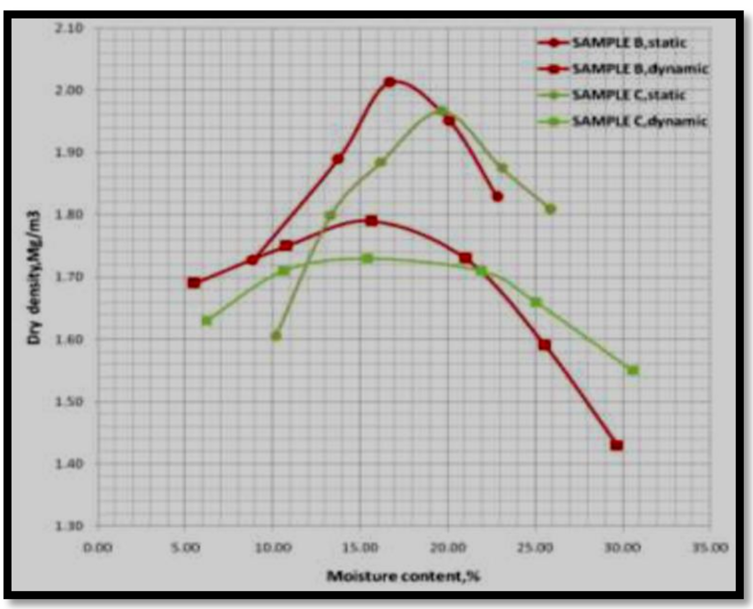

Fig. 2.2:Comparison between static compaction method and the dynamic compaction method by Hafez et.al (2010)

Dario et al. (2011) examined the impact of the static and dynamic laboratory compaction procedures on the compaction curves. The mechanical strength of two residual soils from the Zona da Mata Norte, in the state of Minas Gerais, Brazil has also been discussed. Two types of residual soil are tested in the lab: clayey-silty clay (soil 1) and clayey-silty sand (soil 2).

The soil specimens have been compacted at and close to OMC using the typical Proctor compaction effort. Unconfined compressive strength of the compacted specimens, micro morphological examination of thin sections of the laboratory testing program data is incorporated into the research as well.

All specimens were compacted at the standard Proctor compaction effort using nine repetitions of the compaction curve at the following water contents: optimum water content (w_{ot}), w_{ot} – 3%, and w_{ot} + 2%, in an effort to replicate the compaction effort and water content typically used in the field compaction of landfills and sub-grade soil layers. In order to achieve an equilibrium water content in the soil mass, all specimens were compacted 24 hours after mixing. To find the dry unit weight (γ_d) at chosen water content, the compaction tests were conducted using dynamic and static compaction laboratory procedures.

Dynamic compaction was done as per Standard Proctor compaction test and with the aid of a hydraulic pump, static compaction was carried out by applying enough pressure to each layer of the three-layered specimen to enable the achievement of the intended dry density at a chosen water content, which corresponds to dynamic compaction. Since the applied force to the specimen was uncontrollable during the static compaction process, only the mass and layers of height were controlled. The acceptance criteria adopted for specimen preparation was water content maximum deviation of ± 0.3%.

Figure below shows the compaction curves and unconfined compression data from laboratory tests performed by them in specimens of soils 1 and 2 respectively.

Soil	w_{ot} - 3% (%)	γ_d (kN/m^3)	w_{ot} (%)	$\gamma_{d\,max}$ (kN/m^3)	w_{ot} + 2% (%)	γ_d (kN/m^3)
1	27.50	13.62	30.50	14.18	32.50	13.78
2	11.90	17.15	14.90	17.42	16.90	17.15

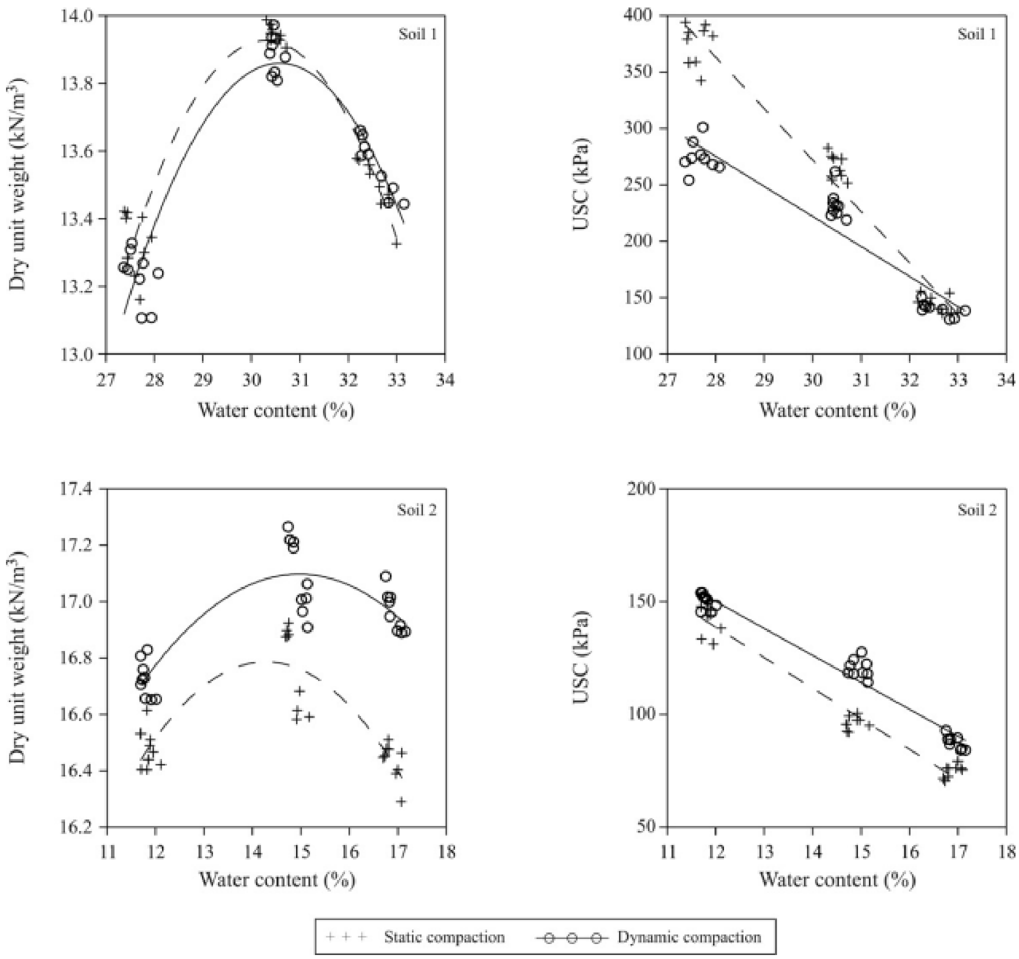

Fig. 2.3: Compaction curves and Unconfined Compressive Strength (UCS) of soil 1 and soil 2 (Dario et al. (2010))

For fine-grained soil sample-1 of the CH category, it is evident from the graph that static compaction results in higher dry density and higher unconfined compressive strength up to a specific water content (in the wet side of optimum), as indicated in figure. For the same soil, an opposing trend in dry density and mechanical strength is observed after the particular water content. However, compared to static compaction, dynamic compaction produced higher dry density and mechanical strength values for the SC type of soil, regardless of water content. Therefore, it is clear from the result that the method of compaction significantly affects the mechanical strength of soil.

Using the dynamic compaction data as a point of reference, Figure below illustrates the relative differences between the mean values of the parameters γ_d and UCS of soils 1 and 2.

The relative differences between the γ_d mean values are not significant for engineering applications in practice, with soil 1 showing a difference of less than 1%.and 3% for soil 2; however, the relative differences are greater when it comes to the UCS mean values, reaching roughly 37% for soil 1 and 20% for soil 2, highlighting the important impact of the compaction process on soil mechanical strength.

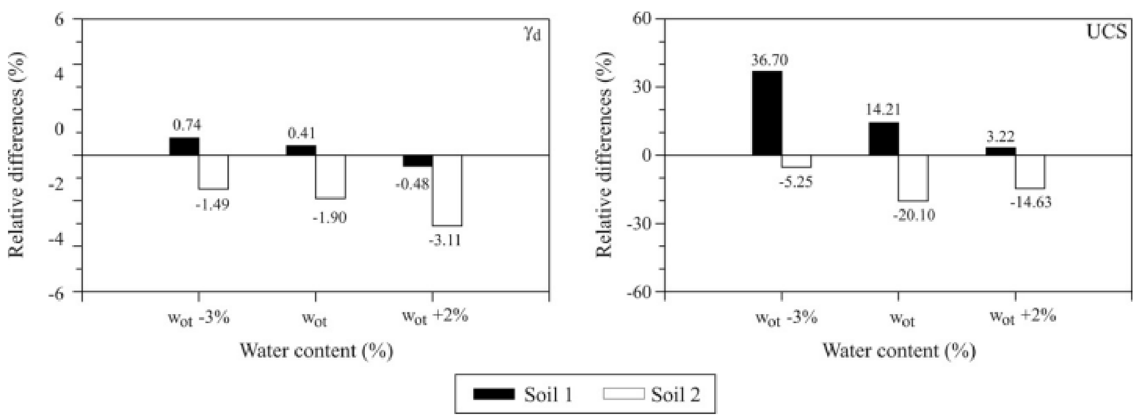

Fig. 2.4: Relative differences between mean values of the parameters γ_d and UCS of soils 1 and 2, adopting the dynamic compaction data as reference (Dario et al. 2010)

Statistical analyses of γ_d and UCS data from soils 1 and 2 at the 5% significance level indicate statistically significant differences between the data from the static and dynamic compaction procedures with respect to the parameter γ_d. On the other hand, taking into account the UCS parameter, the results of statistical analysis confirm that the compaction procedure affects the mechanical strength of soil, with the exception of specimens of soil 1 compacted at the water content w_{ot} + 2%.

The micro morphological analysis was performed using an optical microscope on a thin section of the specimen that was compacted statically and dynamically at a water content of w_{ot}- 3%. The QUANTIPORO software was used to determine the porosity data associated with this water content.

Figure (a) at OMC illustrates the original microaggregation characteristics of the statically compacted soil 1 specimens, including the presence of original nodules, the creation of isolated gaps and fissured and oriented porosity, as well as low porosity, approximately 3%. Conversely, figure (b) indicates that, at this same water content, dynamically compacted specimens retain approximately 2% of their original porosity and still display a few original microaggregation features. As seen in figures (c) and (d), the static compaction applied to soil 1produced a structure with strong original micro aggregation and gap features, and porosity of about 11% on the dry side of optimum, at water content w_{ot} -3%.

From an alternative perspective, the original micro aggregation was destroyed by dynamic compaction, resulting in partially bonded microstructured argillaceous plasma with a porosity of approximately 2%—much lower than that imposed by static compaction

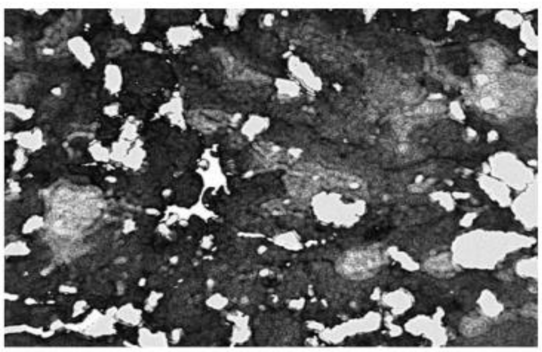
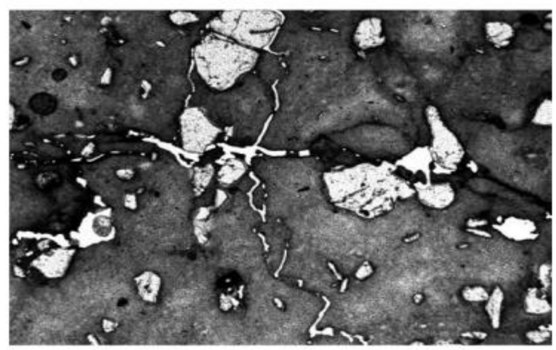

Fig. (a) Static compaction at OMC

Fig. (b) Dynamic compaction at OMC

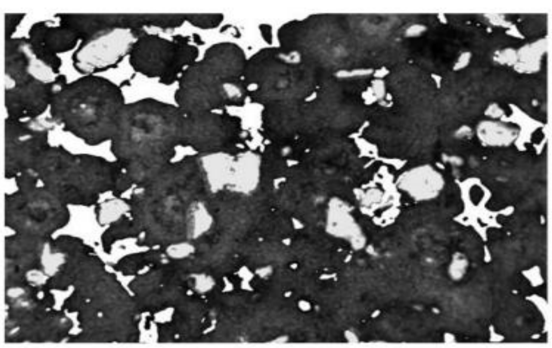
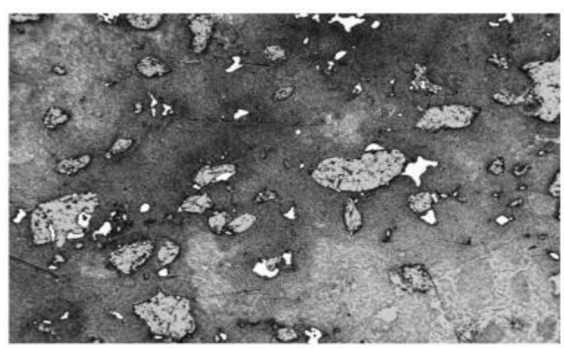

Fig. (c) Static compaction at (OMC –3)

Fig (d) Dynamic compaction at (OMC-3)

Fig.2.5 Photomicrographs taken from thin section obtained from of soil specimen 1 (Dario et al. (2011))

It should be emphasized that soil 1 exhibits silty-sandy clay texture, with significant clay fraction of 66%. Geotechnically, it is classified as mature residual soil, and pedologically, as red-yellow latosol, indicating occurrence of advanced pedogenetic formation processes. It also presents granular structure, with well individualized granules and highly porous aspect that can present potential collapse according to Azevedo (1999). Therefore, in soil specimen 1, there can be predominance of interparticle forces that were affected or destroyed by the dynamic compaction, producing structures with lower shear strength. This kind of behavior is compatible with the one described by Bueno et al. (1992) when analyzing the effect of dynamic compaction in a red-yellow latosol in comparison with its mechanical response under undisturbed field condition.

Performing the requisite tests, the researchers have concluded that there is significant influence of the compaction procedures on the optimum compaction parameters as well as on the soil structure. The researchers have concluded that compared to the dynamic compaction, the static procedure produced specimens with higher UCS for the clayey soil (soil 1), and lower UCS for the granular soil (soil 2), bringing up the importance of soils formation processes in their mechanical responses. Considering the applied compaction methods, statistically significant differences were identified in the parameters γ_d and UCS of both soils, except for specimens of soil 1 compacted 2% above the optimum. Therefore, the use of the static compaction procedure in laboratory to obtain compaction and mechanical strength parameters of soils for field applications requires careful study. Moreover, differences in the soils structure produced by the static and dynamic compaction procedures can be justified through optical microscopy technique.

Asmani et al. (2013) developed a new laboratory compaction set up to investigate the CBR values based on OMC values by using Static Laboratory Compaction Method. Two methods were employed to prepare the specimens: Standard Proctor method and Static Packing Pressure method. In order to calculate and compare the CBR values between packing pressure and dynamic compaction specimens, three soil samples were examined in the laboratory in unsoaked conditions. The two directions from which the soil specimens were tested were top and bottom. The maximum CBR value of the CBR_{top} and CBR_{bottom} at 2.5 mm or 5.0 mm penetration was selected as the CBR value in this study. With the help of an electric motor, the soil specimen was compressed through the static packing pressure CBR mould. Next, the CBR value was determined using the 2.5 mm and 5.0 mm penetrations shown in the CBR graph. The standard forces for these penetrations were13.2 kN and 20 kN, respectively. Then, soil samples were prepared for determination of CBR value using the conventional Standard Proctor method (dynamic method). The CBR value was determined in a similar way as it was in the case of the static packing pressure test. According to the data, for unsoaked soil conditions, packing pressure compacted soil specimens had higher CBR values than dynamic compaction. In general, the variations in CBR values varied from 10.96% to 53.9% for static and dynamic compaction. It was observed that there was an influence of the plasticity index (PI) over OMC on the CBR values obtained. Lower CBR values were obtained in the soil sample with higher PI over OMC value. In general, it was seen that the CBR values are influenced by the characteristics of the soil sample and the rise or fall in OMC values. In conclusion it could be said that static packing pressure yielded higher strength value which minimizes the failure and damages of subgrade road layers and a higher CBR value reduces the cost of road construction.

B. Sharma & P.Talukdar (2014) developed a laboratory procedure to determine the maximaum dry density (MDD) at optimum moisture content (OMC) value by using static compaction. Three different soils with different plasticity characteristics were tested in total in their analysis to show that the relationship between water content and dry density in static compaction is parabolic in nature. An attempt has been made for improvements to be made over conventional methods of comapction to get immediate results without affecting the accuracy. In this analysis they have made an effort to obtain compaction characteristics using the static compaction method in order to obtain the compaction characteristics of the soil equivalent to Proctor's test in the laboratory, thereby avoiding the large time and effort required to carry out the standard Proctor's test.

The objective of their study was to determine the equivalent static pressure at which the standard Proctor's MDD at OMC can be obtained. A comparison was also drawn in order to determine how the OMC and MDD values of the static and standard Proctor compaction methods differ.

The dynamic compaction properties were determined by standard Proctor’s compaction test, conforming to the standard specification as per IS: 2720 (Part 7)-1980. A new method was implemented in the lab in order to achieve static compaction.

A constant weight was placed on the prepared soil for the first layer with known moisture content in the standard Proctor mould. On top of the soil sample in the mould, two metal plates with a diameter of 100 mm and a thickness of 5 mm and 16 mm were placed one on top of the other. The entire assembly was ten placed under a cylindrical plunger and load was statically applied to the soil. For different applied loads, the amount by which the soil was compacted was calculated by measuring the height of the soil inside the mould. By dividing the various applied load values by the area to which it was applied, the static pressure was computed. Also, as the water content at which soil was filled was known, dry density was also computed.

The mould was filled with three different heights for static compaction to ascertain whether there can be variation in dry density with layer thickness. Thus, the process for static compaction was repeated three times for each moisture content of a single soil sample, corresponding to the three distinct soil layers, while maintaining a constant soil weight for each layer in all three soil samples.

It was seen from the test resuts that the dry density increases to its maximum value and then remains constant with further increase in static pressure. I t was also observed that there was no significant variation in dry density for compacting the soil in three different thickness . The curves plotted for dry density against static pressure were obtained as shown in the figure below for the three soil samples.

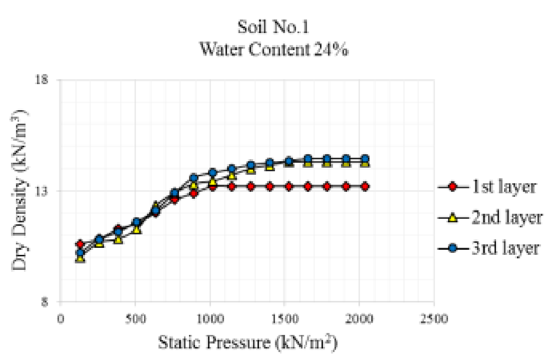

Fig. 2.6: Dry density vs static pressure for soil no.1 at 24% water content (B.Sharma et.al,2014)

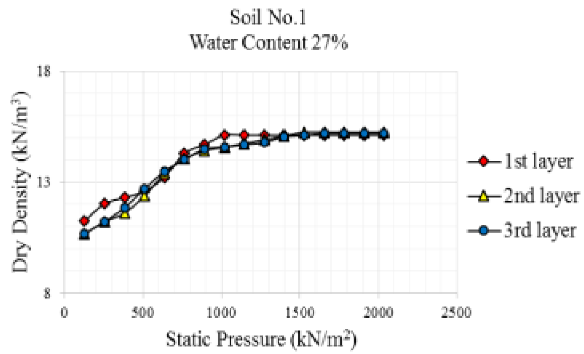

Fig. 2.7: Dry density vs static pressure for soil no.1 at 27% water content (B.Sharma et.al,2014)

The relationship between dry density and moisture content for each of the three layers is found for a given static pressure. This relationship between moisture content and dry density for a particular soil at a particular static pressure is found to be parabolic in nature. Also,they found that there was negligible variation for the the static maximum dry density in the three different layers .

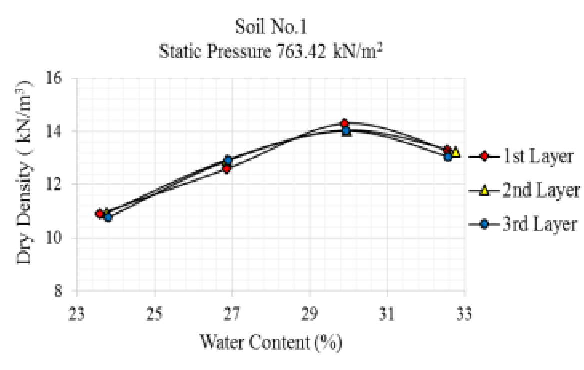

Fig. 2.8: Dry density vs water content curve for soil no.1 at 763.42 kN/m^2(B.Sharma et.al,2014)

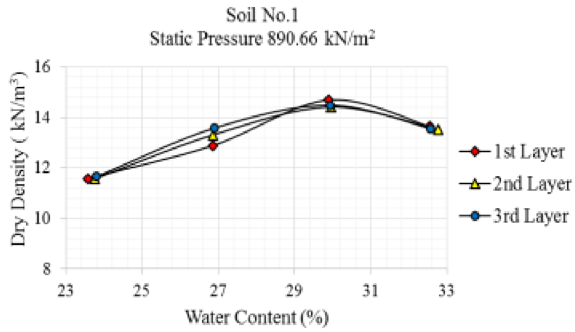

Fig. 2.9: Dry density vs water content curve for soil no.1 at 890.66 kN/m^2(B.Sharma et.al,2014)

A number of curves corresponding to different static pressures are superimposed along with standard Proctor compaction curve as shown.

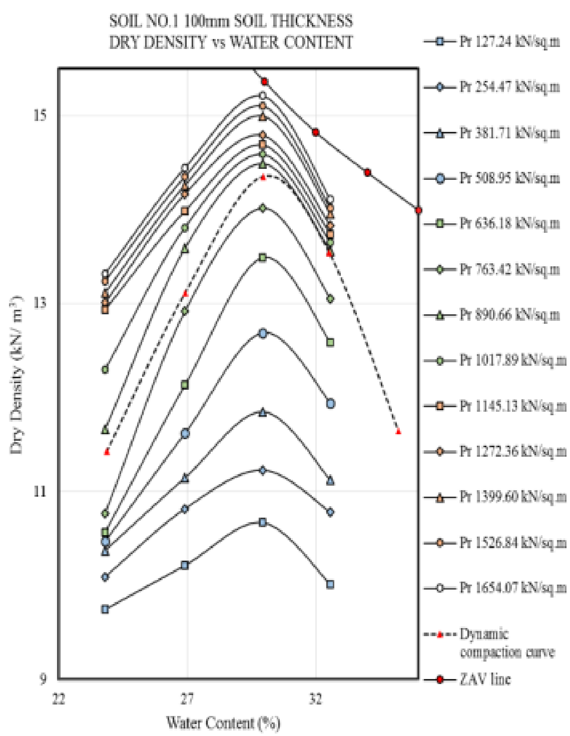

Fig. 2.10: Dry density vs moisture content curve for soil no.1 (B.Sharma et.al,2014)

It is observed from the curves that with the increase in static pressure, the maximum dry density increases but the optimum moisture content remains almost the same. It's clear from the curves that a static pressure between 700 and 850 kN/m2 is needed to achieve the standard Proctor MDD value at OMC. Considering two maximum dry densities corresponding to two static pressures, equivalent static pressure at which standard Proctor MDD value at OMC as determined from the standard Proctor's test was obtained.

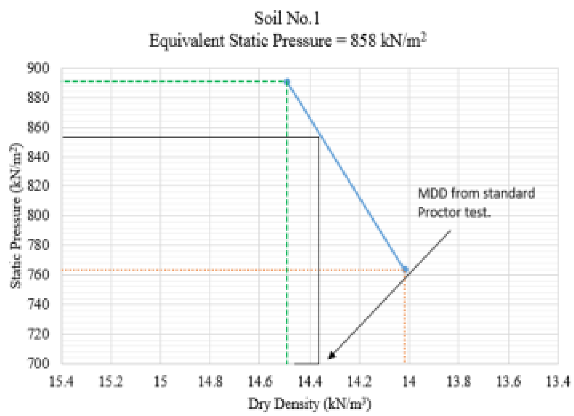

Fig. 2.11: Determination of equivalent static pressure for soil no.1 (B.Sharma et.al,2014)

It has been observed from this study that the relation between moisture content and dry density obtained from static compaction test to be parabolic in nature. . The OMC obtained from static and standard Proctor test has been found to be the same. An equivalent static pressure of around 820 kN/m^2 has been obtained from this study which can be used in the field to obtain maximum dry density and OMC corresponding to standard Proctor's test.

Alexandr et al. (2015) in their study examines the behaviour of four soil mixtures that have been statically compacted at a constant rate of strain and have varied clay contents. Compressed earth blocks, or CEBs, are widely used in the field of earth construction. Cylindrical samples that are representative of CEBs can be created using the static compaction test. Although standard Proctor tests are frequently used to determine the water content of soil used in the production of CEBs, experimental data suggest that the optimum moisture content for static and dynamic compaction differs. In their study, the results of the standard Proctor test were compared with the static compaction curves. It was found that; static compaction is more efficient than dynamic compaction in clayey soil. It was found that an increase in water content helped achieve higher densities at lower pressures, which could enhance the efficiency of manual CEB presses.

The selection of the soils to be tested was guided by the narrowest granulometric range advised for CEBs. Four distinct soils were created, each with a different amount of clay and a fixed inert fraction. To find the particle size distributions of the mix's constituent parts as well as their corresponding specific gravities and consistency limits, characterization tests were conducted. To estimate approximate parameters for static compaction tests, like water content and dry density ranges, standard Proctor compaction was carried out for each of the four soil mixes with an energy input of 574 kJ/m^3. A universal testing machine was used for static compaction tests, adapted with a cylindrical steel compactor and mini CBR mold (50 mm diameter, 130 mm height), ensuring a 0.02 mm gap for air escape and soil expulsion. The testing apparatus could generate a static pressure of 15 MPa for specimens with a diameter of 50 mm and had a maximum loading capacity of 30 kN. The test involved measurements from the load cell and loading frame displacement at a frequency of one hertz, with the displacement speed being controlled. Based on the test results, load-displacement curves could be created, which allowed for the calculation of soil density and the amount of energy that was transferred to the soil. The static compaction test involved mixing dry soil with water, allowing it to equilibrate, and then compressing it into a mini CBR mould until consolidation was visible, up to a maximum pressure of 15 MPa.

For the purpose of obtaining energy density values, the compaction energy was calculated by the integration of load-displacement curves and was divided by the specimen volume at each point of the curve. The energy density curves corresponding to the Proctor test result were plotted in order to compare the effectiveness of static and dynamic compaction techniques for the specified soil types. It was discovered that the optimum moisture content occurred at the transition between consolidation and compaction in every instance except for one sample where it was smaller than in Proctor tests. The conclusion that can be drawn from this study is that, the conditions of the experiment and the rate of strain determines the shape of static compaction curves. Static compaction is defined by maximum pressure, while dynamic compaction is typically accomplished by applying fixed energy. The energy used during static compaction needs to be computed in order for the results of these two tests to be comparable. Wetter soils can be statically compacted to increase the efficiency of manual presses and achieve higher densities without compromising the quality of CEB. Studies of feasibility ought to be carried out as drying times grow longer.

Edwin I et al. (2015) studied the effect of static and dynamic methods of compaction on the strength of soils. By adding peat at 0%, 4%, 8%, and 12% air-dry mass basis to three agricultural soils, soil samples with varying densities were produced. Using 5, 15, and 25 blows of the Proctor hammer at varying moisture contents (5% to 55%), the soils were dynamically compacted. Bulk density and penetration resistance were then measured using a hand-pushed spring-type Proctor penetrometer (ASTM, 1985). After that, the soil was loosened and repacked using a hydraulic press to enforce static compaction at the same bulk densities, and the penetration resistance was once again measured. When the peak strengths of the soils produced by the two compaction techniques were compared, there was a strong correlation between the two sets of values and it indicated that the process used to achieve soil compaction has no effect on the strength of the soil as long as samples are compacted at identical bulk densities to identical moisture contents. This goes against the findings of Seed (1954), which demonstrated that statically compacted soils can be compacted more readily to higher strength values than dynamically compacted ones. Similar trend was observed for the silty sandy clay soil studied by Crispin et al. (2011). The results obtained by these authors could have been influenced by the fact that they performed both static and dynamic compaction of their soils using separate soil samples.

Sharma et al. (2016) investigated the compaction properties of fine-grained soil using the static compaction method in a laboratory setting. Three distinct soil thicknesses were tested for static compaction at varying moisture contents. Using a cylindrical plunger, a standard Proctor mould with a 1000 cc capacity was statically compacted using a known weight of soil at a specific moisture content that was inserted up to a certain height. When applying a load at a different load level, the height of penetration of the metal plunger is measured from the top surface of the mould at a rate of 1.25 mm/min, proving a ring constant of 0.05 KN/division. Significant variations in dry density are seen at lower static pressures, while negligible variations are seen at higher static pressures. Furthermore, changing the height of the soil sample does not result in a discernible change in dry unit weight that corresponds to a change in static pressure. However, only soil samples with a maximum height of 100 mm were used in the study. Additionally, the researcher discovered that when the relationship between static pressure and dry density is investigated, a nonlinear curve is seen at different water contents. At varying static pressures, a parabolic relationship between dry density and moisture content is observed; MDD from the static compaction test is found to be higher than that from the standard Proctor compaction test. It is suggested to apply an equivalent static pressure of about 820 KN/m^2 to the soil sample in order to obtain the standard Proctor's maximum dry density, which corresponds to OMC.

Sharma and Deka (2016) employed the same mechanism as suggested by Sharma et al. (2016) in an attempt to determine the compaction characteristic using the static compaction method. In order to obtain the maximum dry unit weight and the optimum water corresponding to the four different compactive efforts, an attempt has been made to determine the equivalent static pressures to the modified Proctor test (MP), the reduced modified Proctor test (RMP), the standard Proctor test (SP), and the reduced standard Proctor test (RSP). To ascertain the relevant physical properties and characteristics of static compaction, a total of seven fine-grained inorganic soil samples were tested. Additionally, the MP, RMP, SP, and RSP tests were run to ascertain the dynamic compaction characteristics. The relationship between static pressure and dry unit weight, corresponding to different water contents, has been plotted in the form of curves which is found to be nonlinear. The curves show that when the static pressure is increased further, the dry unit weight increases to its maximum value and then remains constant. The relationship between water content and dry unit weight is found to be parabolic for a given static pressure and water content. A characteristic shared by all the curves in all the soil samples was that the dry density did not change above a static pressure of about 1513 KN/m^2. When the dynamic compaction curves of the SP, RMP, SP, and RSP are superimposed with the static compaction curves of a given soil sample that correspond to various static pressures, it can be observed that, for both the standard Proctor test and the reduced standard Proctor test, a static pressure in the range of 750–875 KN/m^2 is necessary to obtain the maximum dry unit weight value at OMC, and for the reduced modified Proctor test curves in all seven soil samples, a static pressure in the range of 1375–1500 KN/m^2 is necessary to obtain the maximum dry unit weight value. Furthermore, it is noted that in all seven soil samples, the parabolic curve that corresponds to the maximum static pressure of 1513 KN/m^2 is located below the modified Proctor test curve.

B Sharma et al. (2018), in their study, attempted to compare the dynamic compaction characteristics at various compactive efforts with the static compaction characteristics of coarse- and fine-grained soils. In order to further develop knowledge of compaction, the modified Proctor test, reduced modified Proctor test, standard Proctor test, and reduced standard Proctor test were used to identify the dynamic compaction characteristics of both coarse and fine grains soil. Static compaction test was done by the method devised by Sharma et al. (2016). This test study includes a total of 12 soil samples of IS classifications CH, CI, SC, SM, and SP in order to ascertain the static compaction characteristics of both coarse- and fine-grained soils as well as the transition in these characteristics from fine-grained soil to coarse-grained soil.

After examining the test data, it was determined that, for the CI & CH class of soil, the relationship between moisture content and dry unit weight in static compaction for various static pressures is parabolic in nature. For SP class of soil, both the static and dynamic compaction curves show an undulatory pattern with maximum dry unit weight near dry and towards saturated condition. Both the SC and SM classes of soil have a parabolic dynamic compaction curve. While only a one-sided compaction part of the curve for the rising portion of the dry of optimum side was generated for the SC class of soil, the static compaction curve for the SM class of soil displays a wavy pattern with maximum dry unit weight at dry and near saturated condition. It is not possible to determine an equivalent static pressure for coarse-grained soils as it is for fine-grained soils, at which the maximum dry unit weight at the optimum moisture content can be obtained corresponding to different dynamic efforts.

Helal Al-Radi et al. (2018) carried a study to draw a comparison between CBR values obtained from dynamic and static methods for four different types of soils that locate in Selangor, Malaysia. California Bearing Ratio (CBR) test results in the laboratory, which is done to determine the shear strength and stiffness modulus of subgrade in pavement design works, do not accurately represent behavior at the field condition. Therefore, in order to close the gap between laboratory and field data regarding the improvement of engineering parameters, particularly for pavement design, a new method was developed to determine the CBR values based on the MDD and OMC values through the use of static CBR tests.

Static packing pressure apparatus and Standard Proctor test was employed as means of static and dynamic compaction respectively. The findings of their study showed better results for statically done CBR values than dynamic. The static compaction method was described as a faster and more comfortable method than dynamic compaction. According to the results of the test, the static CBR method was found more dependable than the dynamic CBR method for designing the thickness of the road layers at a lower cost and with better quality.

Kayabali et al. (2020) in their work investigated the proper level of the compactive effort for the static compaction test and compared the compaction characteristics from standard Proctor and static compaction tests. They also compared the undrained shear strength and hydraulic conductivity obtained from both tests. Standard Proctor and static compaction tests were employed as compaction methods for ten soil samples of different gradational and plasticity characteristics. The theoretical energy delivered to compacted soil in this test was 592.7 kNm/m^3.

In their work they found that when using the static compaction method, a soil's compaction curve could be created with 60% less energy. The entire soil mass is subject to displacement in the static compaction test, no energy is wasted, and nearly all the energy is utilized to densify the soil. According to the results of the compaction energy applied to all soil samples, the compaction energy level needed for the static compaction test is approximately 40% of the standard Proctor method, or 237 kJ/m^3.

From the undrained strength tests of compacted specimens, the results of the static compaction test yielded slightly lower undrained shear strengths than those of the standard Proctor approach. The variances are regarded as falling within the permissible bounds.

Similarly, the hydraulic conductivities ascertained through the static compaction test exhibited a slight decrease in comparison to the results obtained from the compacted samples of the standard Proctor technique. The differences in hydraulic conductivity between the two compaction methods' results were insignificant when compared to the wide variations in typical permeability tests conducted in the field or in a lab.

L. Xu et al. (2021) studied the compaction characteristics of raw earth specimens using a double-faced static compaction and the traditional Proctor test as dynamic process. For each samples, corresponding compaction energies were investigated. By a simple method using filter papers, matric suctions for the samples were also measured. The conclusions that can be made based on the results obtained in their study are:

1. A family of iso-energy curves (i.e. tests with the same compaction energy) is found for the set of static compaction tests, which resemble traditional Proctor tests. There is a reduction in optimum moisture content and an increase in maximum dry density with increasing compaction energy.

2. A new term has been coined called optimum saturation degree, described as the saturation degree at which maximum dry density is obtained for a specific compaction method and a given compaction energy value. This value is found to be constant and a unique compression curve exists for both static and dynamic compaction methods.

3. For static compaction specimens, the matric suction measured with filter papers is marginally higher than the dynamic suction in Proctor tests at the same moisture content, whereas dry density has little influence on the variation of matric suction.

4. Lastly, a new earth compaction control method is proposed, utilizing achievable compaction energies to compact the earth to a target dry density while maintaining the optimum saturation degree.

The literature that was previously discussed has offered a thorough examination of the body of of information that is currently available regarding both static and dynamic compaction. The framework established by this literature review will act as a compass for us as we move forward with later chapters of the study, influencing our own investigation and advancing knowledge in the domain. The aim of this study is to examine the strength characteristics of soil that has been compacted statically and dynamically at the same dry unit weight and at the optimum moisture content and both wet and dry of optimum. This study aims to tackle the same concern.

CHAPTER 3

EXPERIMENTAL PROCEDURE AND RESULTS

3.1 INTRODUCTION

This chapter describes the various laboratory test programs that are used to investigate the different properties of soil and tables and graphs have been used in the presentation of the test results.

3.2 Test program

The primary objective of the experimental study is to comprehend how strength of clayey soil responds to both static and dynamic compaction modes. For this purpose the soil specimens are compacted using the corresponding modes in order to measure the variation of both the unsoaked CBR value and the UCS value.

In addition to the strength tests, the general soil index properties such as liquid limit, plastic limit, optimum moisture content, and maximum dry unit weight of the specimen were established in accordance with Indian Standard specifications to classify the soil samples.

The test program can be divided into the phases shown below.

1. Collection of the soil samples.
2. Preparation of the soil samples for testing.
3. Determination of physical properties of soil.
4. Determination of the compaction properties of soils by Standard Proctor compaction test.
5. Determination of CBR value of soil by static and dynamic method of compaction.
6. Determination of UCS value of soil by static and dynamic method of compaction.

3.2.1 Collection of soil sample

Disturbed soil samples with different engineering properties were collected from different site locations of Guwahati.

The top 30 to 60 cm of the soil is removed from the sites in order to collect soil samples, ensuring that no organic matter has mixed in with the soil specimen. A square trench measuring 1m x 1m yields about fifty kilograms of soil sample.

3.2.2 Preparation of the disturbed samples for testing

To ensure reproducible results, soil samples collected from the field must first be prepared using a standard procedure. First, the soil sample is usually dried, then it is pulverized and any stones present in the sample are taken out before testing. The soil samples were then allowed to air dry at room temperature. Both dynamic and static soil compaction followed this procedure.

3.2.3 Determination of the physical properties of the soils:

1. Determination of liquid limit was performed by cone penetration method according to IS: 2720 (Part 5)-1985.
2. Determination of plastic limit was carried out in the laboratory according to IS: 2720 (Part 5)-1985.
3. Determination of specific gravity was performed according to IS: 2720 (Part 3)-1980.
4. Determination of gradation of the soil samples by wet sieve analysis was performed according to IS 2720 (Part 4) 1985.

3.2.4 Determination of the compaction properties of the soils:

A 2.5 Kg sample of air dried soil passing the 4.75 mm IS sieve is taken. The soil sample is mixed thoroughly with a suitable amount of water depending upon the soil type. After that, the soil sample is kept to mature for at least 24 hours by being kept in an airtight container inside a desiccator. This process is repeated for four to five more samples of the same soil with different water contents. After that, in accordance with **IS: 2720 (part 7)-1980**, the Standard Proctor Compaction test is used in the laboratory to obtain the compaction characteristics i.e. the optimum moisture content corresponding to the maximum dry density of the soil.

3.2.5 Determination of California bearing ratio (CBR):

Unsoaked CBR tests were performed on remoulded specimens by mixing the soil samples at optimum moisture content and also at dry and wet of optimum in accordance with **IS: 2720**

(Part-16)-1987. The soil samples were compacted by means of both static and dynamic mode of compaction to compare the unsoaked CBR values at same molding water contents and same bulk densities for the two methods of compaction.

3.2.5.1 Preparation of test specimen by dynamic compaction:

Using the dynamic method of compaction, a representative sample of air-dried soil, weighing about 4.5 kg and passing through a 19 mm IS sieve, is thoroughly mixed with a predetermined amount of water to reach water content equals to OMC,OMC-3% and OMC+3% (obtained from the standard Proctor test) and for one sample OMC,OMC-5% and OMC+5%. The sample is then left in a desiccator for 24 hours to mature.

The base plate is clamped into the mould that has the extension collar attached to it. A coarse filter paper disc is placed on top of the spacer disc after it has been inserted over the base plate. The soil-water mixture is compacted into the mould using the methods described in IS: 2720 (Part 7) -1980 for moulds with a diameter of 150 mm. Specifically, the test specimen is compacted into three layers with a free fall of 31 cm by applying 56 blows to each layer using a 2.6 kg rammer.

After removing the extension collar and carefully trimming the compacted soil with a straightedge, any holes that may have formed on the surface due to the removal of coarse material are patched with smaller-sized material. After that, the spacer disc and base plate are removed from the mould by turning it upside down. To calculate the bulk density and dry density, the mass of the compacted soil specimen and the mould are measured. A disc of coarse filter paper is placed on the perforated base plate, the mould and the compacted soil is inverted and clamped to the base plate.

Fig 3.1: Different Apparatus Required to Conduct CBR Test

3.2.5.2 Preparation of test specimen by static compaction:

The following expression determines the mass of the wet soil at the required moisture content to obtain the corresponding dry density when occupying the standard specimen volume in the mould:

$$W = \gamma_d (1 + w) V$$

Where,

W= weight of the wet soil at required water content to the corresponding dry density after static compaction

γ_d= dry density

w = placement water content

V = volume of compacted soil corresponding to specimen height of 10 cm

To raise the water content of the air-dried sample to the required moisture content, a sufficient amount is taken, and a calculated amount of water is thoroughly mixed into it. The wet sample is kept in the desiccator for twenty-four hours to mature before being placed into a mould that has filter paper at the bottom and a base plate inside. In order to compact the soil to its maximum dry density, a filter paper and a displacer disc are now placed on top of the soil, and the entire assembly is kept in the compaction set up. The load is applied until the specimen reaches the desired depth of compaction, and the depth of compaction is continuously monitored. The load equal to the necessary depth of compaction is held for a while and then released to counteract the action of swelling.

Fig.3.2: Static Compaction Set Up

3.2.5.3 Penetration Test:

This test is identical for both the statically and dynamically compacted specimens. The specimen-containing mould was set on lower plate of the testing machine with the base plate in place and the top face exposed. Surcharge weights, sufficient to produce an intensity of loading equal to the weight of the base material and pavement was placed on the specimen. Before seating the penetration plunger and adding the remaining surcharge weight, a 2.5 kg annular weight is placed on the soil surface to prevent soil from being upended into the surcharge weight hole. To ensure that the plunger and the specimen surface made complete contact, the plunger was seated under a 4 kg load. Before applying the load, the load and deformation readings are set to zero. An applied load is made on the soil at a rate of 1.25 mm/min. As indicated by the monitor, the load-penetration readings are obtained in accordance with the designated penetration of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0, and 12.5 mm. Additionally, the percentage CBR values of the soil specimens are recorded in accordance with the penetration values of 2.5 and 5 mm. Upon completion, the plunger was lifted and the mould was separated from the loading apparatus.

Fig.3.3: Digital CBR Testing Machine

The top 30 mm of the specimen is sampled, weighing between 20 and 40 g, and the water content is calculated using IS: 2720 (Part 2)-1973.

3.2.5.3.1 Load Penetration Curve:

For every soil specimen, the required specimen data are noted and the load penetration curve is plotted. This curve is typically convex upward, though surface irregularities may cause the initial portion of the curve to be convex downward. When correction is required, the axis of the load is transposed and a tangent is drawn to the point of greatest slope. This allows zero penetration to be determined as the point where the tangent intersects the axis of penetration.

3.2.5.3.2 California Bearing Ratio:

CBR values are typically computed for 2.5- and 5-mm penetrations. Based on the desired penetration value for CBR values, the corrected load value is determined by analyzing the load penetration curve and calculating the CBR in the following manner:

$$\text{California Bearing Ratio} = P_T/P_S \times 100$$

Where P_T = corrected unit (or total) test load corresponding to the chosen penetration from the load penetration curve and

P_S = unit (or total) standard load for the same depth of penetration as for P_T taken from the table 3.1

Table 3.1. Standard load used in CBR test

Penetration depth (mm)	Unit standard load (kg/cm^2)	Total standard load (kgf)	Total standard load (kN)
2.5	70	1370	13.44
5.0	105	2055	20.15

Generally, the CBR value at 2.5 mm penetration is greater than that at 5 mm penetration. Whenever the CBR for 5 mm exceeds that for 2.5 mm, the test is repeated. If identical results follow, the CBR corresponding to 5 mm penetration is reported as CBR value the specimen.

3.2.6 Determination of UCS value:

As per **IS: 2720 (part10)-1991**, soil specimens with a diameter (d) of 38 mm and a length (l) to diameter ratio of 2 are subjected to unconfined compression tests. The type of soil specimen used for the determination of unconfined compressive strength is dynamically and statically compacted specimens at the same water contents at which CBR test is done.

3.2.6.1: Preparation of test specimen by dynamic compaction:

About 2.5 kg of soil sample passing through 4.75 mm sieve is taken and mixed thoroughly with calculated amount of water to get the required water content. Then the sample is kept in a desiccator for 24 hours to mature. When compacting the specimen, it is done using a mould of circular cross-section and the test specimen is compacted into three layers with a free fall of 31 cm by applying 25 blows to each layer using a 2.6 kg rammer.

3.2.6.2: Preparation of test specimen by static compaction:

The required mass of the wet soil at the required moisture content to obtain the corresponding dry density when occupying the standard specimen volume in the mould is first calculated. The soil is then statically compacted in the standard Proctor mould using the same loading set up as shown in Fig.3.2.

After the specimen is formed, the ends are trimmed perpendicular to the long axis and removed from the mould in both dynamic and static compaction. Then the unconfined compressive strength test is done on the specimen in accordance with the specified Indian Standard.

Fig: 3.4: UCS Testing Machine

3.3 Test results

The tables and graphs below display the experimental results from the different tests that are conducted.

3.3.1 Test results of the physical properties:

The test results for the physical properties of soil samples tested are shown in the Table 3.2 and the classification of soil samples based on Atterberg limits and plasticity are also incorporated with it.

Table 3.2: Physical properties of the soil samples

Sample No.	Site location	Depth from G.L. (m)	Colour	Odour	Specific Gravity (Gs)	Plastic Limit W_P (%)	Liquid Limit W_L (%)	Plasticity Index I_P	Soil Type	% of (silt +clay)
1	AEC Hostel 5	1	Light Brown	NIL	2.65	19.652	45.49	25.838	CI	92.65
2	Beharbari	1	Red	NIL	2.714	23.166	58.4	35.234	CH	71.85
3	AEC Hostel 7	1	Brown	NIL	2.65	20.056	39.20	19.144	CI	83.838
4	Maligaon	1.5	Red	NIL	2.767	31.03	68.7	37.67	CH	90.17
5	Dipor Beel	0.5	Light Brown	NIL	2.65	21.04	30.10	9.06	CL	98.04
6	Borjhar	0.5	Light Brown	NIL	2.66	27.05	46.81	19.76	CI	95.94

The soil gradation is shown based on the wet sieve analysis results for the soil samples from Figure 3.5 to 3.10

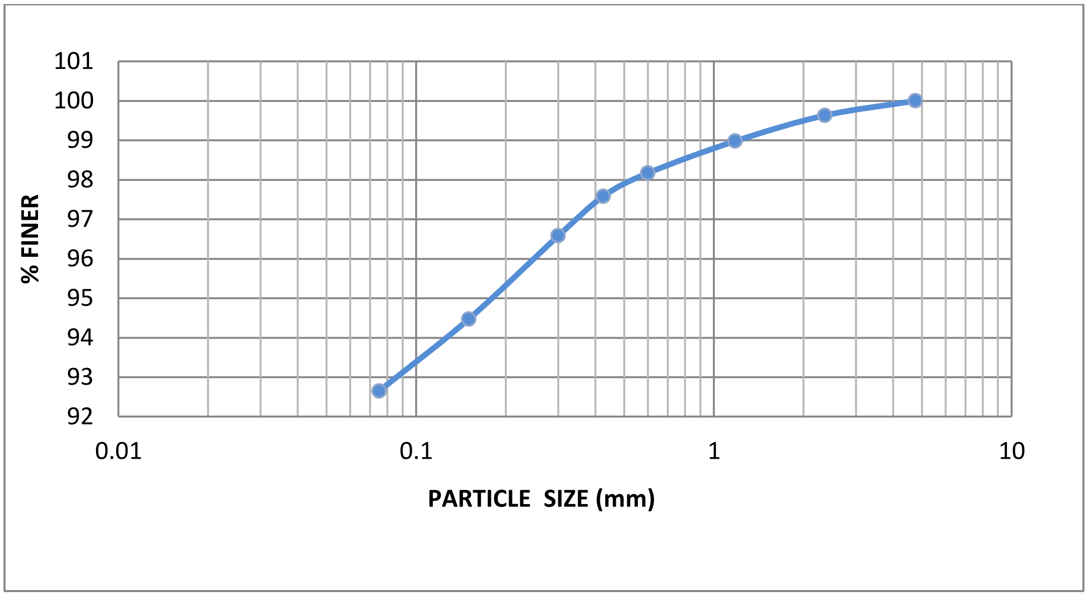

Fig. 3.5: Gradation curve for sample 1

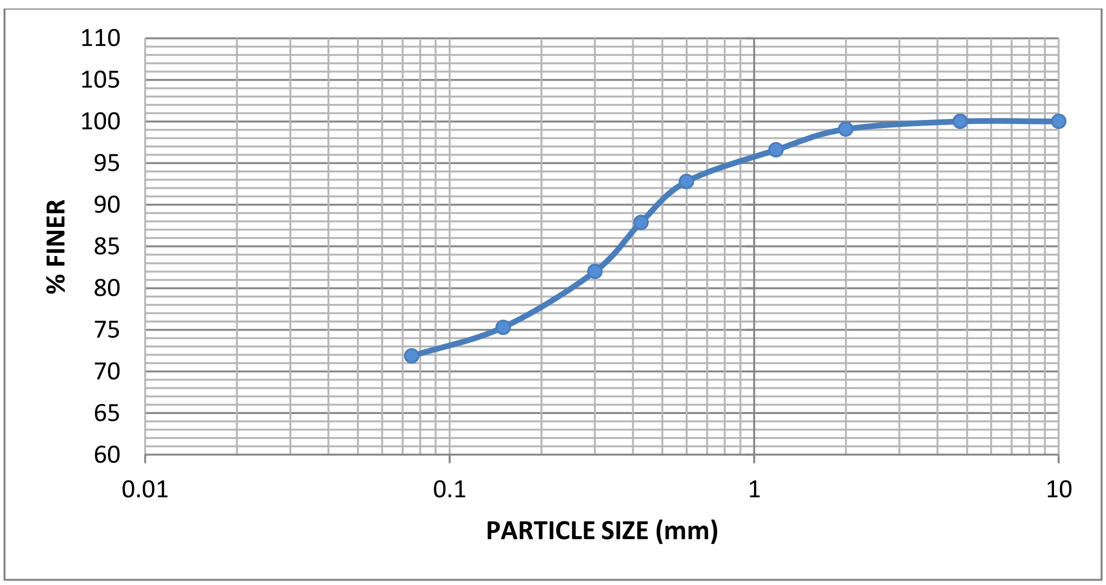

Fig. 3.6: Gradation curve for sample 2

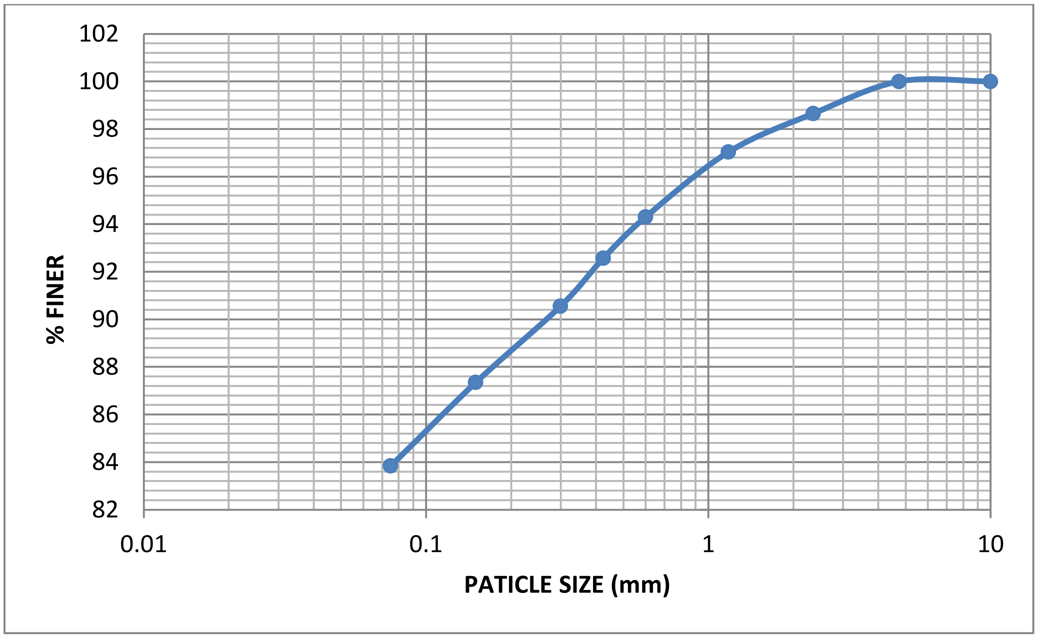

Fig. 3.7: Gradation curve for sample 3

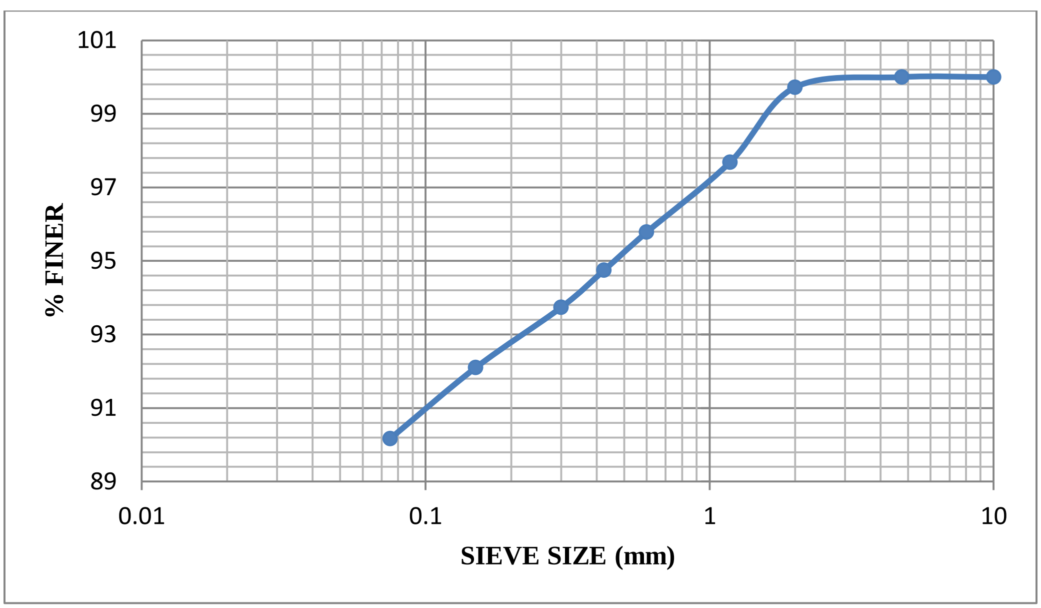

Fig. 3.8: Gradation curve for sample 4

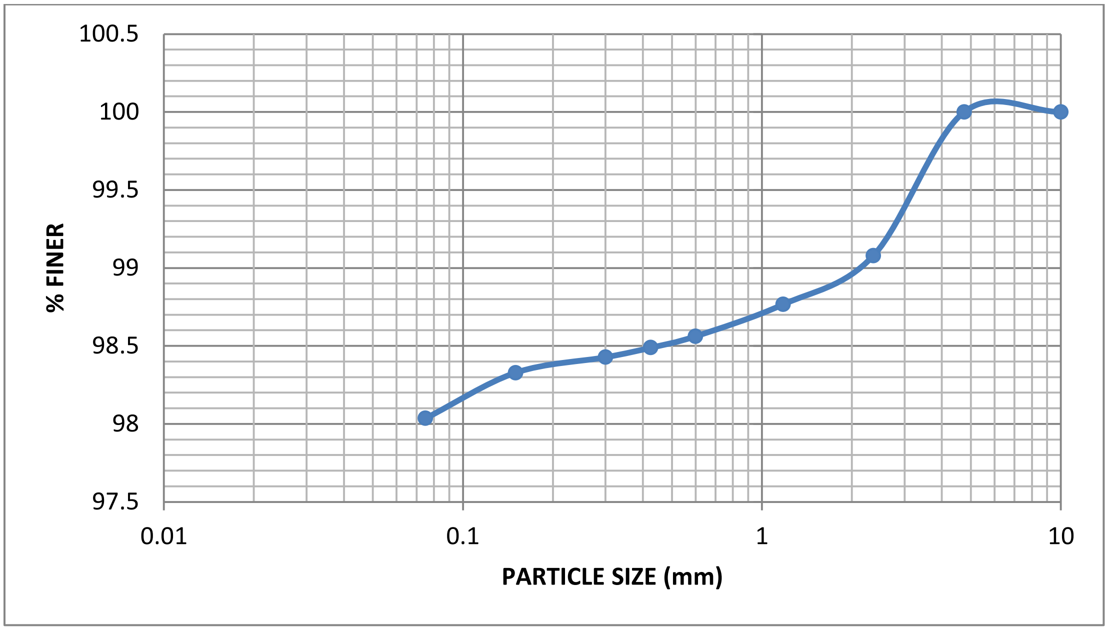

Fig. 3.9: Gradation curve for sample 5

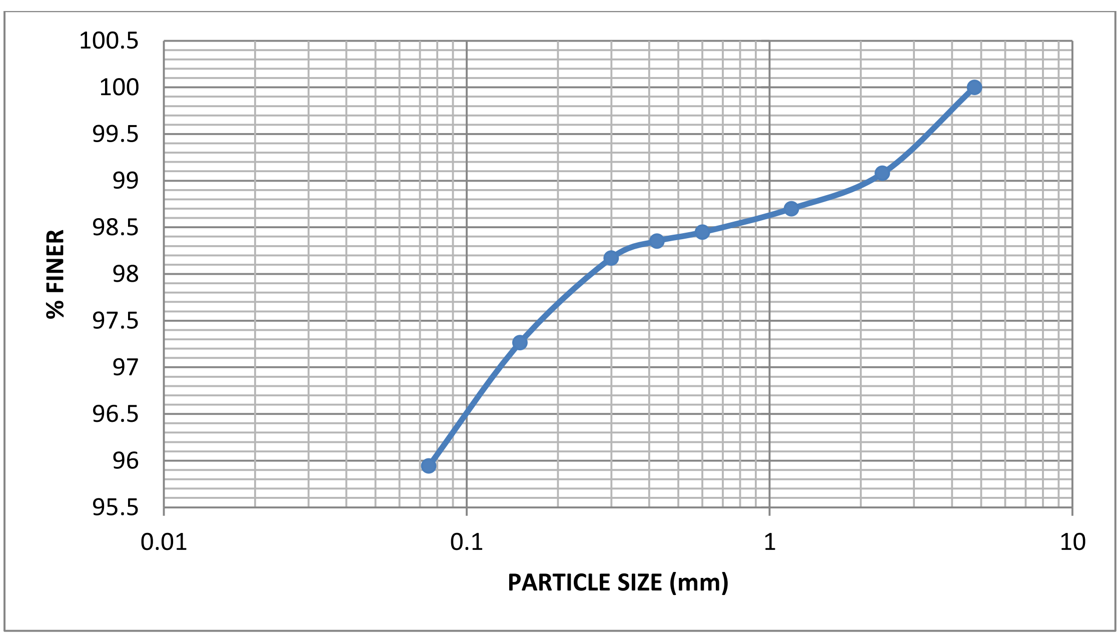

Fig. 3.10: Gradation curve for sample 6

3.3.2 Test results of compaction properties of the soil:

The experimental results of dynamic compaction test performed on the soil samples by Standard Proctor Test are shown in the Table 3.3

Table 3.3: Results of Optimum Moisture content and Maximum Dry Density by standard Proctor compaction test.

Sample No.	Site Location	Maximum Dry Unit Weight (MDUW) (kN/m^3)	Optimum Moisture Content (OMC) (%)
1	AEC Hostel 5	16.142	20.3
2	Beharbari	14.90	23
3	AEC Hostel 7	15.55	18.6
4	Maligaon	14.79	24
5	Dipor Beel	16.22	19.10
6	Borjhar	15.92	20.80

The dynamic compaction curves of the soil samples are shown below from Figure 3.11 to 3.16

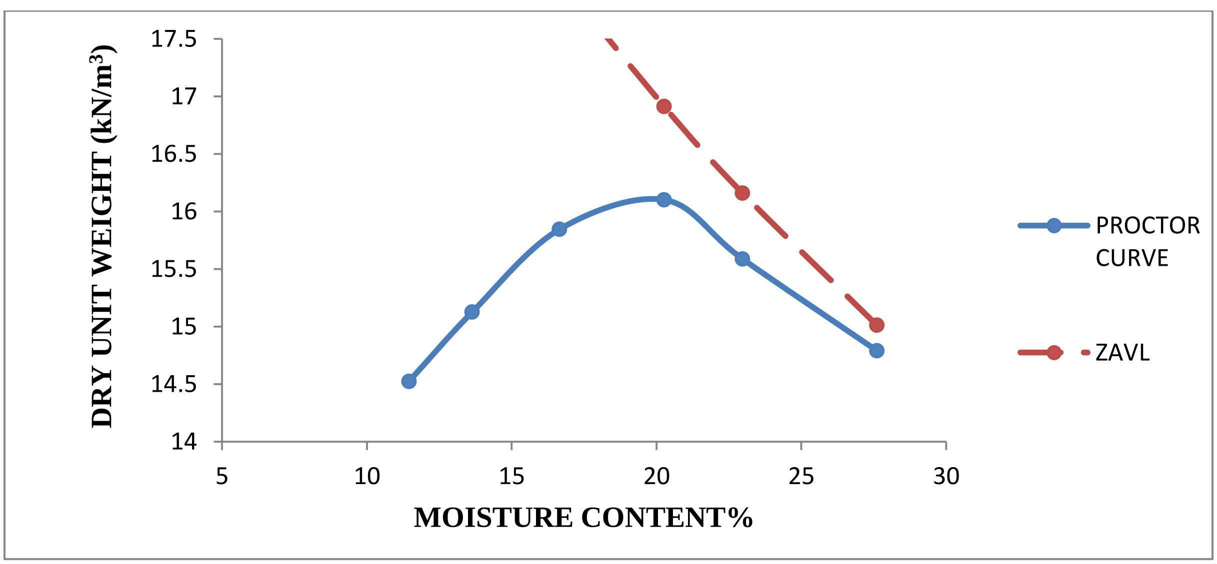

Fig.3.11. Dynamic compaction curve for sample 1

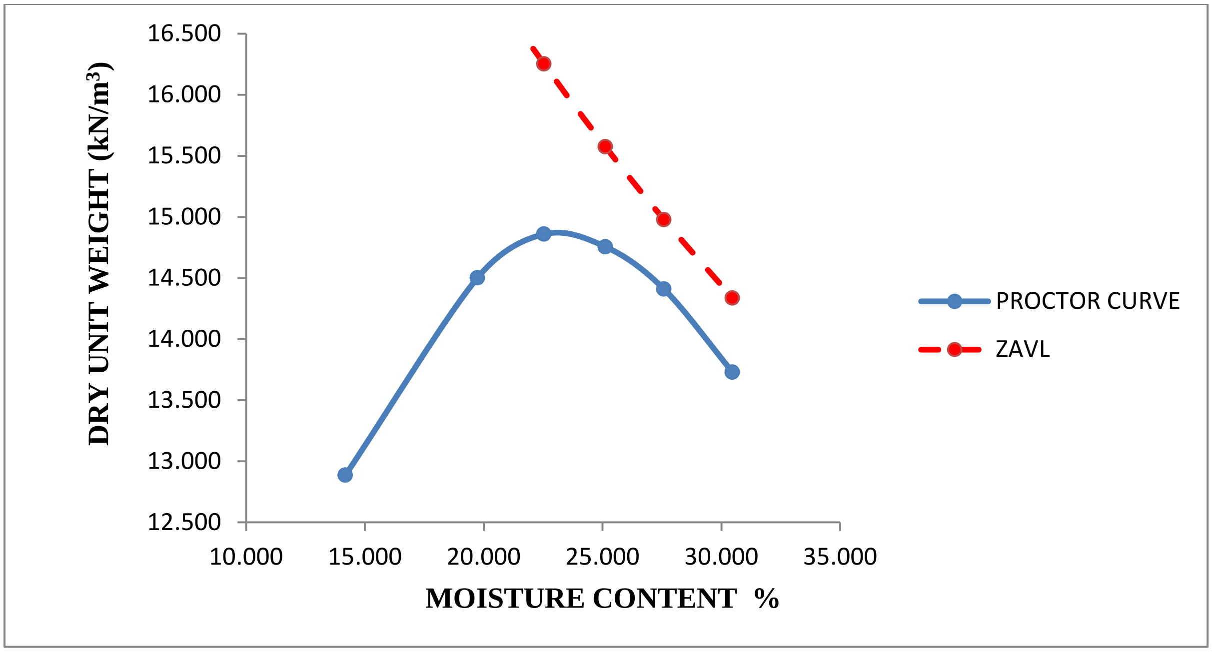

Fig.3.12. Dynamic compaction curve for sample 2

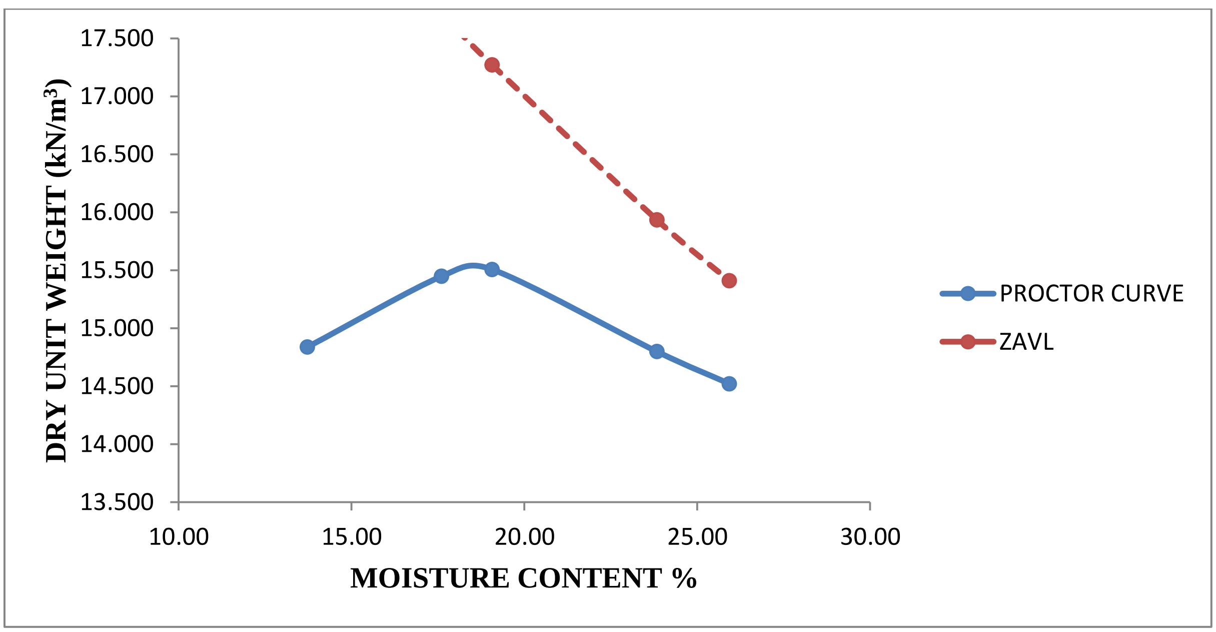

Fig.3.13. Dynamic compaction curve for sample 3

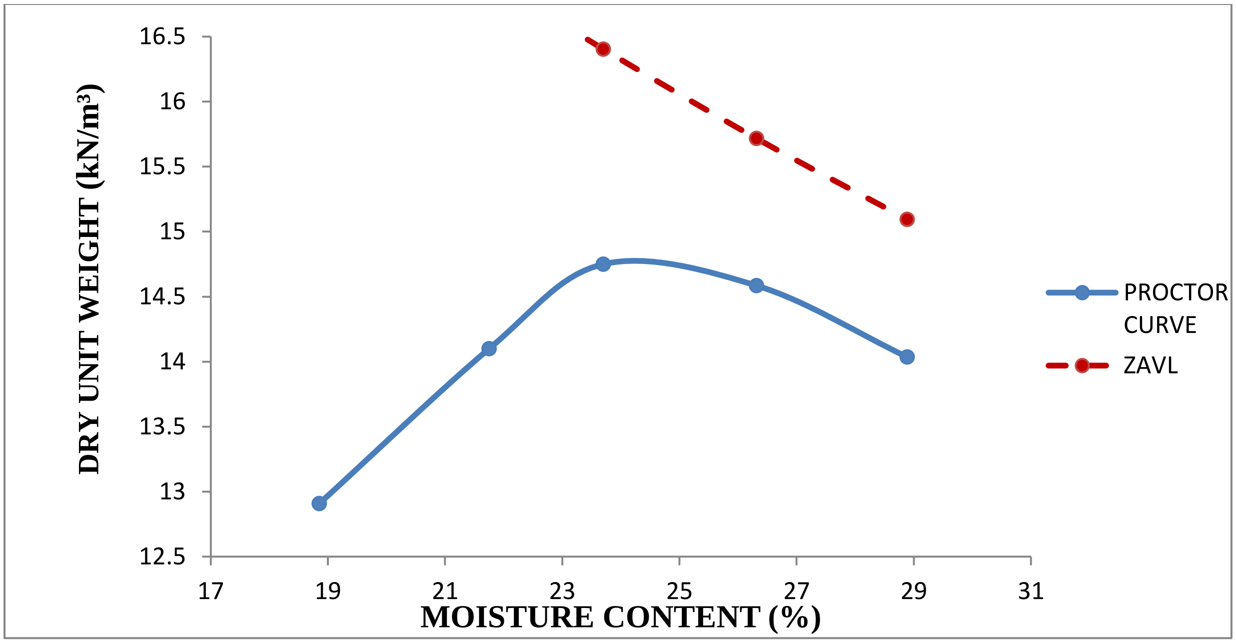

Fig.3.14. Dynamic compaction curve for sample 4

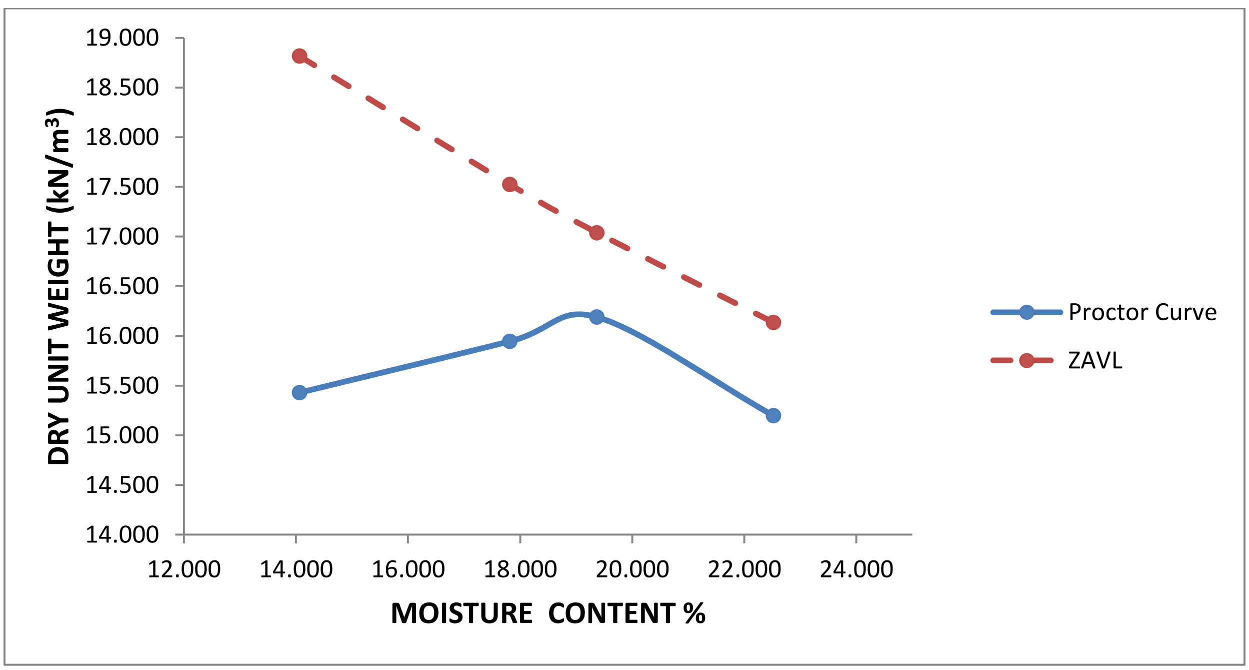

Fig.3.15. Dynamic compaction curve for sample 5

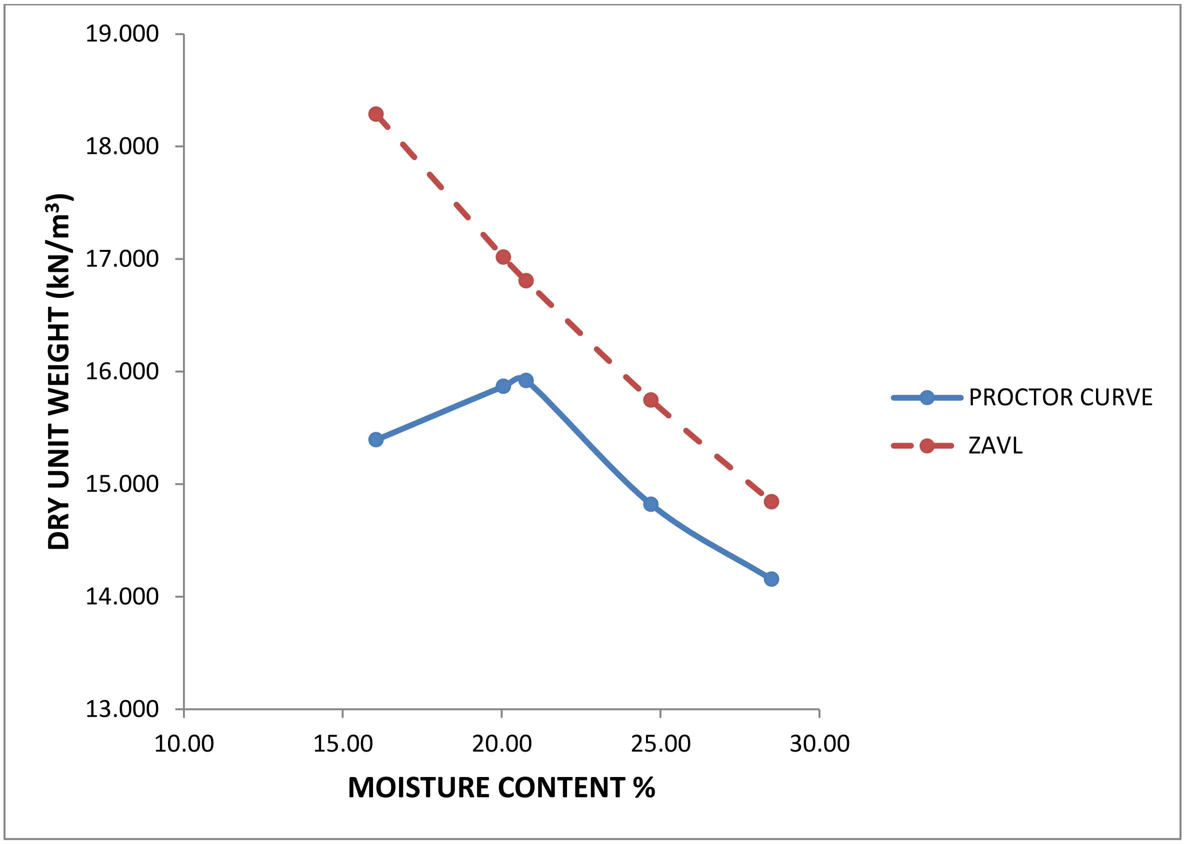

Fig.3.16. Dynamic compaction curve for sample 6

3.3.3: Determination of unsoaked CBR value of the soil samples:

The CBR value obtained for the soil samples tested for both statically and dynamically compacted soil specimens at three different moisture contents along with their respective load-penetration curves are shown below.

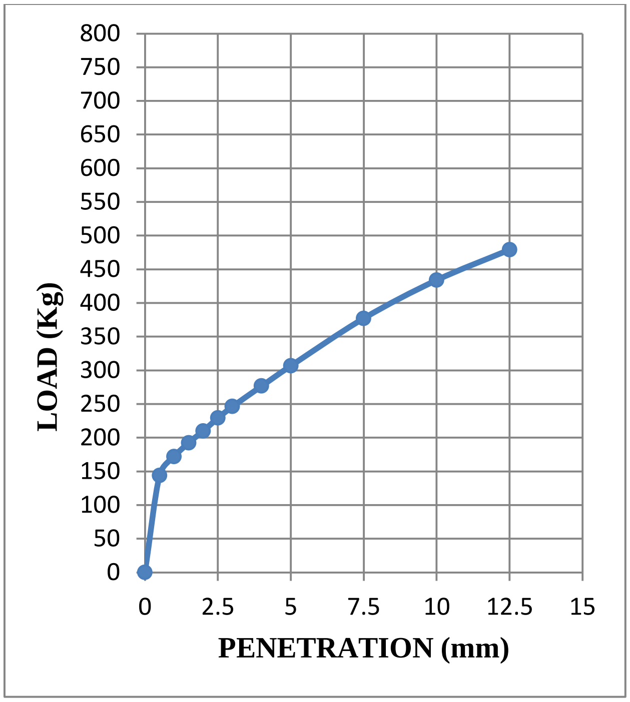

Fig 3.17: Load-penetration curve at OMC-3% of sample 1 (dynamically compacted soil)

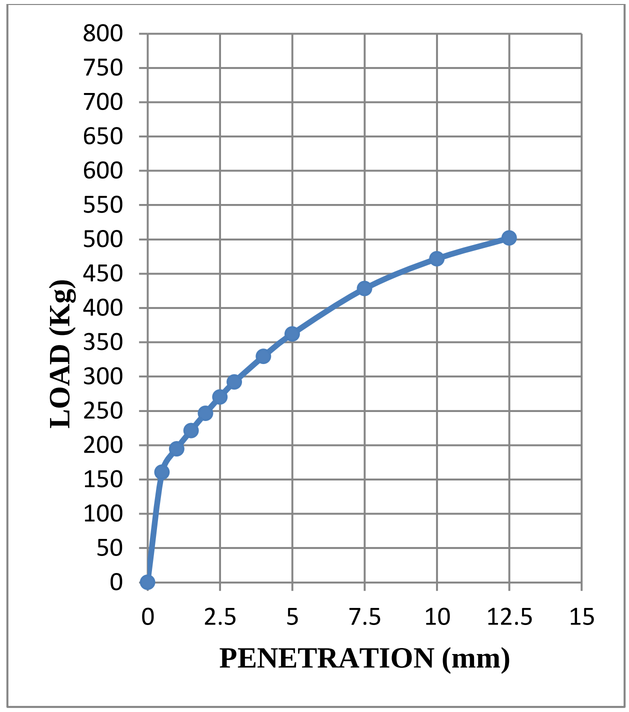

Fig.3.18: Load-penetration curve at OMC-3% of sample1 (statically compacted soil)

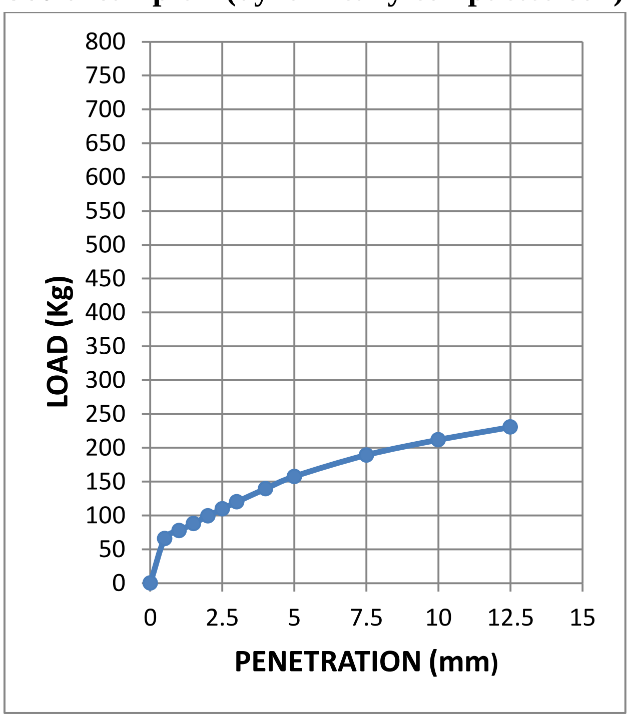

Fig.3.19: Load-penetration curve at OMC of sample 1 (dynamically compacted soil)

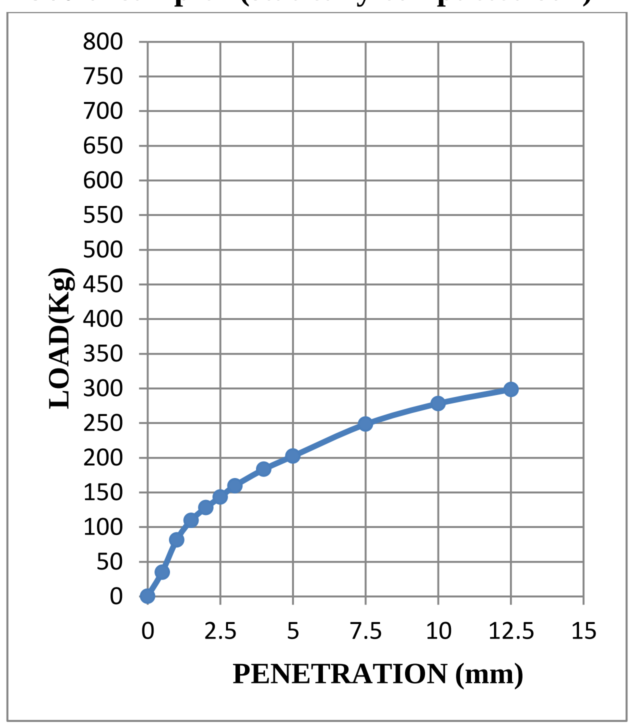

Fig.3.20: Load-penetration curve at OMC of sample1 (statically compacted soil)

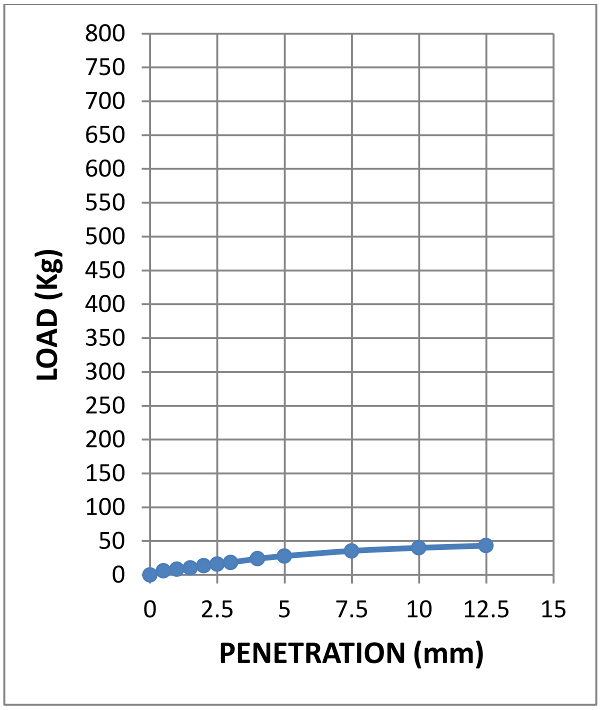

Fig 3.21: Load-penetration curve at OMC+3% of sample1 (dynamically compacted soil)

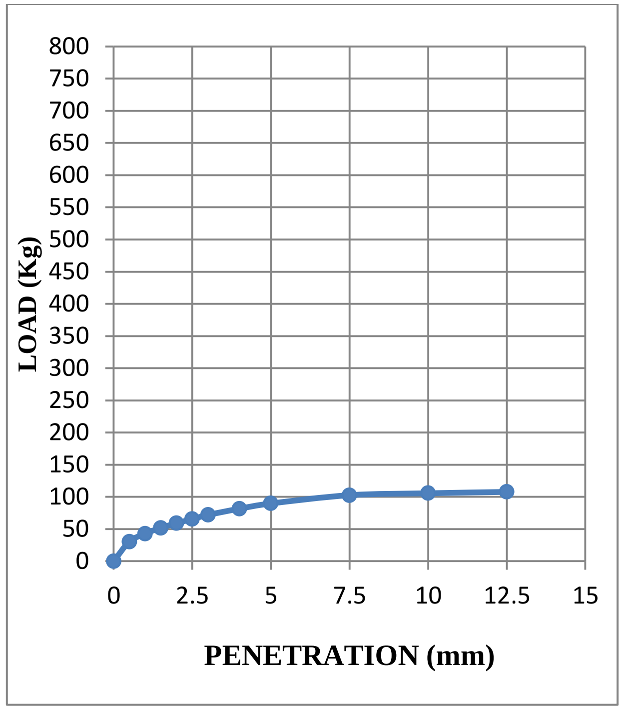

Fig.3.22: Load-penetration curve at OMC+3% of sample1 (statically compacted soil)

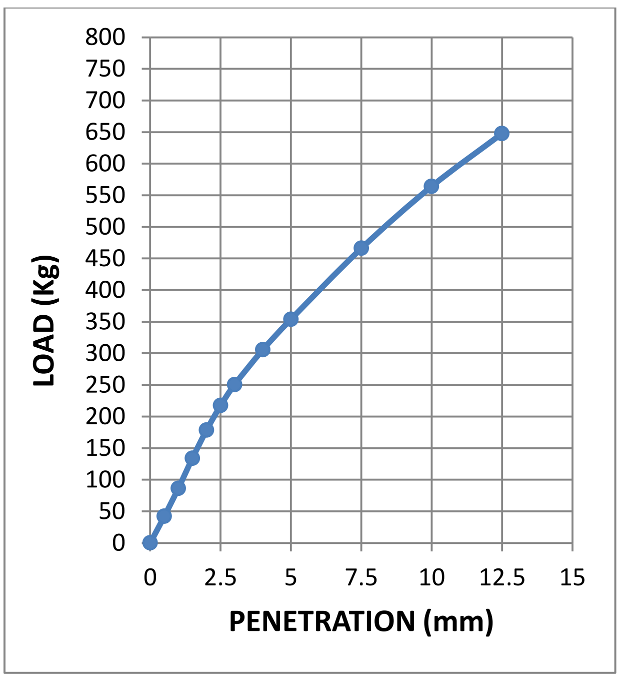

Fig. 3.23: Load-penetration curve at OMC-5% of sample 2 (dynamically compacted soil)

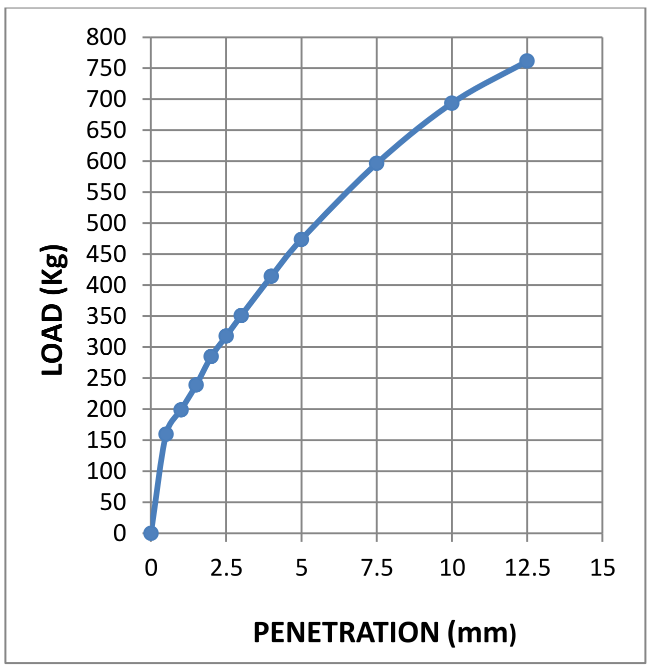

Fig. 3.24: Load-penetration curve at OMC-5% of sample2 (statically compacted soil)

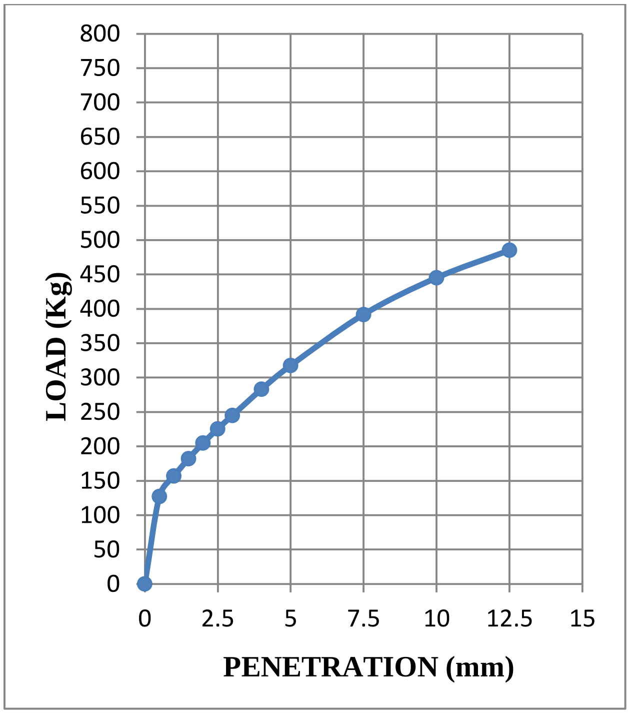

Fig. 3.25: Load-penetration curve soil at OMC of sample 2 (dynamically compacted)

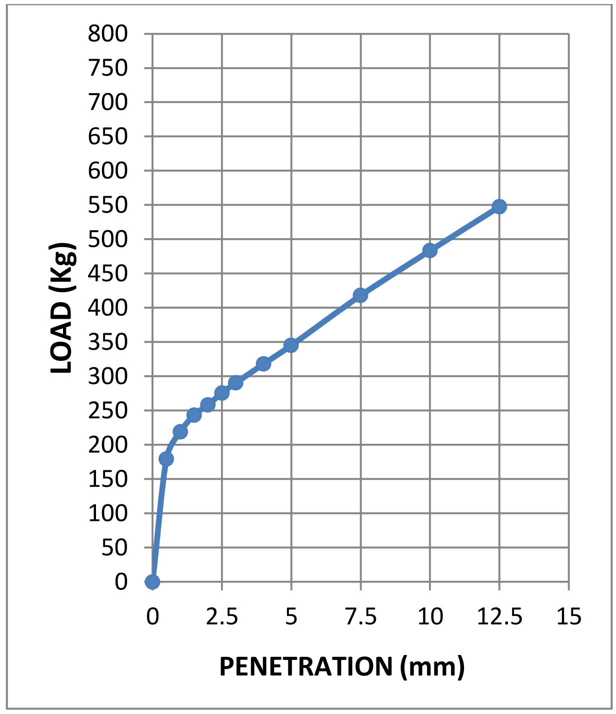

Fig. 3.26: Load-penetration curve at OMC of sample 2 (statically compacted soil)

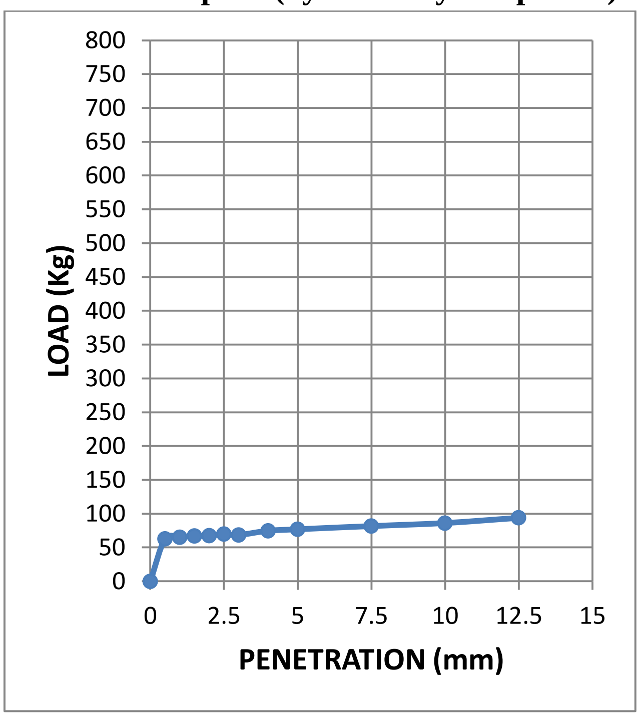

Fig. 3.27: Load-penetration curve at OMC+5% of sample 2 (dynamically compacted soil)

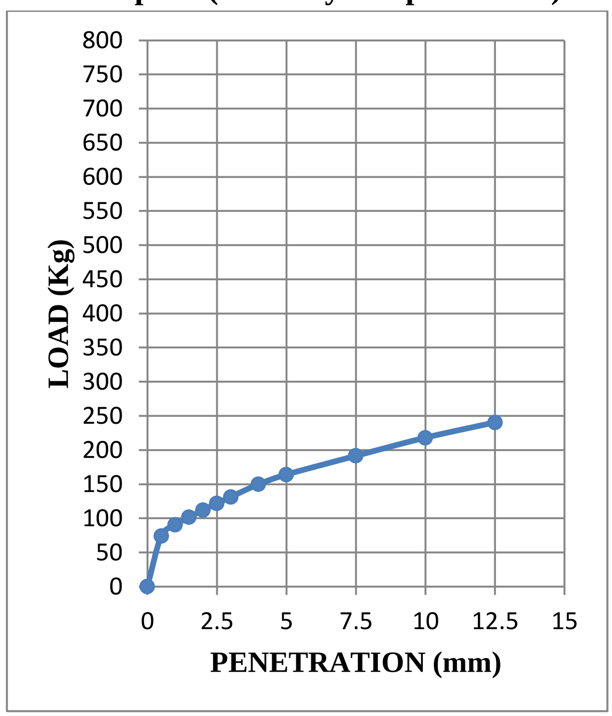

Fig. 3.28: Load-penetration curve at OMC+5% of sample 2 (statically compacted soil)

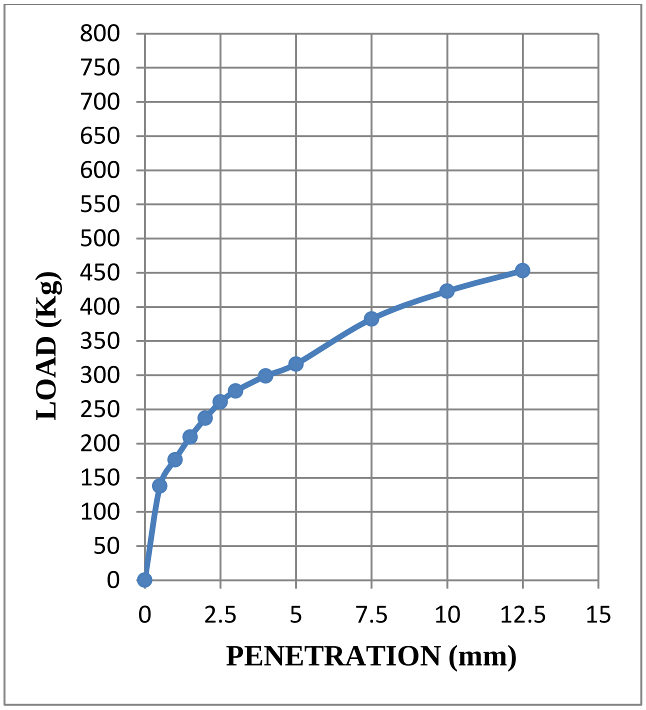

Fig. 3.29: Load-penetration curve at OMC-3% of sample 3 (dynamically compacted soil)

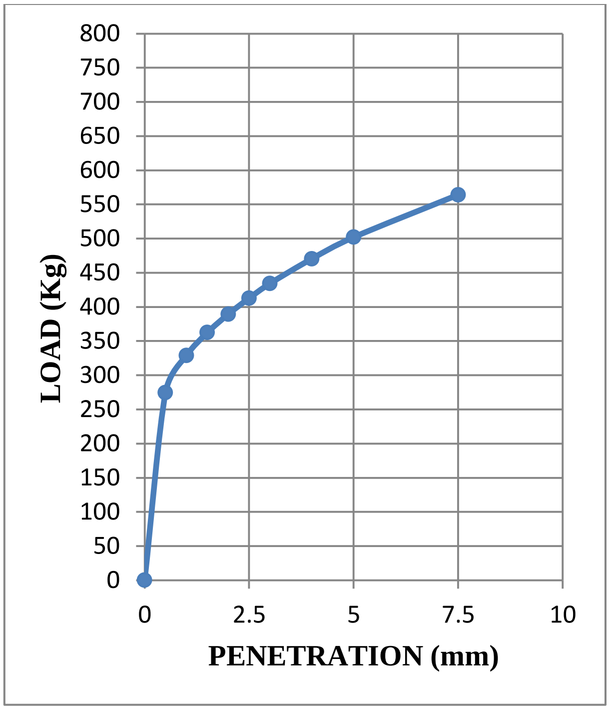

Fig. 3.30: Load-penetration curve at OMC-3% of sample 3 (statically compacted soil)

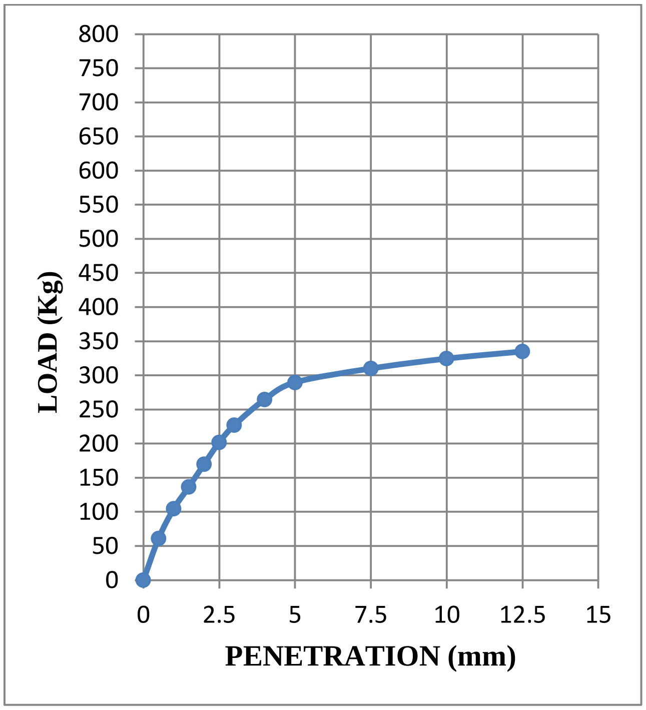

Fig. 3.31: Load-penetration curve at OMC of sample 3 (dynamically compacted soil)

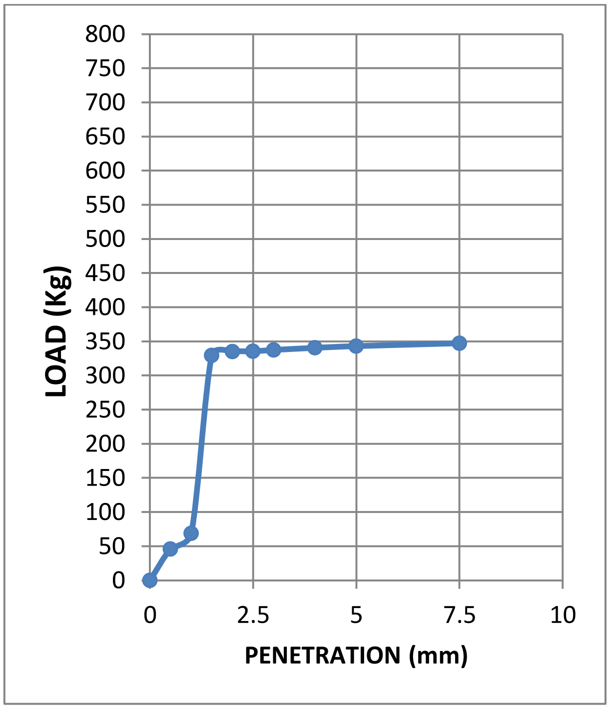

Fig. 3.32: Load-penetration curve at OMC of sample 3 (statically compacted soil)

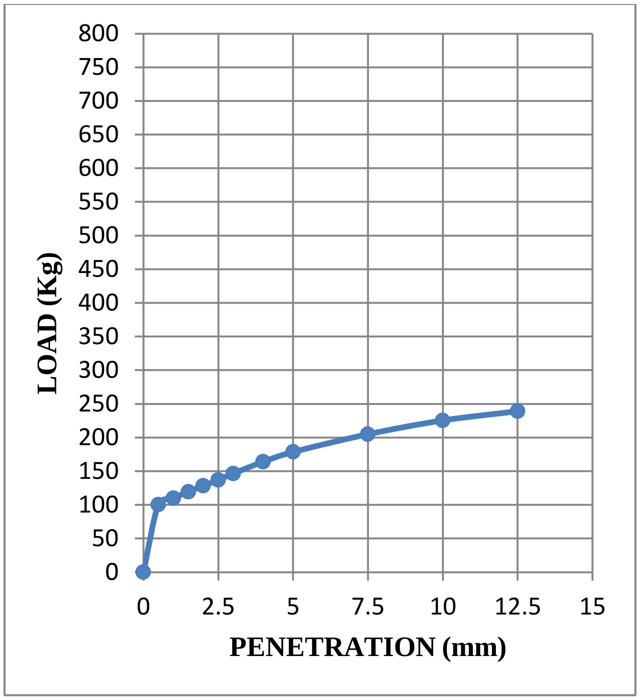

Fig. 3.33: Load-penetration curve at OMC+3% of sample 3 (dynamically compacted soil)

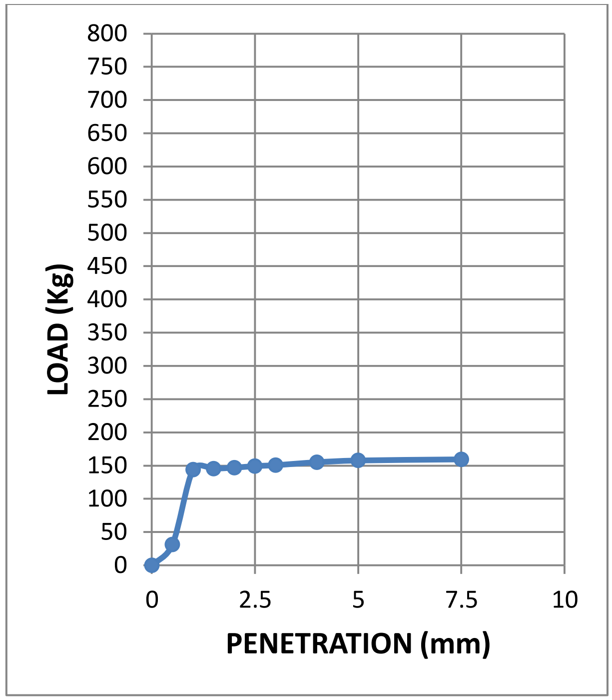

Fig. 3.34: Load-penetration curve at OMC+3% of sample 3 (statically compacted soil)

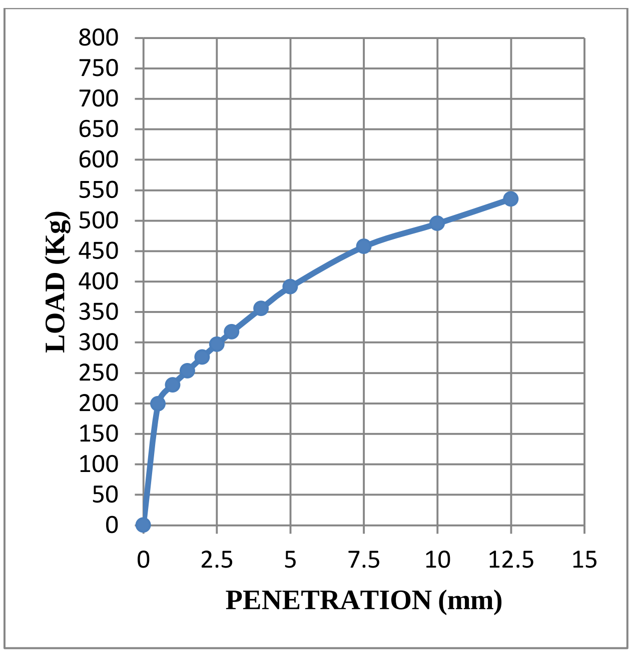

Fig. 3.35: Load-penetration curve at OMC-3% of sample 4 (Dynamically compacted soil)

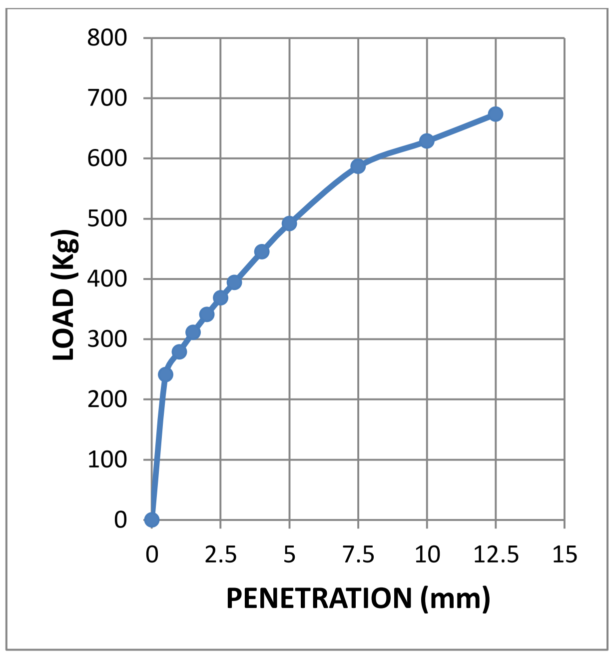

Fig. 3.36: Load-penetration curve at OMC-3% of sample 4 (Statically compacted soil)

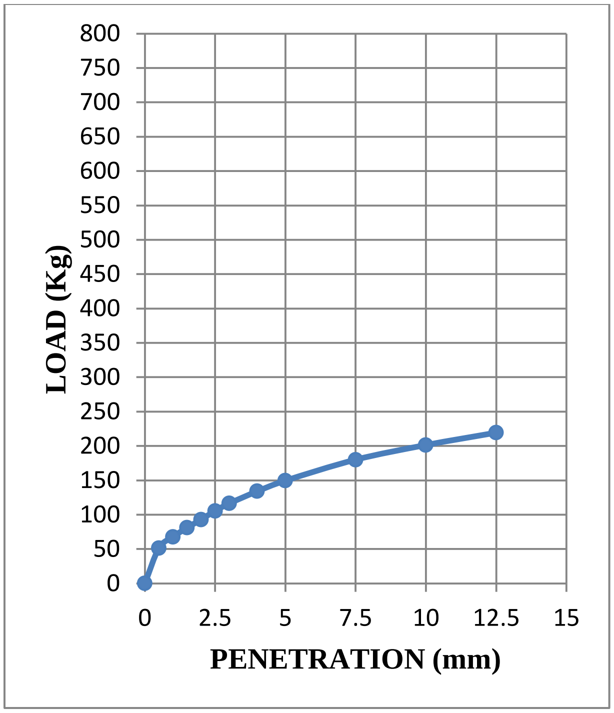

Fig. 3.37: Load-penetration curve at OMC of sample 4 (Dynamically compacted soil)

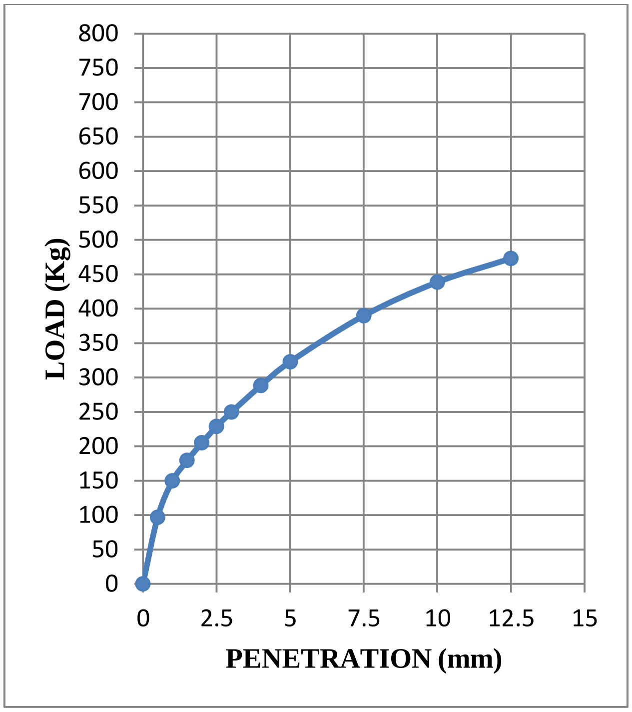

Fig. 3.38: Load-penetration curve at OMC of sample 4 (Statically compacted soil)

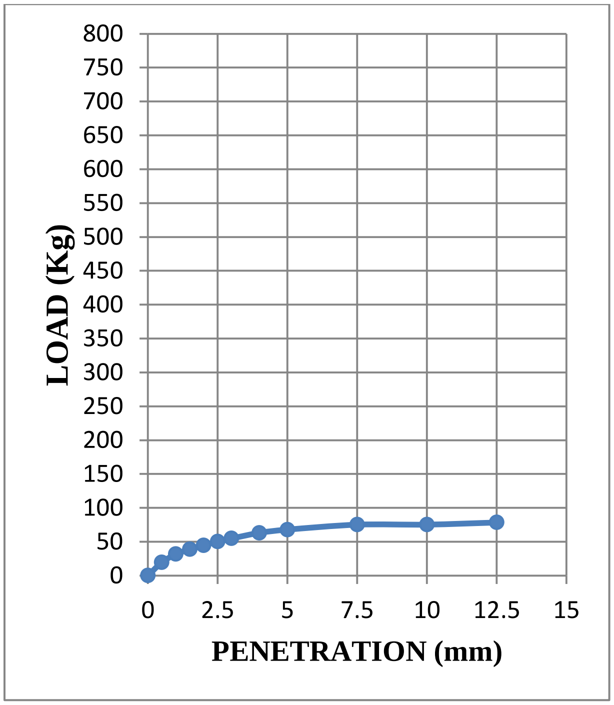

Fig. 3.39: Load-penetration curve at OMC+3% of sample 4 (Dynamically compacted soil)

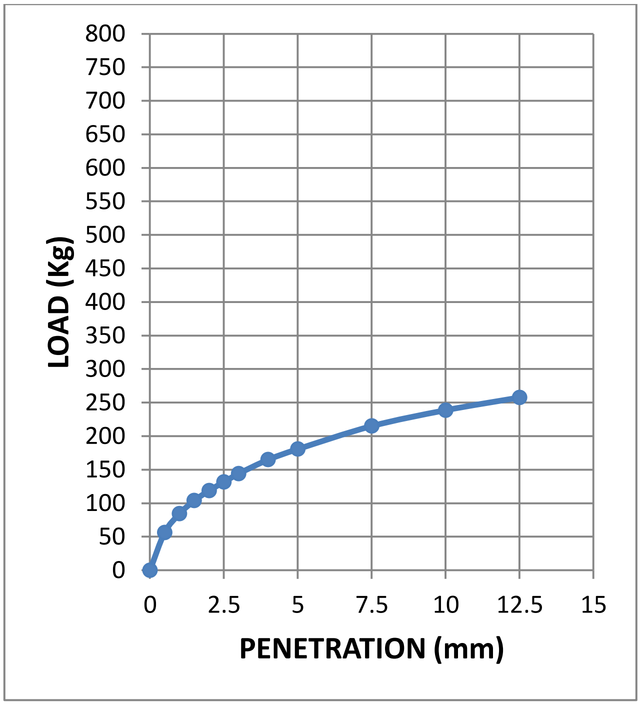

Fig. 3.40: Load-penetration curve at OMC+3% of sample 4 (statically compacted soil)

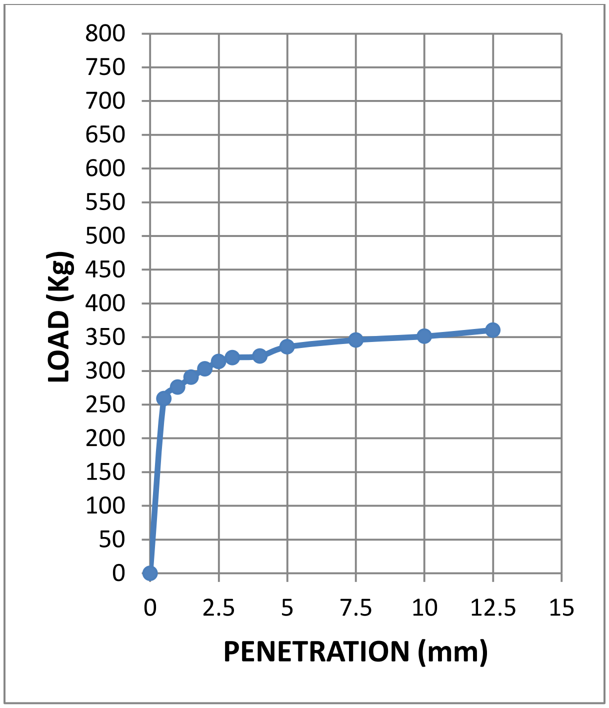

Fig. 3.41: Load-penetration curve at OMC-3% of sample 5 (dynamically compacted soil)

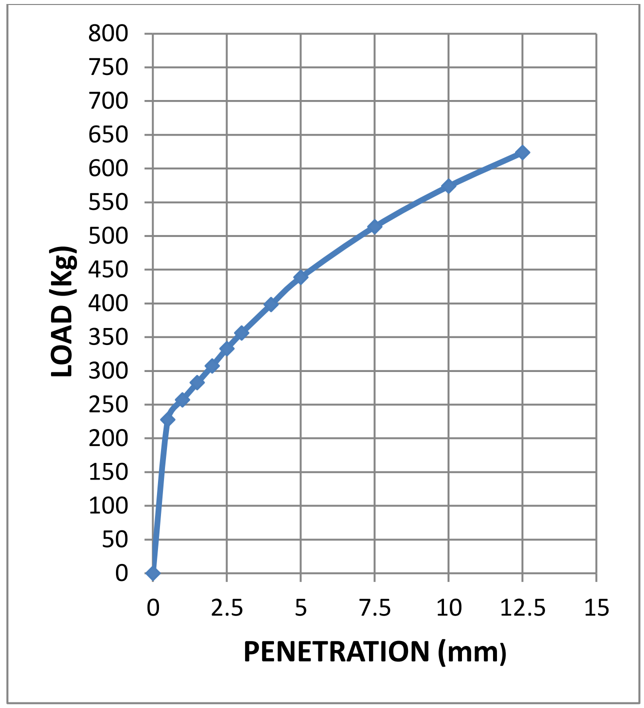

Fig. 3.42: Load-penetration curve at OMC-3% of sample 5 (statically compacted soil)

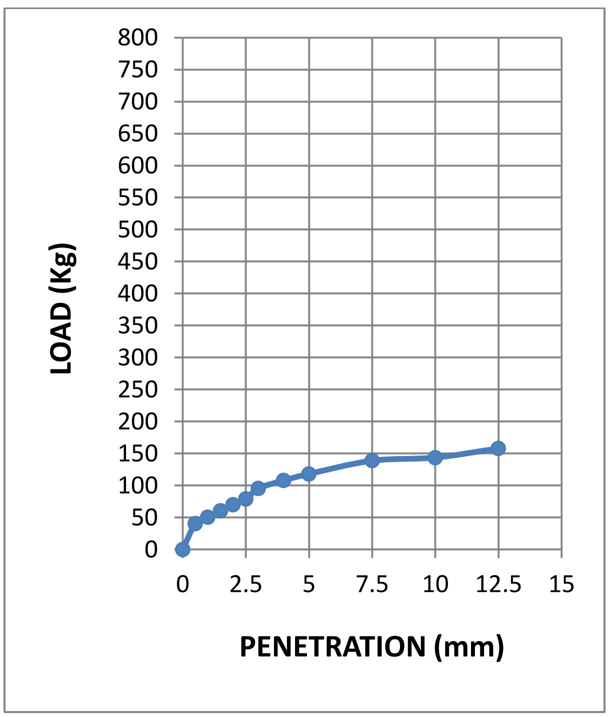

Fig. 3.43: Load-penetration curve at OMC of sample 5 (dynamically compacted soil)

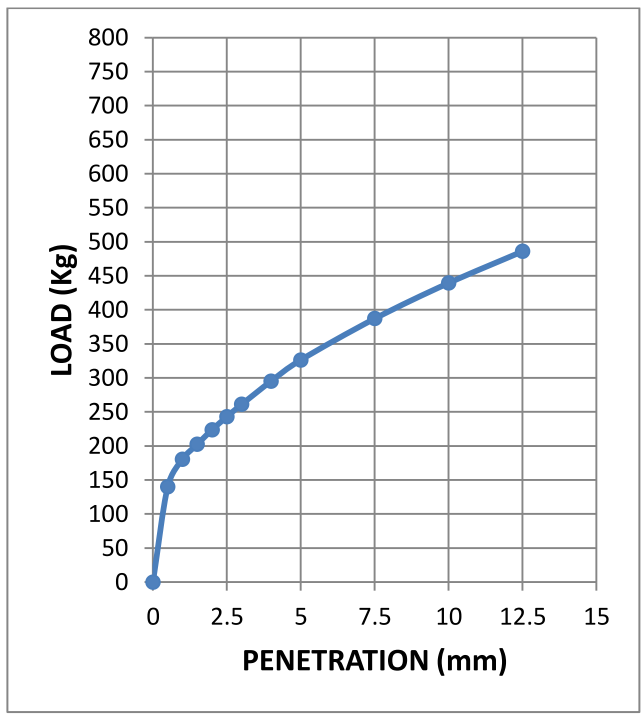

Fig. 3.44: Load-penetration curve at OMC of sample 5 (statically compacted soil)

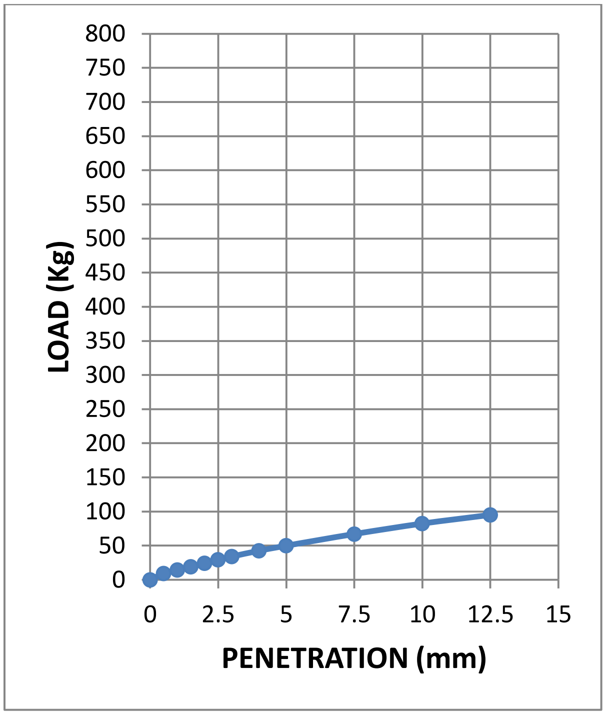

Fig. 3.45: Load-penetration curve at OMC+3% of sample 5 (dynamically compacted soil)

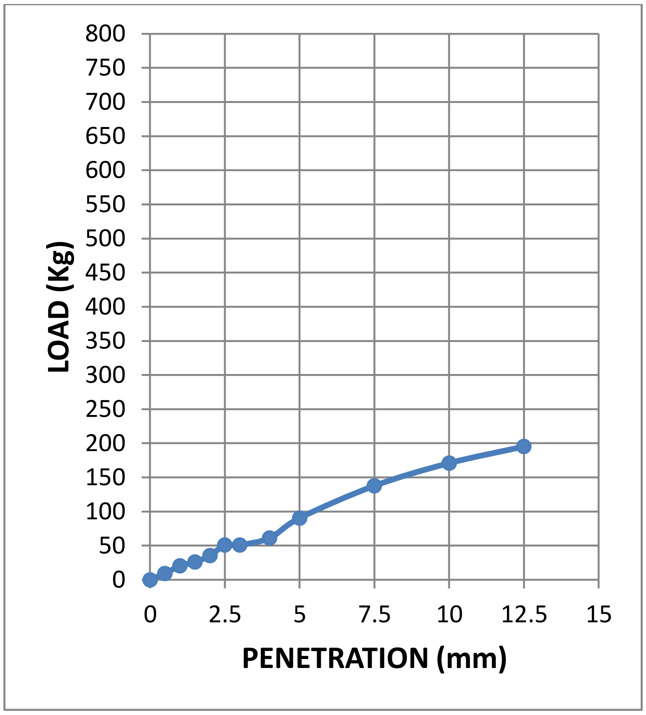

Fig. 3.46: Load-penetration curve at OMC+3% of sample 5 (statically compacted soil)

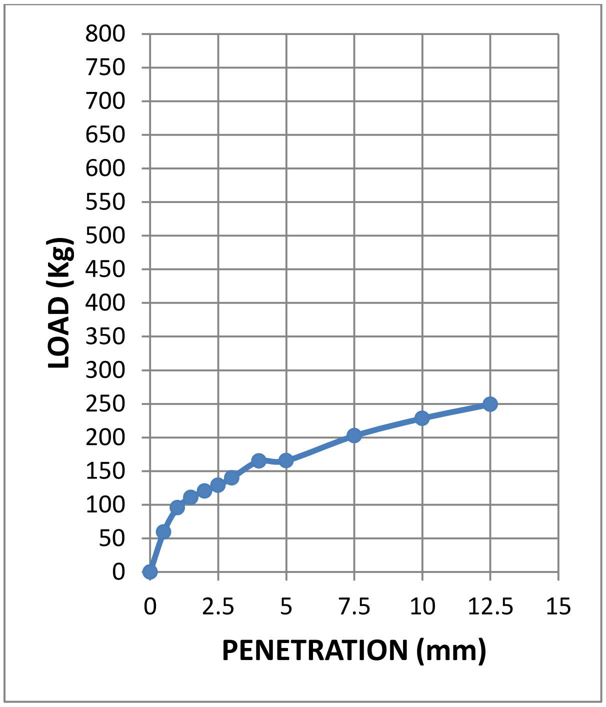

Fig. 3.47: Load-penetration curve at OMC-3% of sample 6 (dynamically compacted soil)

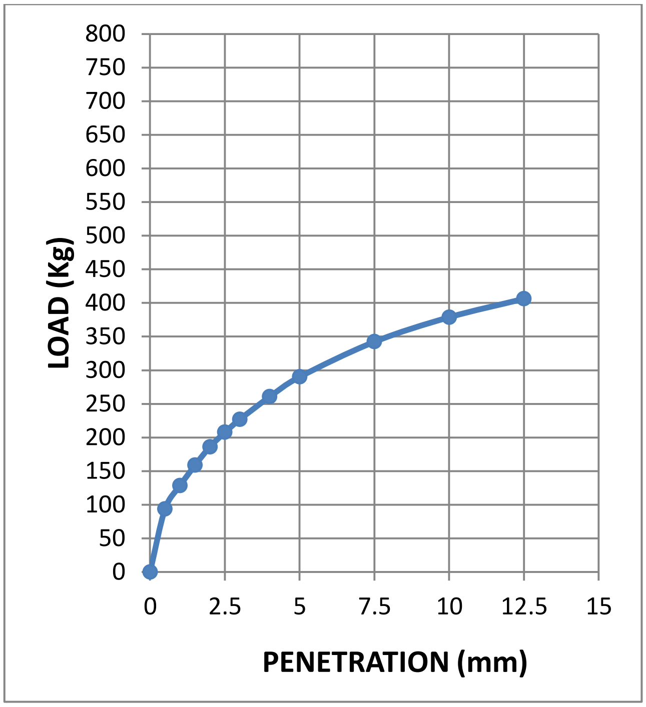

Fig. 3.48: Load-penetration curve at OMC-3% of sample 6 (statically compacted soil)

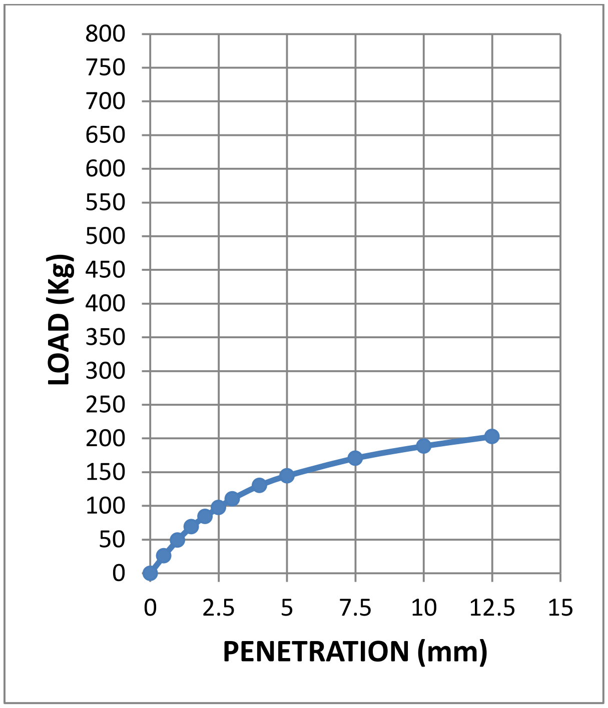

Fig. 3.49: Load-penetration curve at OMC of sample 6 (dynamically compacted soil)

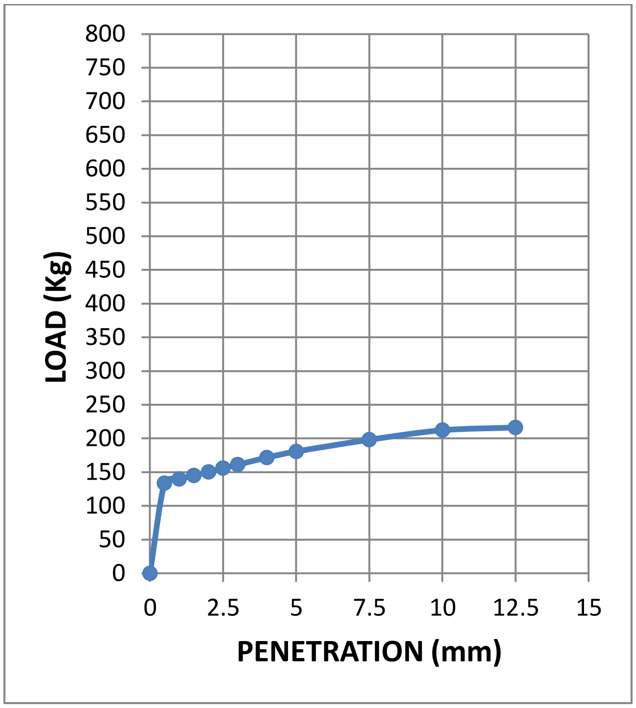

Fig. 3.50: Load-penetration curve at OMC of sample 6 (statically compacted soil)

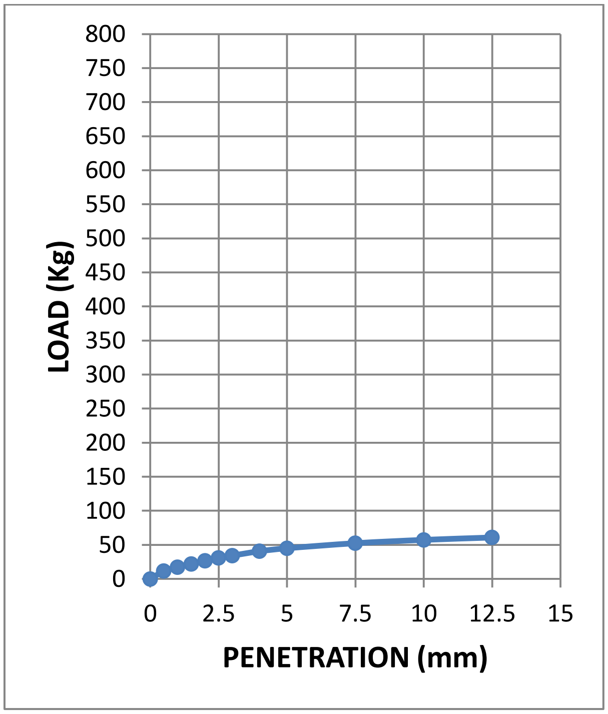

Fig. 3.51: Load-penetration curve at OMC+3% of sample 6 (dynamically compacted soil)

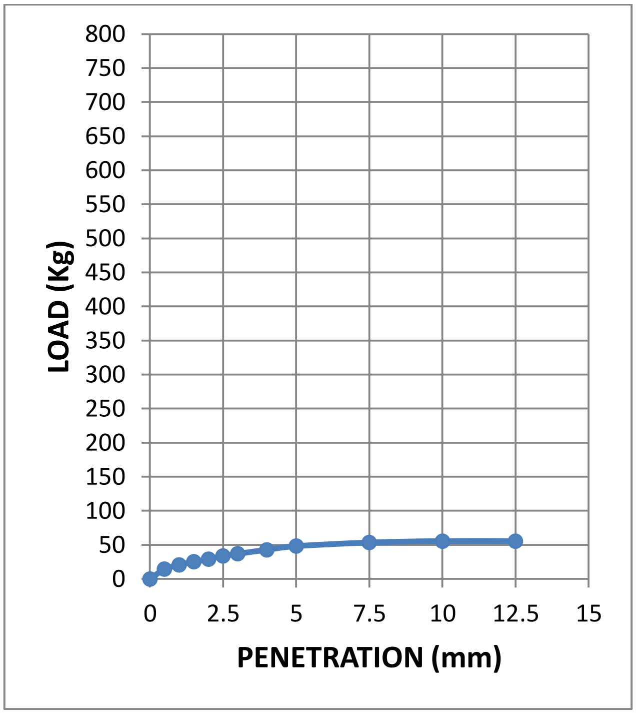

Fig. 3.52: Load-penetration curve at OMC+3% of sample 6 (statically compacted soil)

The unsoaked CBR values obtained on each statically and dynamically compacted soil specimens are shown in the following table:

Table 3.4: Unsoaked CBR values obtained by static and dynamic method of compaction

Sample No.	Water Content %	CBR Value %	
		Statically Compacted Soil	Dynamically Compacted Soil
1	OMC-3%	19.74	16.72
	OMC	10.45	8.01
	OMC+3%	4.78	1.36
2	OMC-5%	23.19	17.22
	OMC	20.13	16.47
	OMC+5%	8.87	5.10
3	OMC-3%	30.13	19.04
	OMC	24.49	14.74
	OMC+3%	10.90	10.00
4	OMC-3%	26.89	21.67
	OMC	16.71	7.71
	OMC+3%	9.60	3.66
5	OMC-3%	24.30	22.91
	OMC	17.72	5.76
	OMC+3%	4.40	2.43
6	OMC-3%	15.14	9.39
	OMC	11.39	7.11
	OMC+3%	2.45	2.24

3.3.4: Determination of unconfined compressive strength of soil samples

The unconfined compression tests are done on the soil samples to determine the unconfined compressive strength on statically and dynamically compacted soil specimens at the required water content. The test results are shown in the graphs below

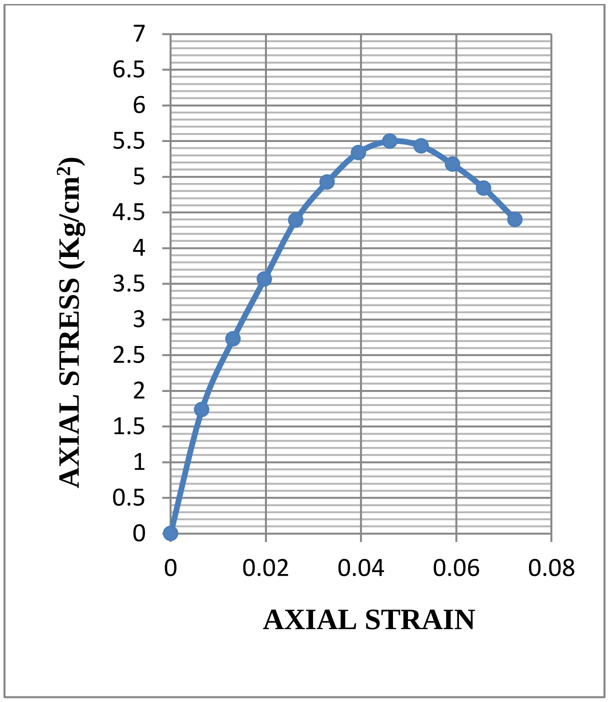

Fig.3.53: Stress-strain graph of UCS test for sample 1 at OMC-3% (Statically Compacted)

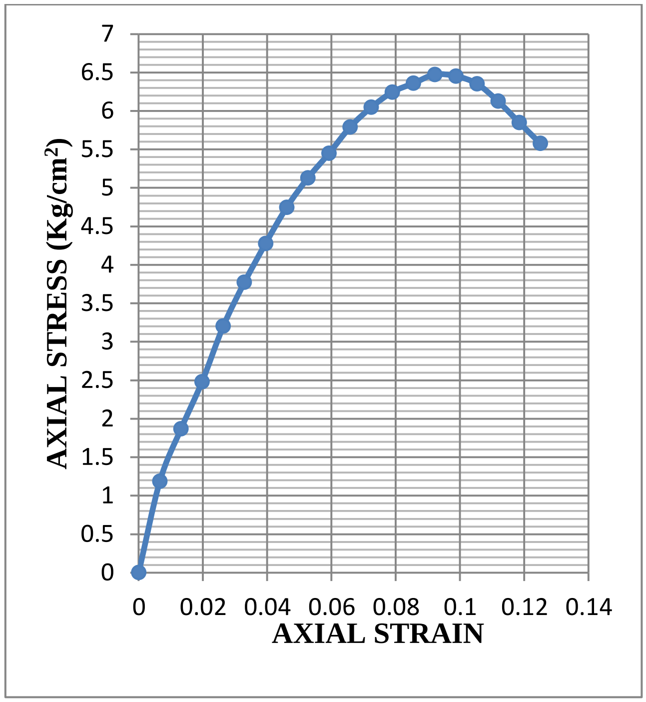

Fig.3.54: Stress-strain graph of UCS test for sample 1 at OMC-3% (Dynamically Compacted)

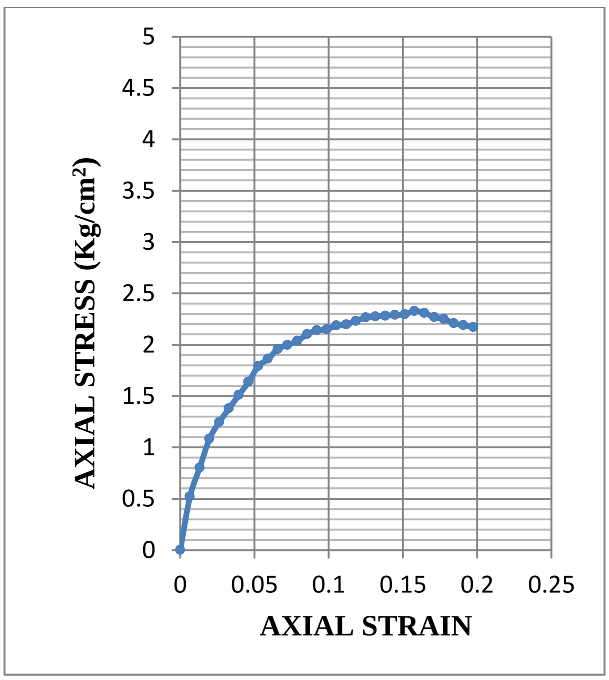

Fig.3.55: Stress-strain graph of UCS test for sample 1 at OMC (Statically Compacted)

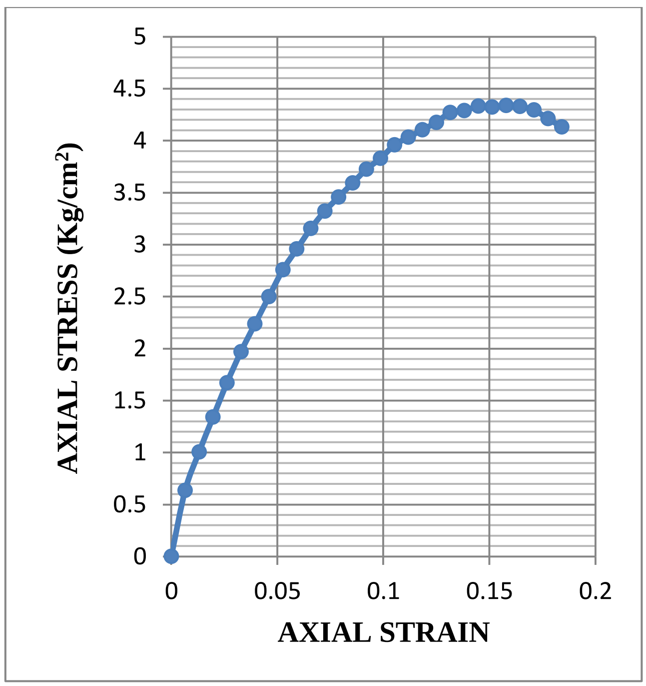

Fig.3.56: Stress-strain graph of UCS test for sample 1 at OMC (Dynamically Compacted)

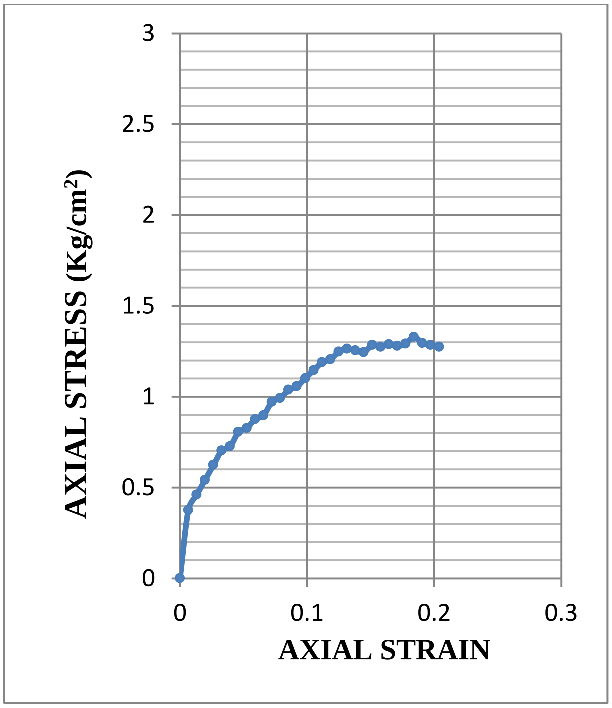

Fig.3.57: Stress-strain graph of UCS test for sample 1 at OMC+3% (Statically Compacted)

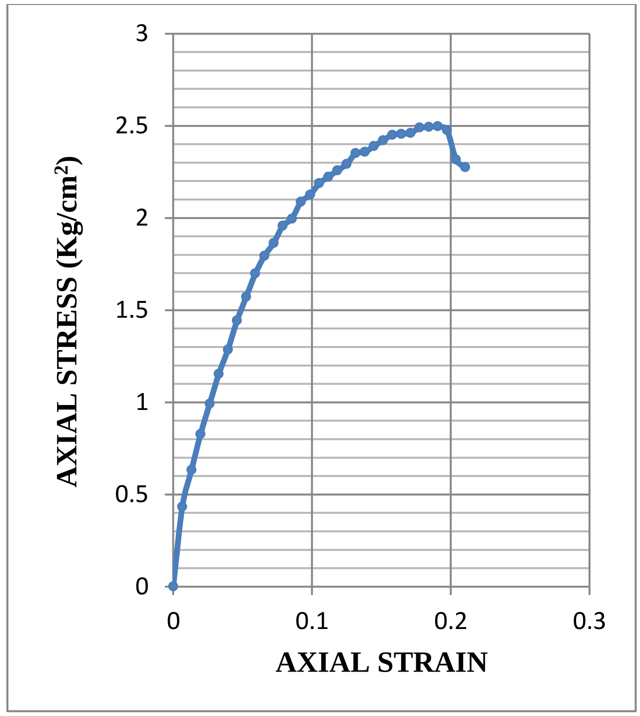

Fig.3.58: Stress-strain graph of UCS test for sample 1 at OMC+3% (Dynamically Compacted)

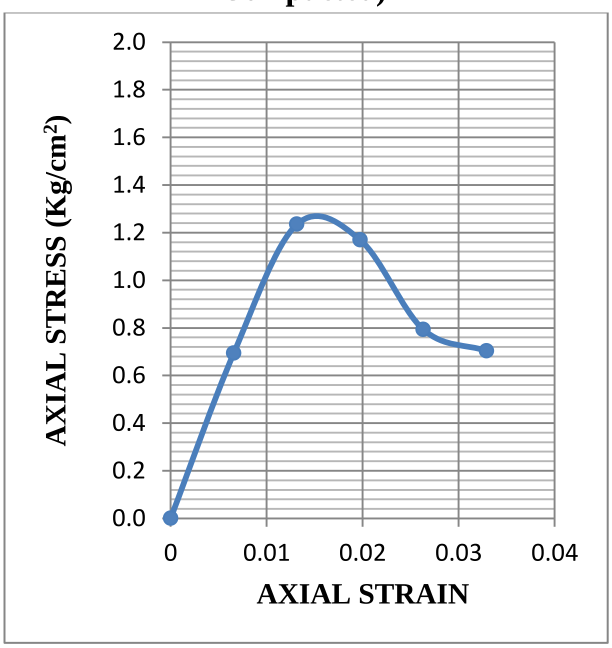

Fig.3.59: Stress-strain graph of UCS test for sample 2 at OMC-5% (Statically Compacted)

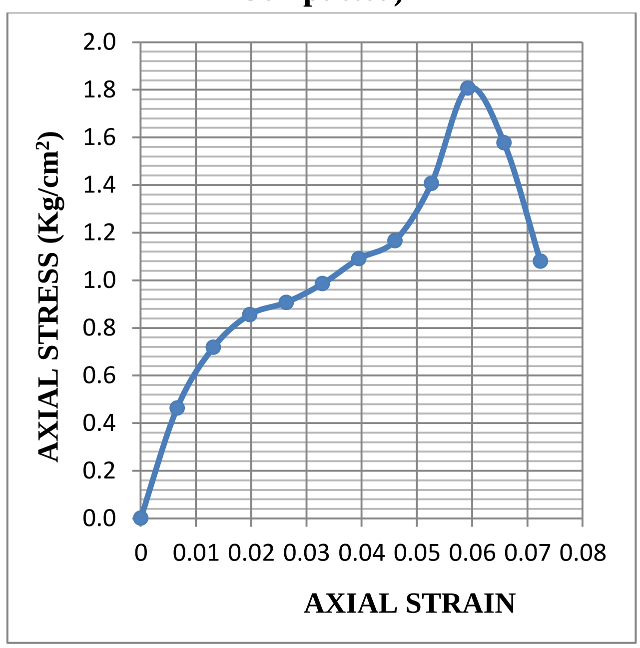

Fig.3.60: Stress-strain graph of UCS test for sample 2 at OMC-5% (Dynamically Compacted)

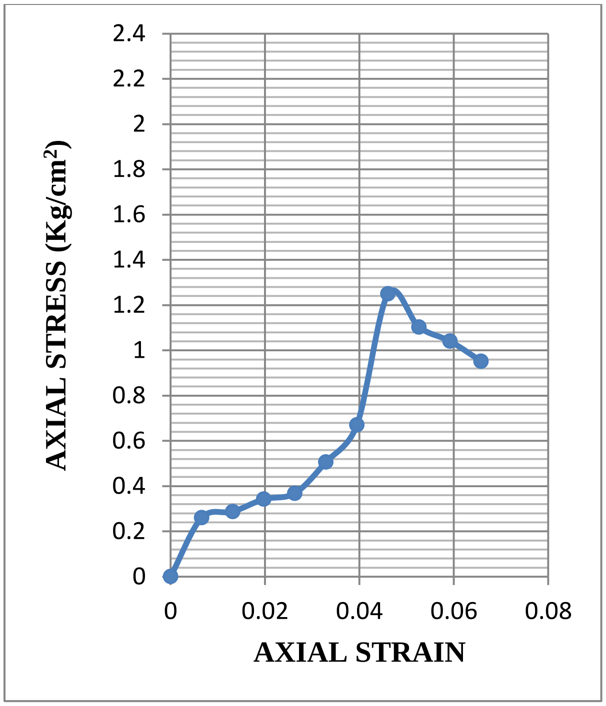

Fig.3.61: Stress-strain graph of UCS test for sample 2 at OMC (Statically Compacted)

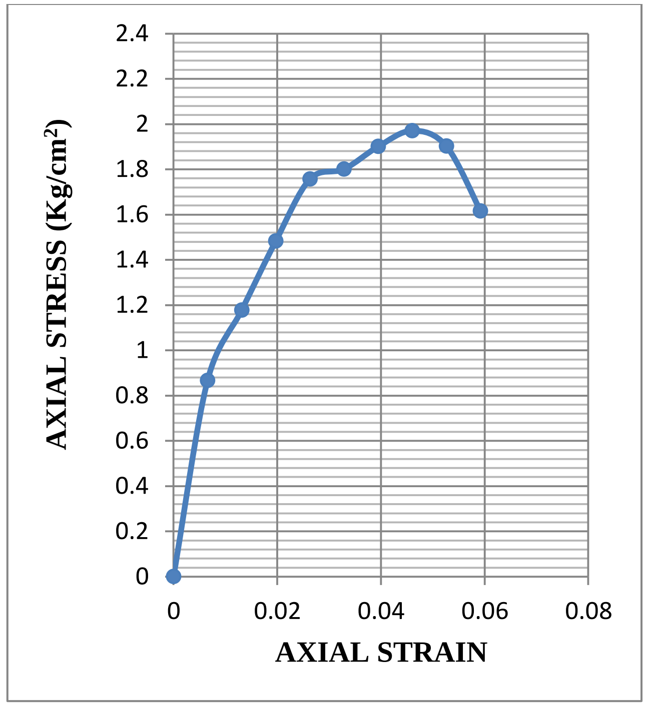

Fig.3.62: Stress-strain graph of UCS test for sample 2 at OMC (Dynamically Compacted)

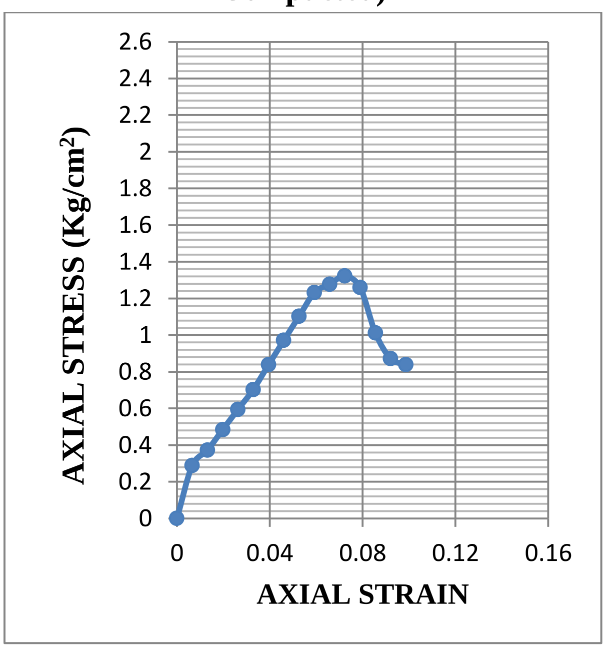

Fig.3.63: Stress-strain graph of UCS test for sample 2 at OMC+5% (Statically Compacted)

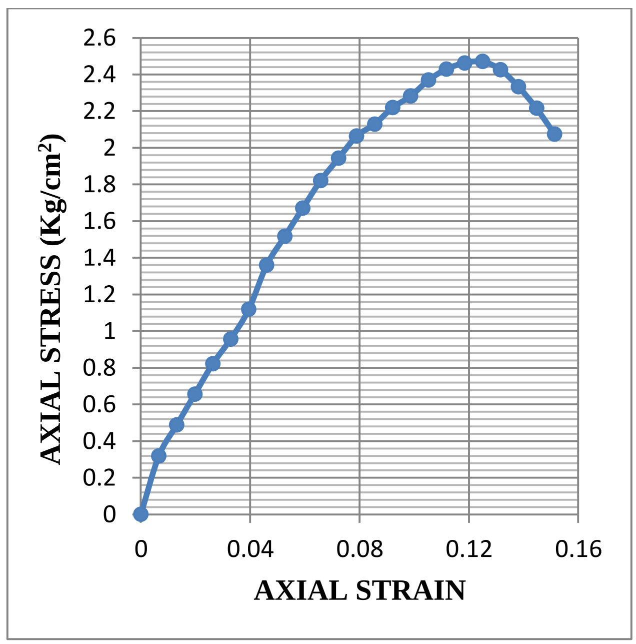

Fig.3.64: Stress-strain graph of UCS test for sample 2 at OMC+5% (Dynamically Compacted)

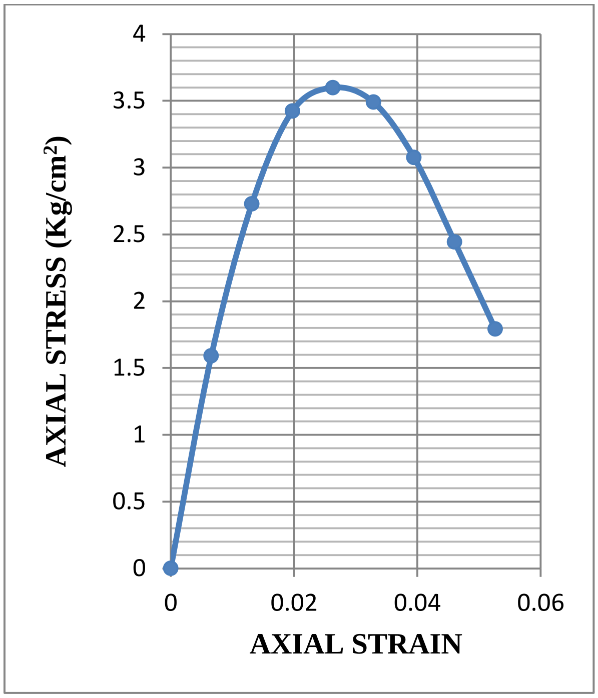

Fig.3.65: Stress-strain graph of UCS test for sample 3 at OMC-3% (Statically Compacted)

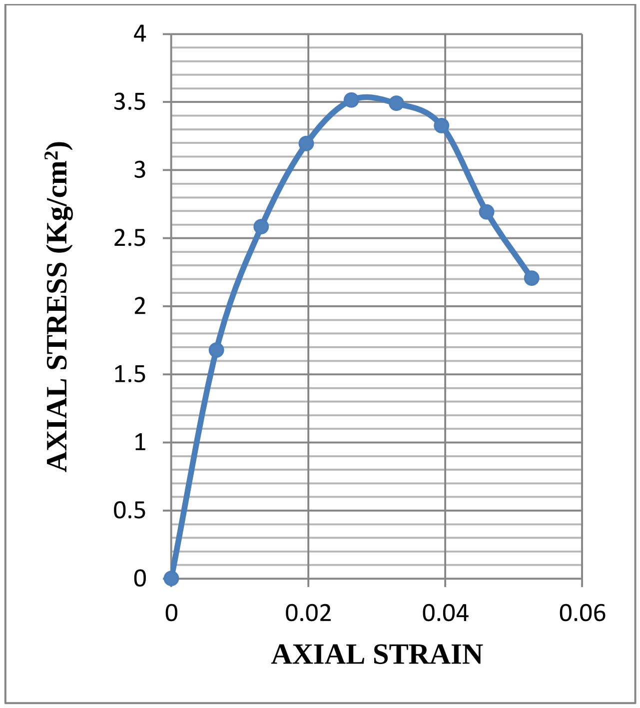

Fig.3.66: Stress-strain graph of UCS test for sample 3 at OMC-3% (Dynamically Compacted)

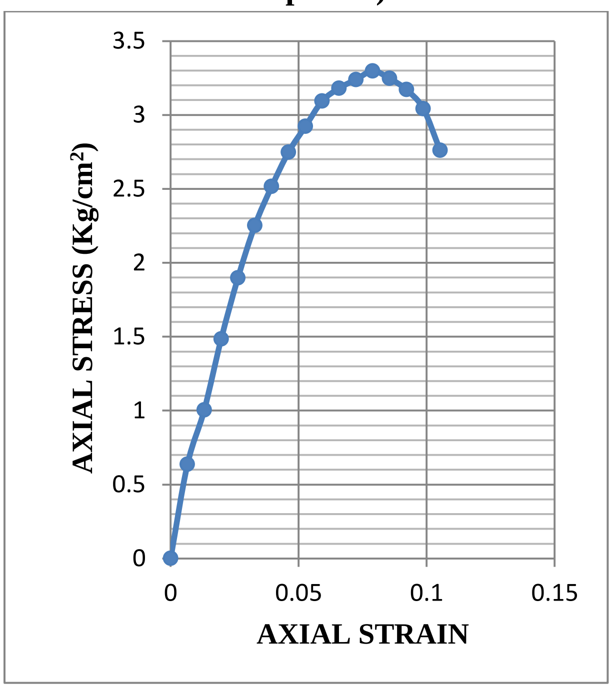

Fig.3.67: Stress-strain graph of UCS test for sample 3 at OMC (Statically Compacted)

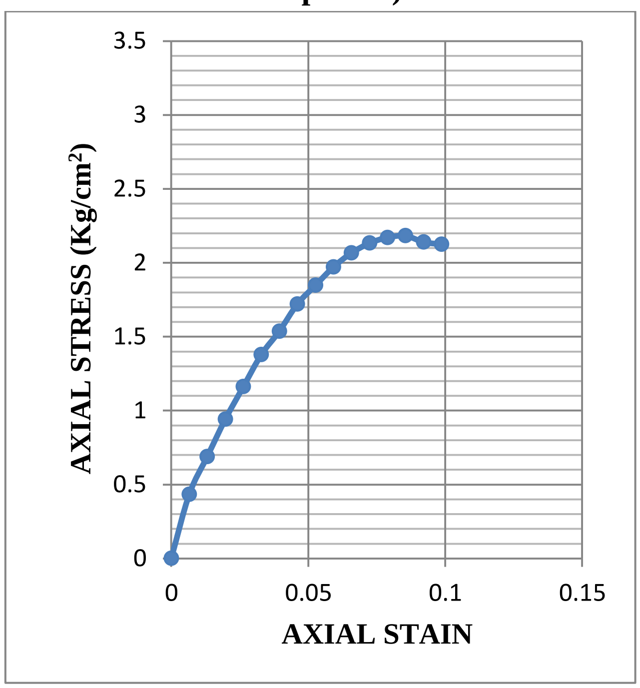

Fig.3.68: Stress-strain graph of UCS test for sample 3 at OMC (Dynamically Compacted)

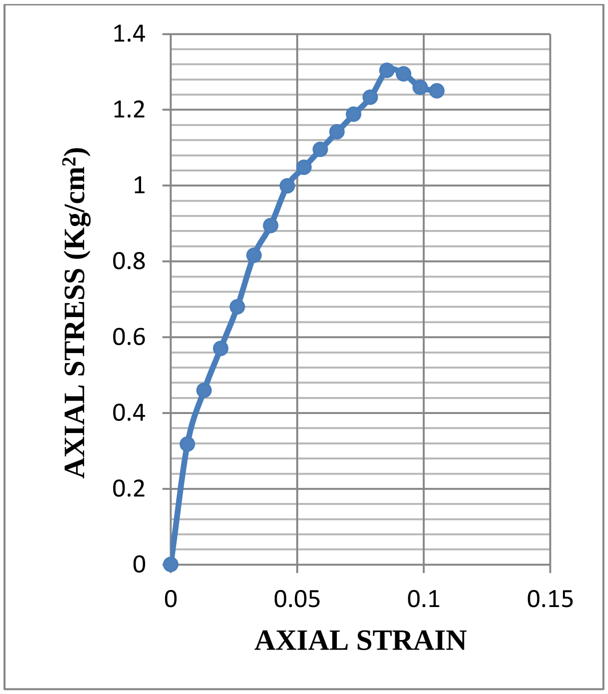

Fig.3.69: Stress-strain graph of UCS test for sample 3 at OMC+3% (Statically Compacted)

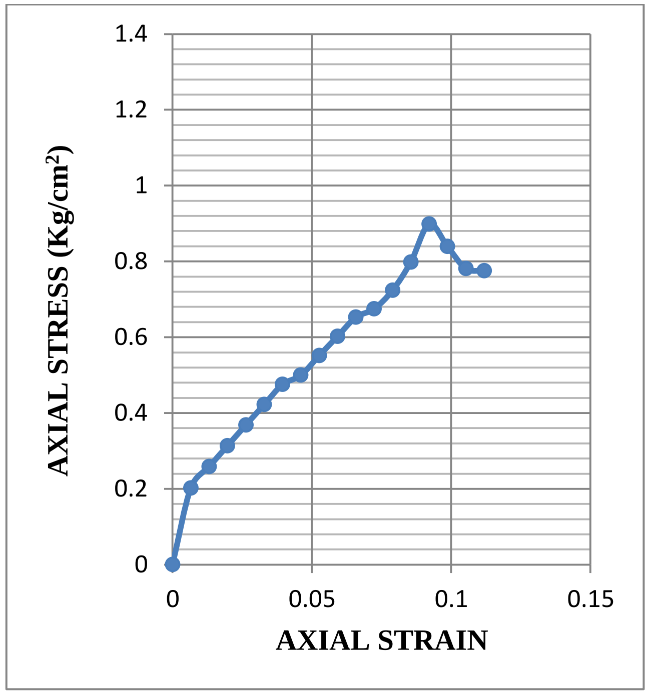

Fig.3.70: Stress-strain graph of UCS test for sample 3 at OMC+3% (Dynamically Compacted)

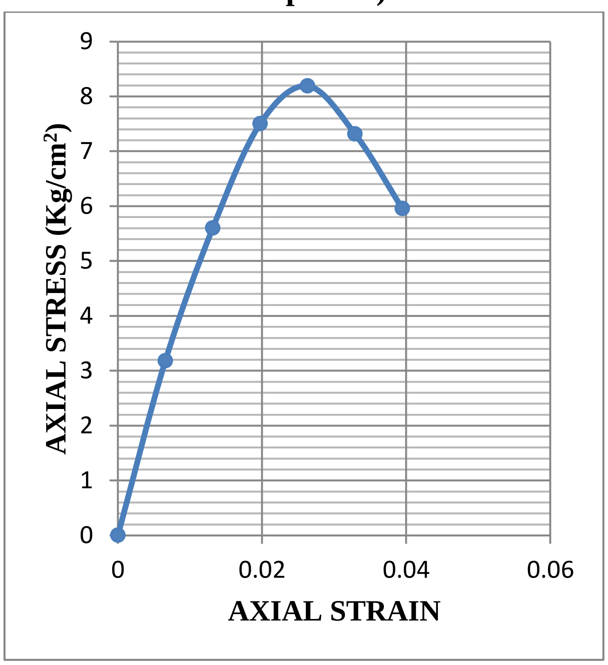

Fig.3.71: Stress-strain graph of UCS test for sample 4 at OMC-3% (Statically Compacted)

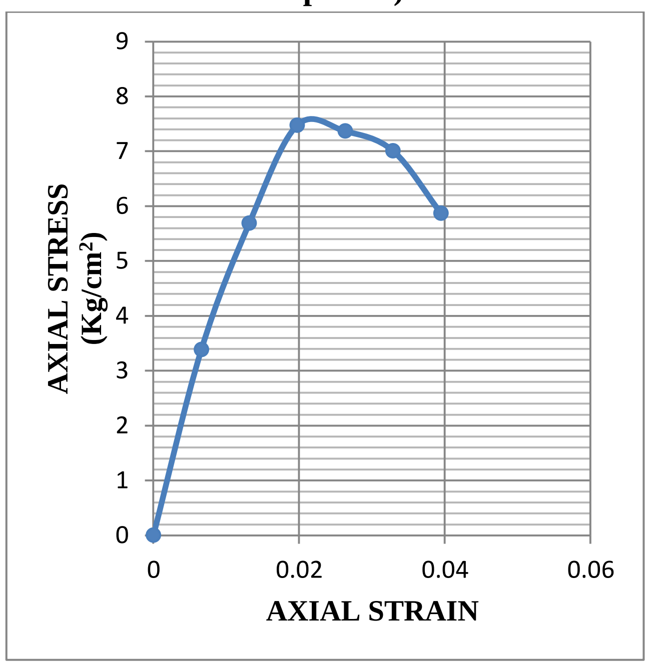

Fig.3.72: Stress-strain graph of UCS test for sample 4 at OMC-3% (Dynamically Compacted)

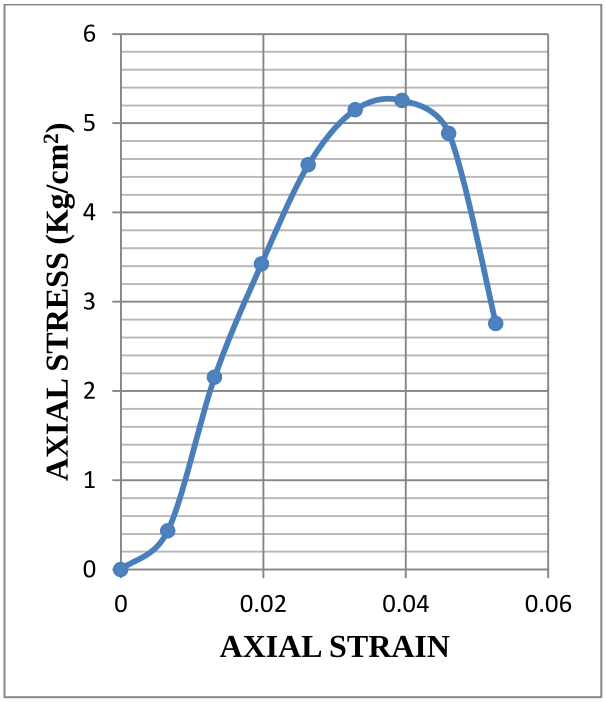

Fig.3.73: Stress-strain graph of UCS test for sample 4 at OMC (Statically Compacted)

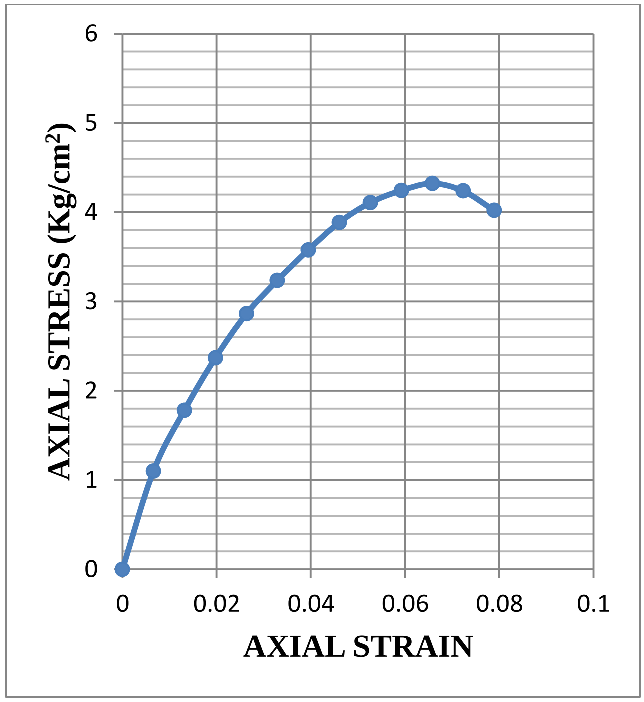

Fig.3.74: Stress-strain graph of UCS test for sample 4 at OMC (Dynamically Compacted)

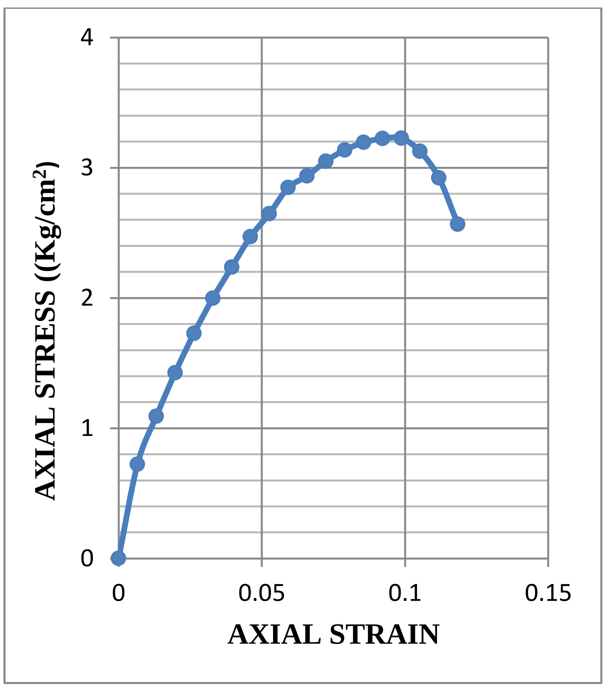

Fig.3.75: Stress-strain graph of UCS test for sample 4 at OMC+3% (Statically Compacted)

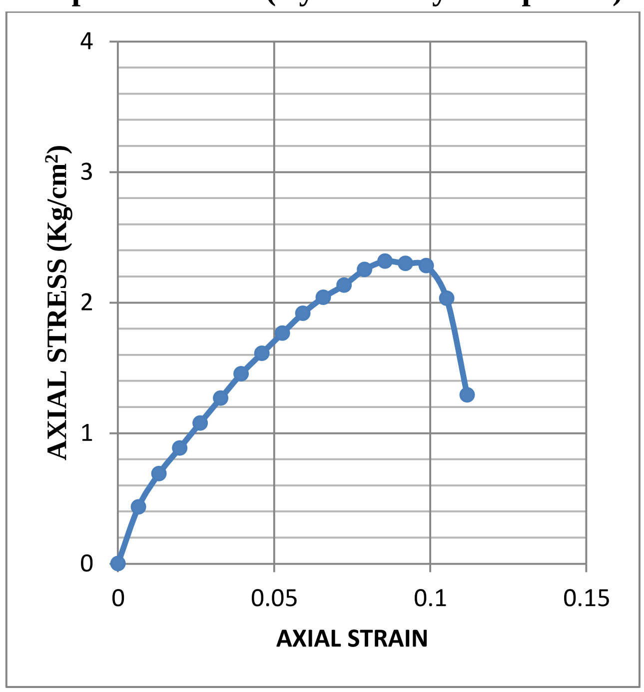

Fig.3.76: Stress-strain graph of UCS test for sample 4 at OMC+3% (Dynamically Compacted)

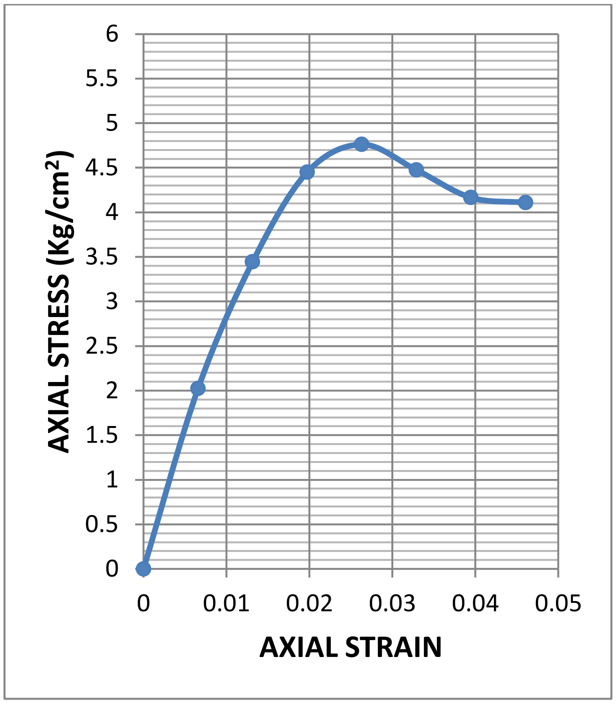

Fig.3.77: Stress-strain graph of UCS test for sample 5 at OMC-3% (Statically Compacted)

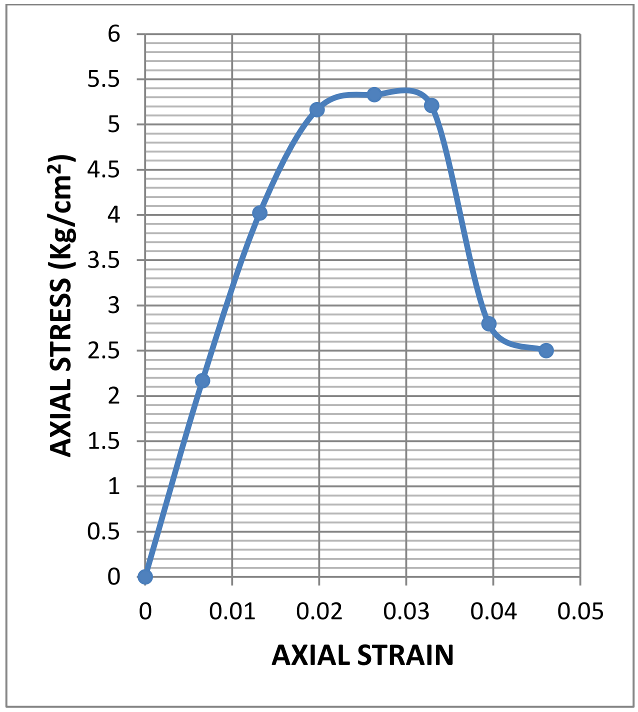

Fig.3.78: Stress-strain graph of UCS test for sample 5 at OMC-3% (Dynamically Compacted)

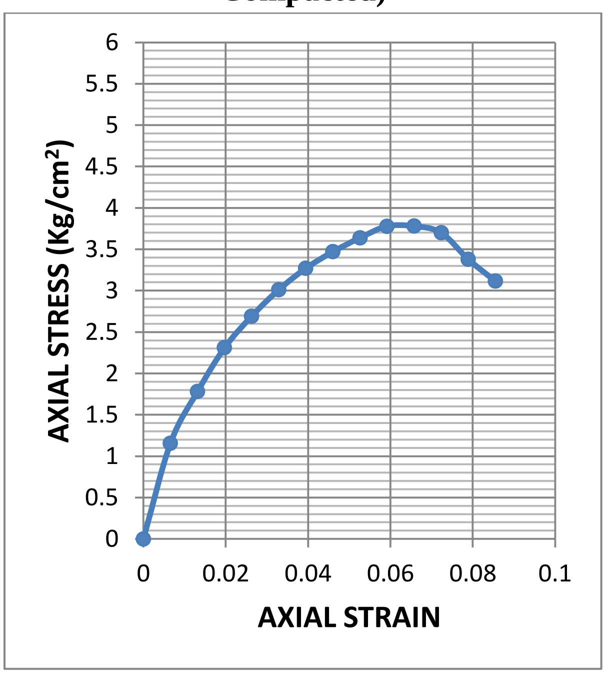

Fig.3.79: Stress-strain graph of UCS test for sample 5 at OMC (Statically Compacted)

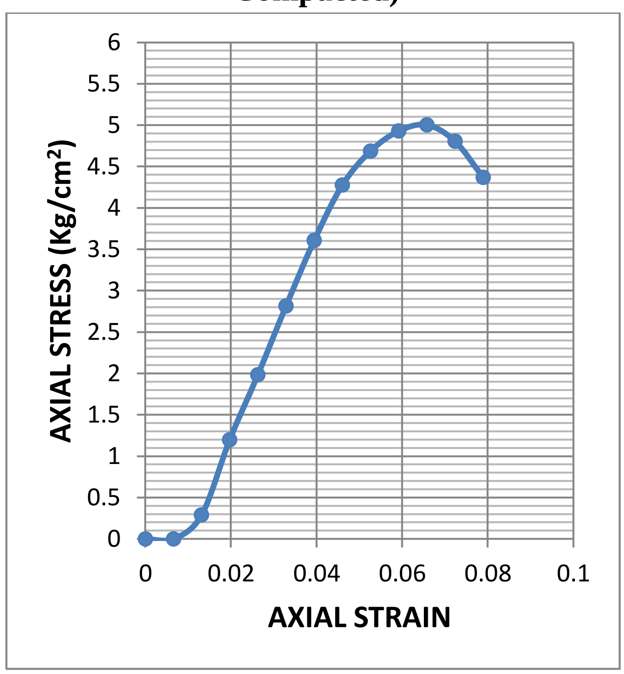

Fig.3.80: Stress-strain graph of UCS test for sample 5 at OMC (Dynamically Compacted)

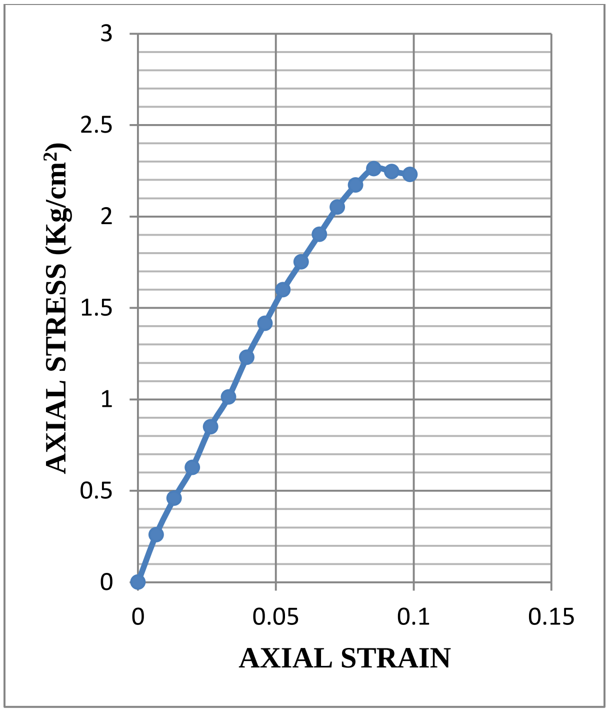

Fig.3.81: Stress-strain graph of UCS test for sample 5 at OMC+3% (Statically Compacted)

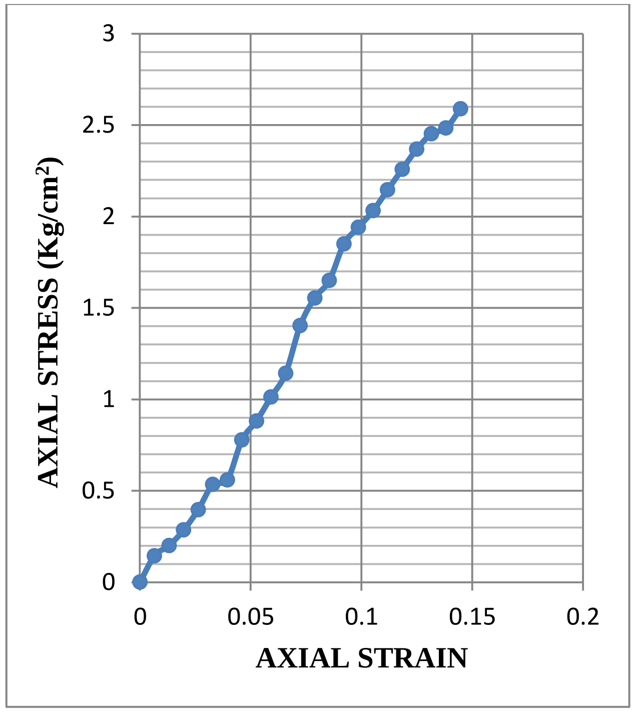

Fig.3.82: Stress-strain graph of UCS test for sample 5 at OMC+3% (Dynamically Compacted)

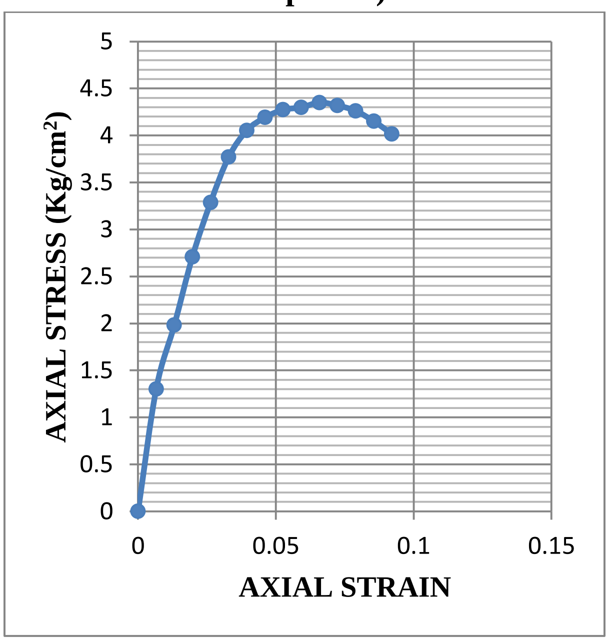

Fig.3.83: Stress-strain graph of UCS test for sample 6 at OMC-3% (Statically Compacted)

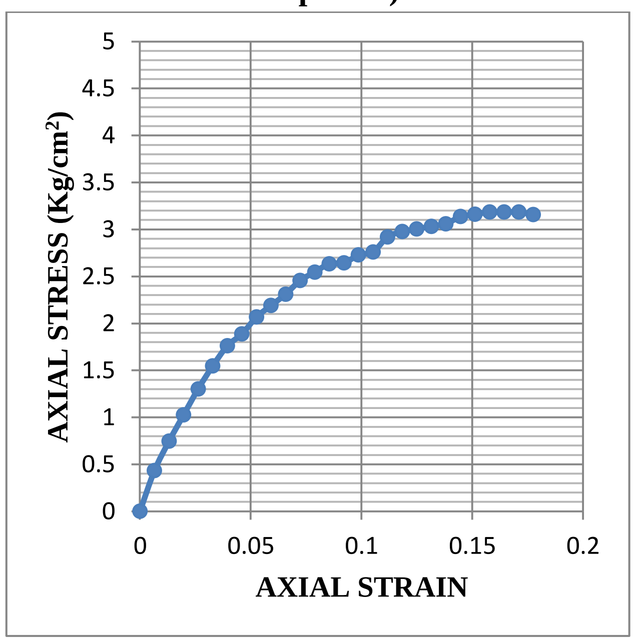

Fig.3.84: Stress-strain graph of UCS test for sample 6 at OMC-3% (Dynamically Compacted)

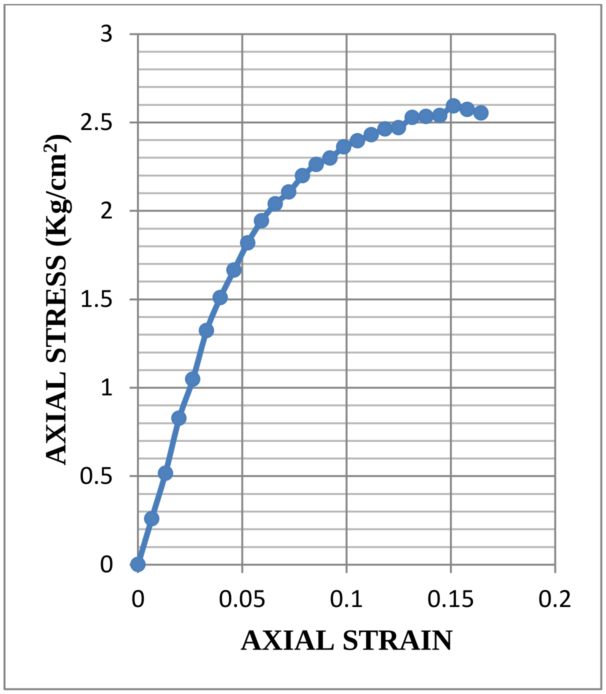

Fig.3.85: Stress-strain graph of UCS test for sample 6 at OMC (Statically Compacted)

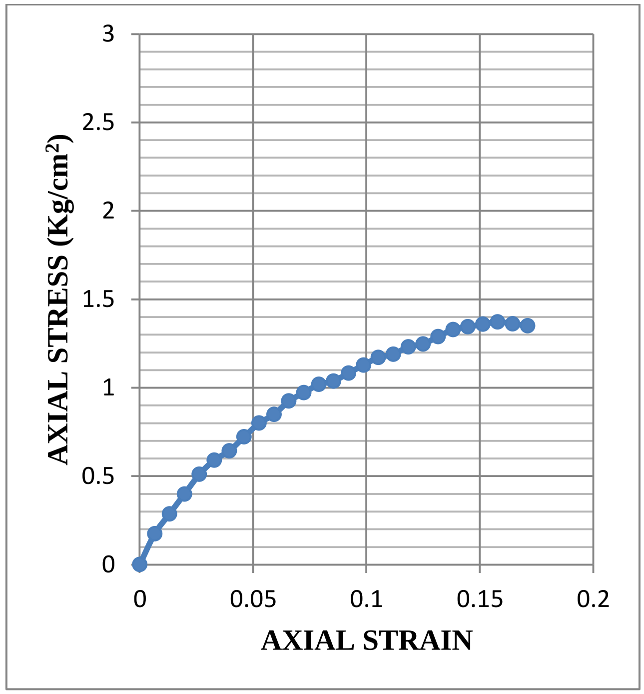

Fig.3.86: Stress-strain graph of UCS test for sample 6 at OMC (Dynamically Compacted)

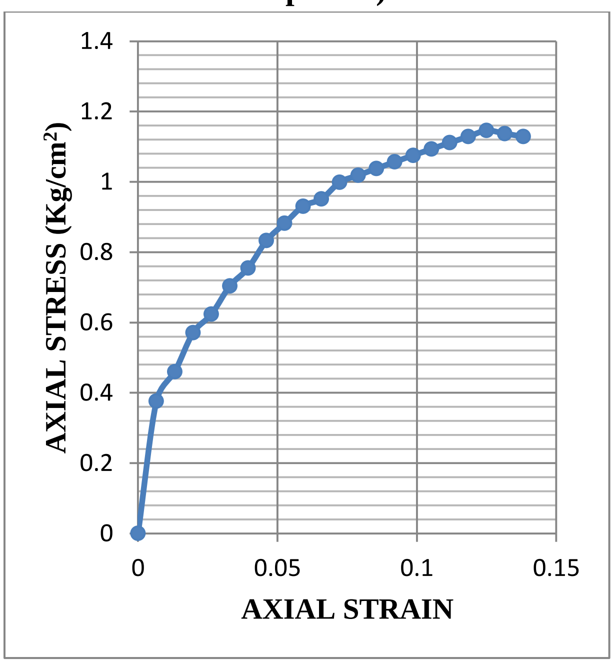

Fig.3.87: Stress-strain graph of UCS test for sample 6 at OMC+3% (Statically Compacted)

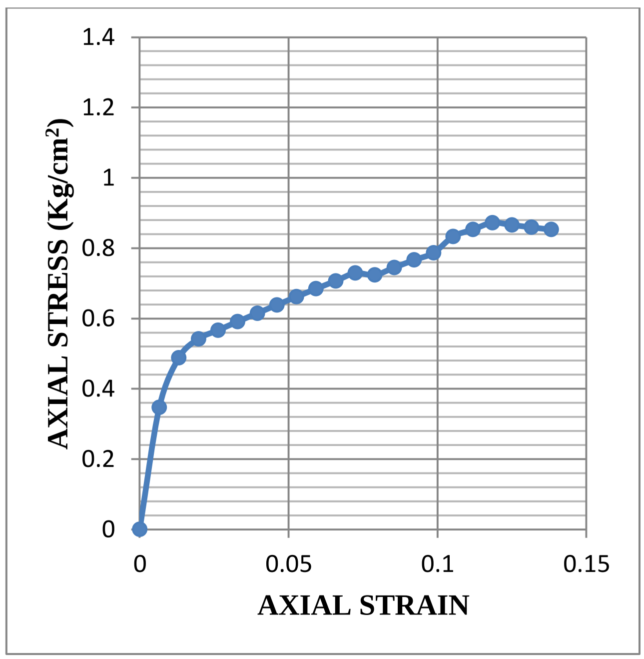

Fig.3.88: Stress-strain graph of UCS test for sample 6 at OMC+3% (Dynamically Compacted)

The test results of UCS tests are represented in tabular form as follows

Table 3.5: Unconfined compressive strength of statically and dynamically compacted soil specimens

Sample No.	Water Content %	Average UCS value (kPa)		Ratio of static and dynamic UCS value	Consistency As per static data	Consistency As per dynamic data
		Statically compacted	Dynamically compacted			
*1	OMC-3%	550	650	0.85	Hard	Hard
	OMC	232	430	0.54	Very Stiff	Hard
	OMC+3%	132.9	250	0.53	Stiff	Very Stiff
*2	OMC-5%	124	180.7	0.69	Stiff	Stiff
	OMC	124.9	197	0.63	Stiff	Stiff
	OMC+5%	126	247	0.51	Stiff	Very Stiff
3	OMC-3%	360	351	1.03	Very Stiff	Very Stiff
	OMC	330	219	1.51	Very Stiff	Very Stiff
	OMC+3%	128.9	90	1.43	Stiff	Medium
4	OMC-3%	820	747	1.09	Hard	Hard
	OMC	521	432	1.21	Hard	Hard
	OMC+3%	322	230	1.4	Very Stiff	Very Stiff
*5	OMC-3%	475	540	0.88	Hard	Hard
	OMC	380	500	0.76	Very Stiff	Hard
	OMC+3%	226	260	0.87	Very Stiff	Very Stiff
6	OMC-3%	435	320	1.36	Hard	Very Stiff
	OMC	260	136	1.91	Very Stiff	Stiff
	OMC+3%	113	87.2	1.29	Stiff	Medium

*Sample is showing higher UCS value when compacted dynamically than statically compacted soil.

3.3.5 XRD test of four soil samples

X-ray diffraction (XRD) test has been conducted on four soil samples out of the six to identify the clay minerals present in them. The following are the diffractograms of the soil samples:

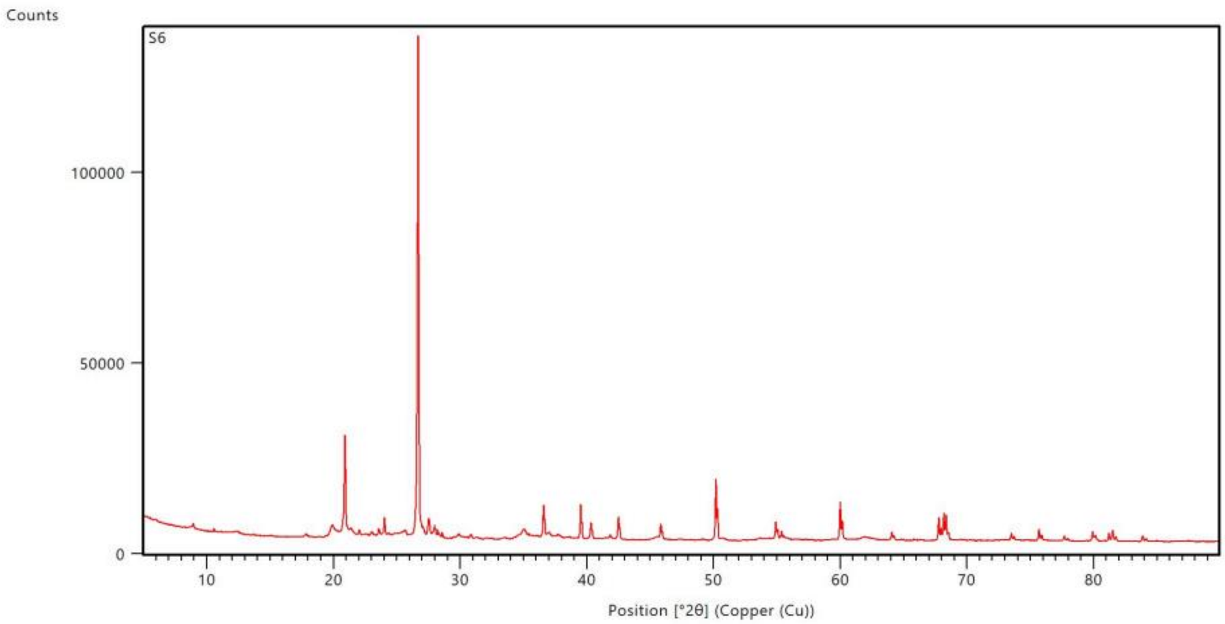

Fig.3.89: Diffractogram of sample 1

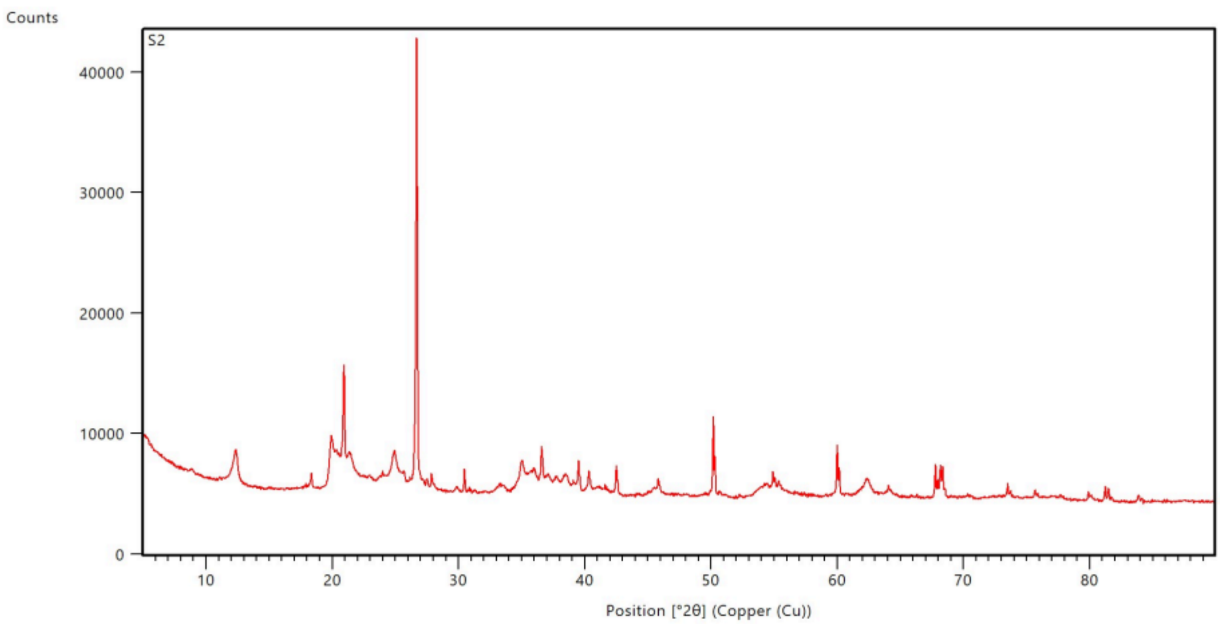

Fig.3.90: Diffractogram of sample 2

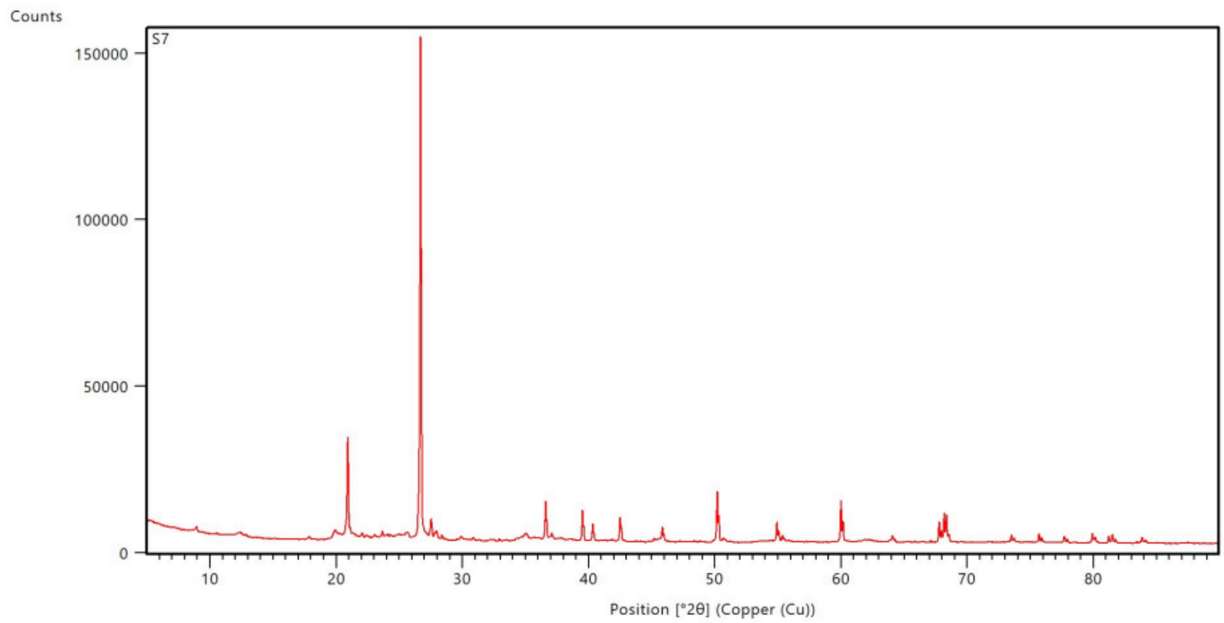

Fig.3.91: Diffractogram of sample 3

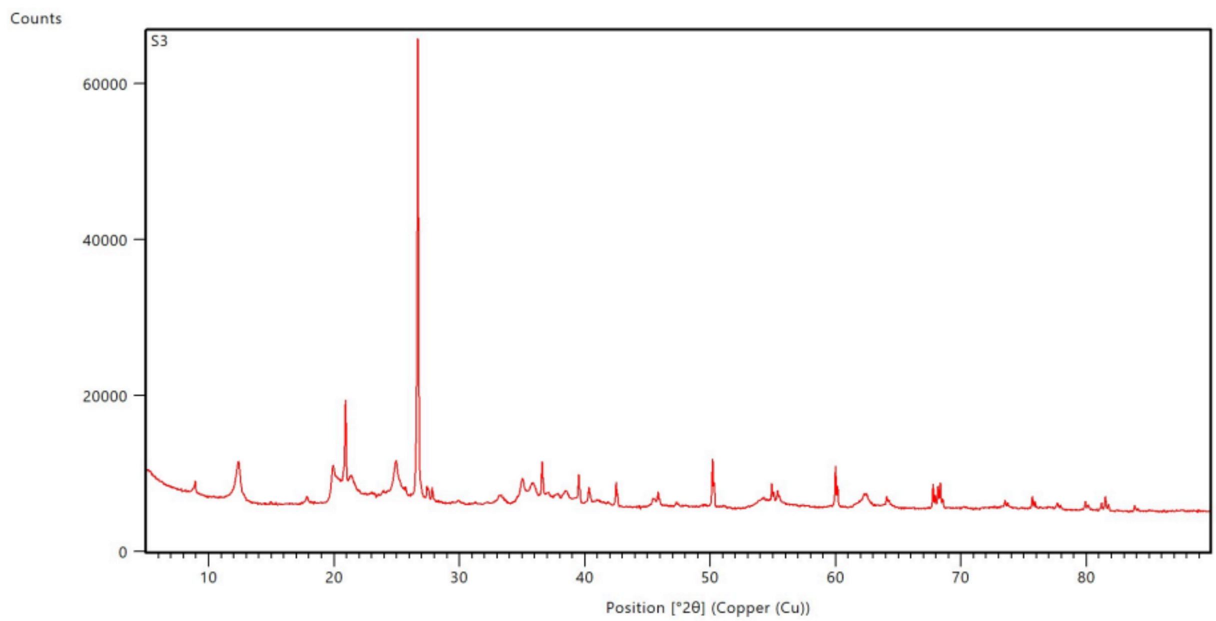

Fig.3.92: Diffractogram of sample 4

The clay minerals present in the soil samples are listed below.

Table 3.6: Clay minerals present in the four tested soil samples:

Soil sample	**Clay minerals**	**Soil type**
1	Montmorillonite, Illite, Chlorite	CI
2	Illite, Chlorire, Kaolinite	CH
3	Illite, Kaolinite, Chlorite	CI
4	Chlorite, Illite, Kaolinite	CH

CHAPTER 4

ANALYSIS OF TEST RESULTS

4.1: Introduction:

The following section addresses the influence of the static and dynamic laboratory compaction procedures in the mechanical strength of the soil samples tested. The experimental results of the study that are shown in Chapter 3 are analyzed in the subsequent sections, emphasizing variations of strength characteristics on dry of optimum, optimum moisture content, and wet of optimum while compacted statically and dynamically.

4.2: Analysis of strength test results of statically and dynamically compacted soil:

The following table illustrates the experimental findings of unsoaked CBR values of the specimens tested for the six statically and dynamically compacted soil samples. The table displays the percentage of the unsoaked CBR value in static compaction relative to the unsoaked CBR value on a dynamically compacted soil specimen as well.

Table 4.1: Relative increase in CBR value:

Sample No.	Soil type	% (silt+clay)	% sand	Water content %	Unsoaked CBR value % (Static compaction) (2)	Unsoaked CBR value % (Dynamic compaction) (3)	% increase in unsoaked CBR value in static compaction
1	CI	92.65	7.35	OMC-3%	19.74	16.72	15.30
				OMC	10.45	8.01	23.35
				OMC+3%	4.78	1.36	71.55
2	CH	71.85	28.15	OMC-5%	23.19	17.22	25.74
				OMC	20.13	16.47	18.18
				OMC+5%	8.87	5.10	42.50

3	CI	83.838	16.162	OMC-3%	30.13	19.04	36.81
				OMC	24.49	14.74	39.81
				OMC+3%	10.90	10.00	8.26
4	CH	90.17	9.83	OMC-3%	26.89	21.67	19.41
				OMC	16.71	7.71	53.86
				OMC+3%	9.60	3.66	61.88
5	CL	98.04	1.96	OMC-3%	24.30	22.91	5.72
				OMC	17.72	5.76	67.49
				OMC+3%	4.40	2.43	44.77
6	CI	95.94	4.06	OMC-3%	15.14	9.39	37.98
				OMC	11.39	7.11	37.58
				OMC+3%	2.45	2.24	8.57

From the experimental results obtained from the CBR test on soil specimens that are statically and dynamically compacted, load-penetration curves have been drawn in Chapter 3 and are superimposed here.

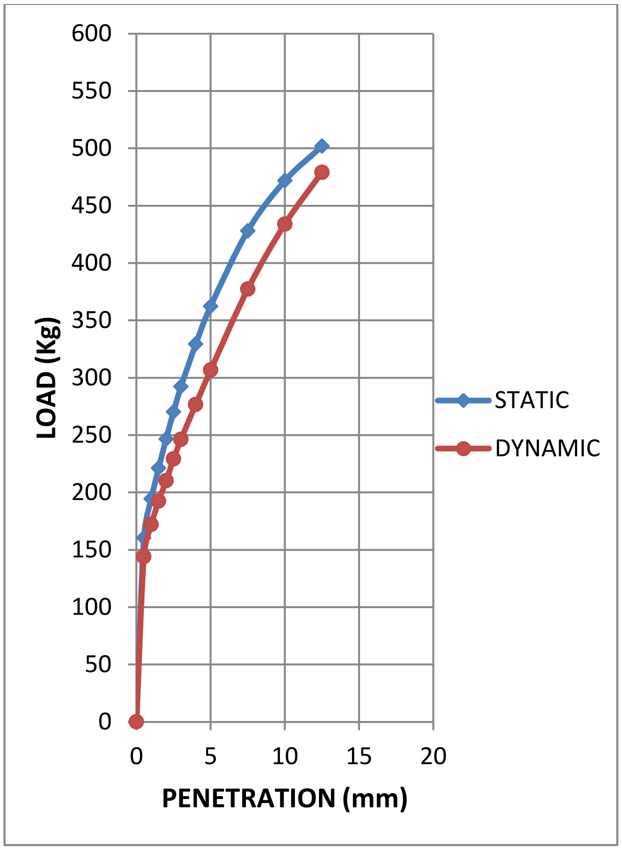

Fig. 4.1: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 1 at OMC-3%

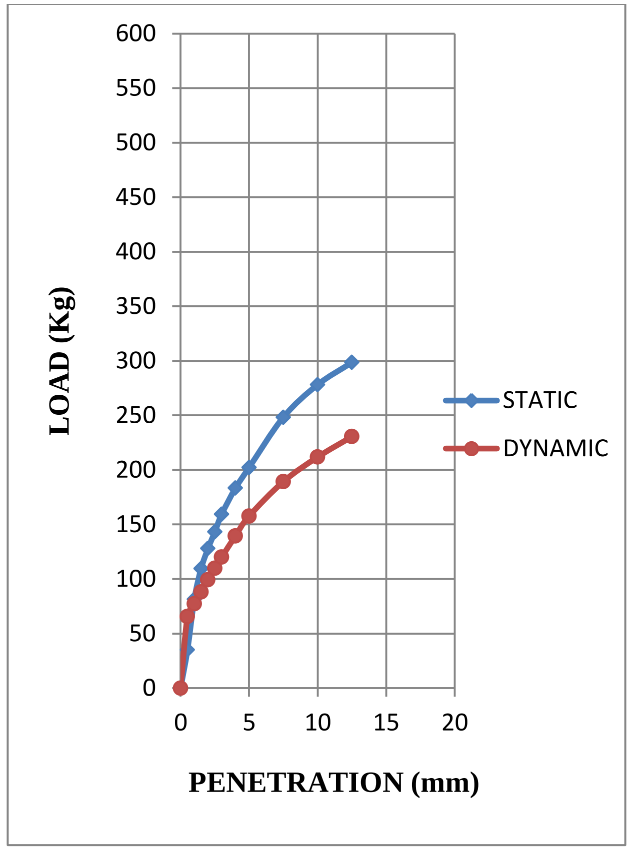

Fig. 4.2: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 1 at OMC

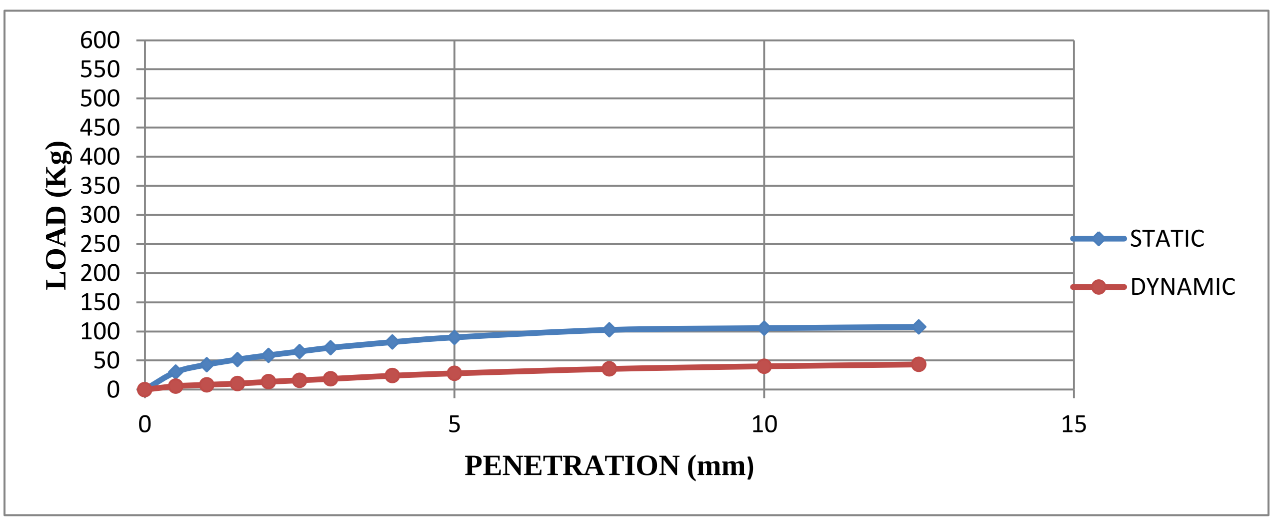

Fig. 4.3: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 1 at OMC+3%

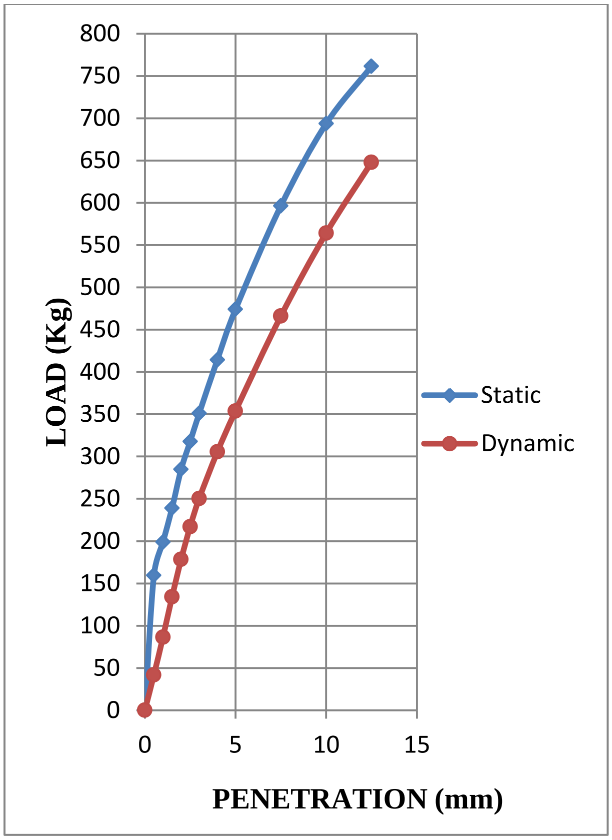

Fig. 4.4: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 2 at OMC-5%

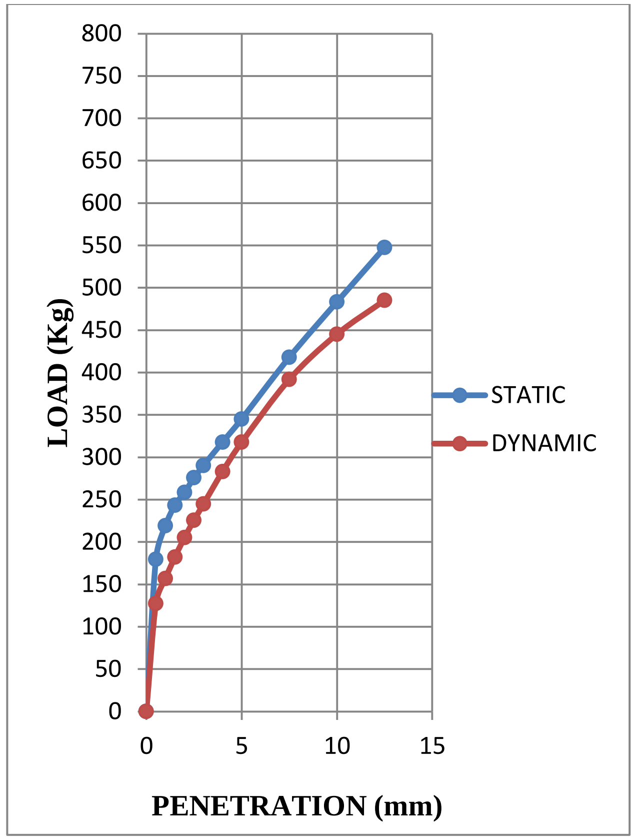

Fig. 4.5: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 2 at OMC

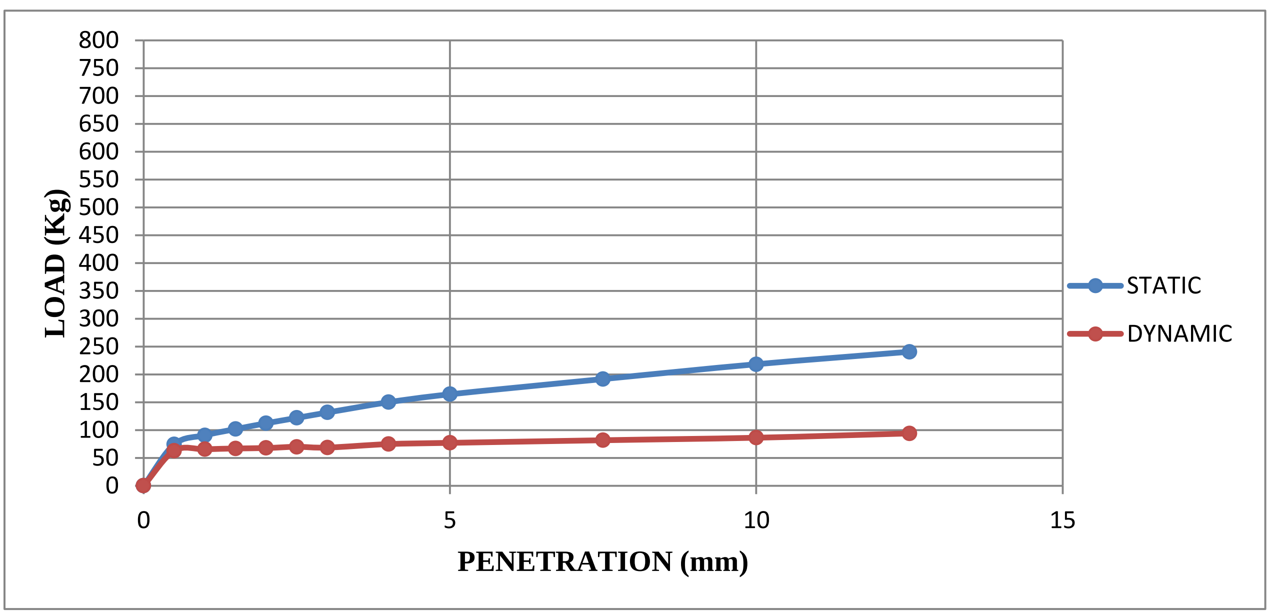

Fig. 4.6: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 2 at OMC+5%

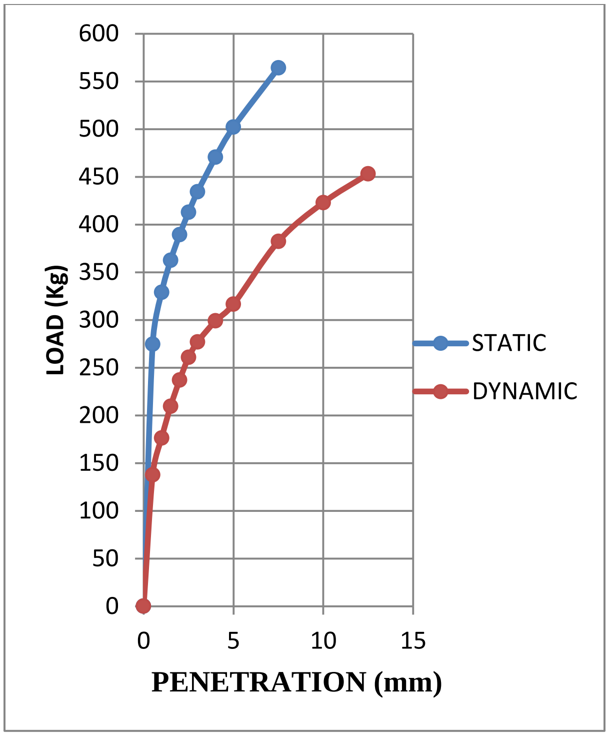

Fig. 4.7: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 3 at OMC-3%

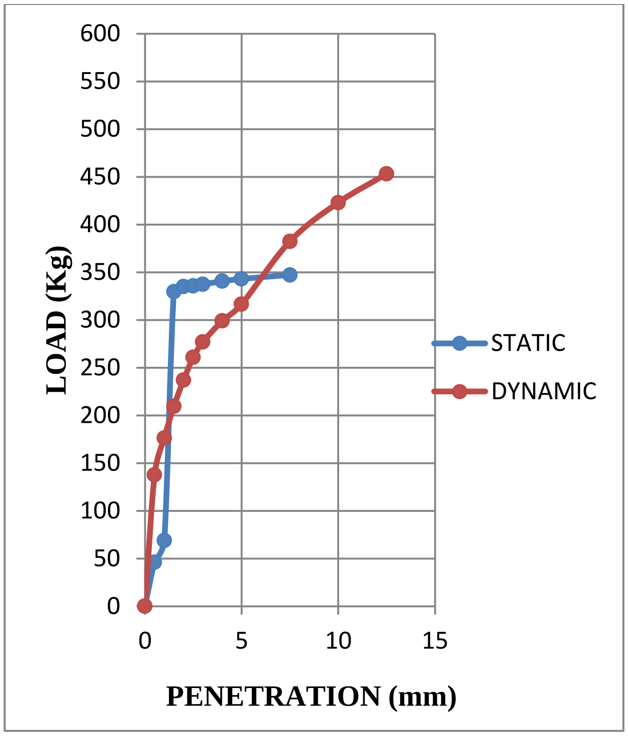

Fig. 4.8: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 3 at OMC%

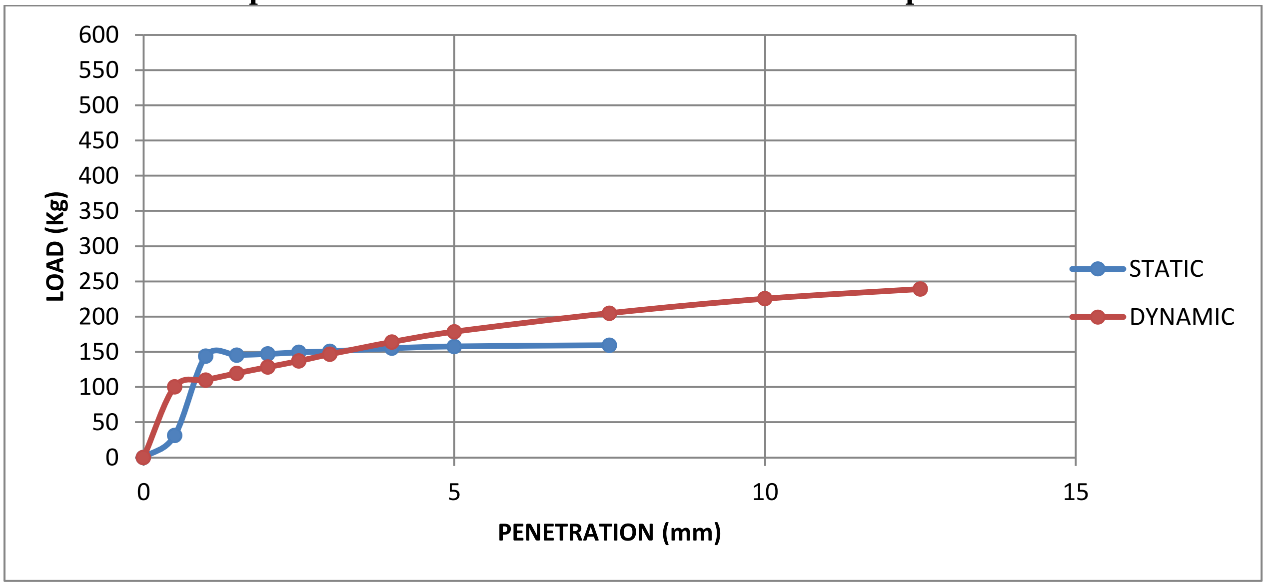

Fig. 4.9: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 3 at OMC+3%

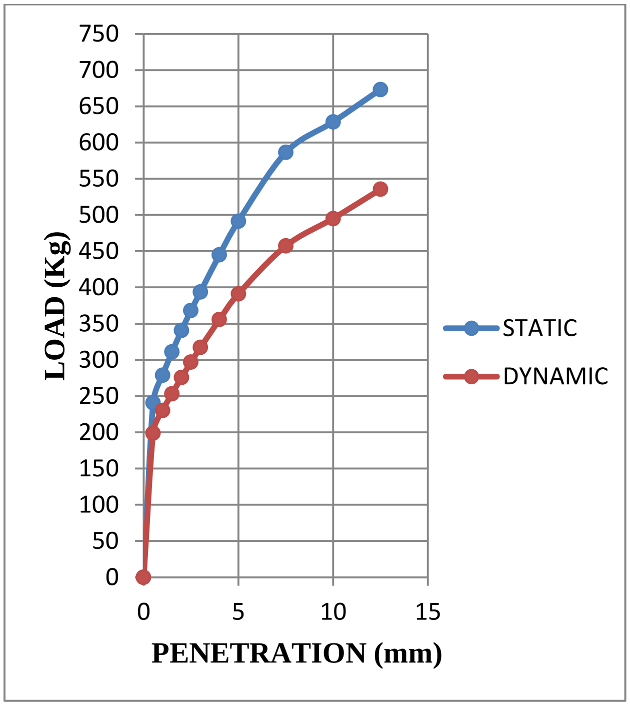

Fig. 4.10: Superimposed curves of CBR test on statically and dynamically compacted soil-sample 4 at OMC-3%

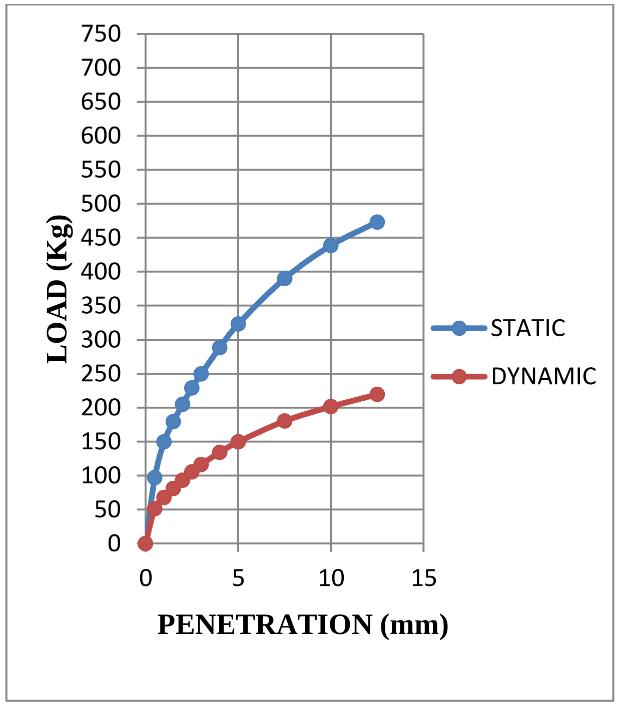

Fig. 4.11: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 4 at OMC

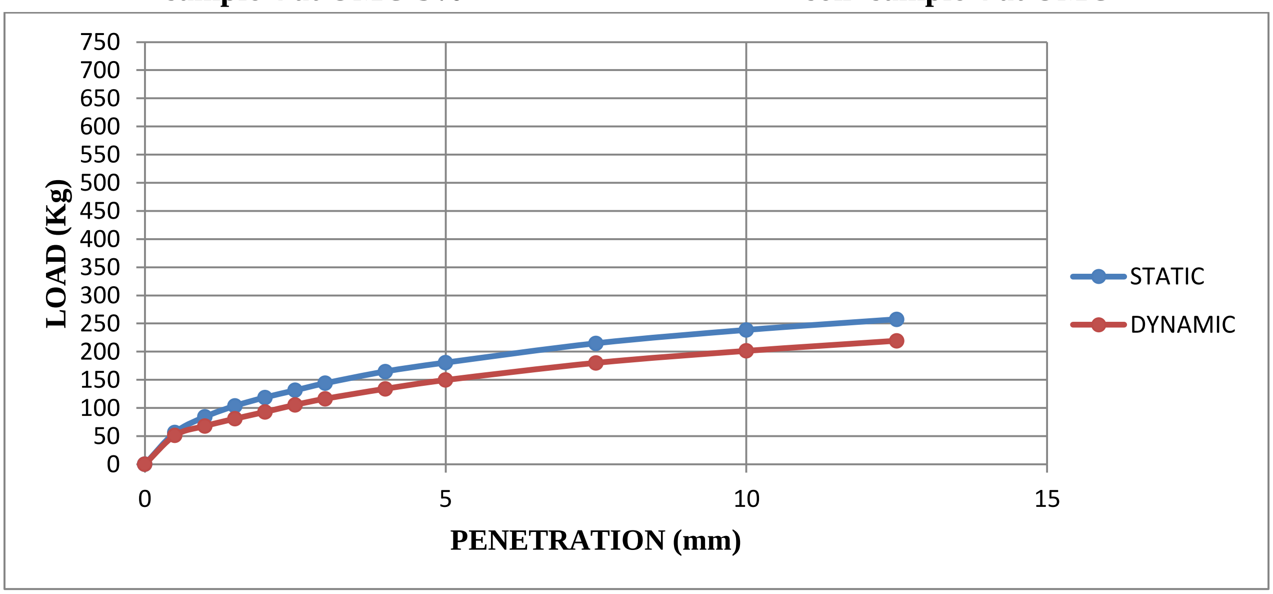

Fig. 4.12: Superimposed curves of CBR test on statically and dynamically compacted soil-sample 4 at OMC+3%

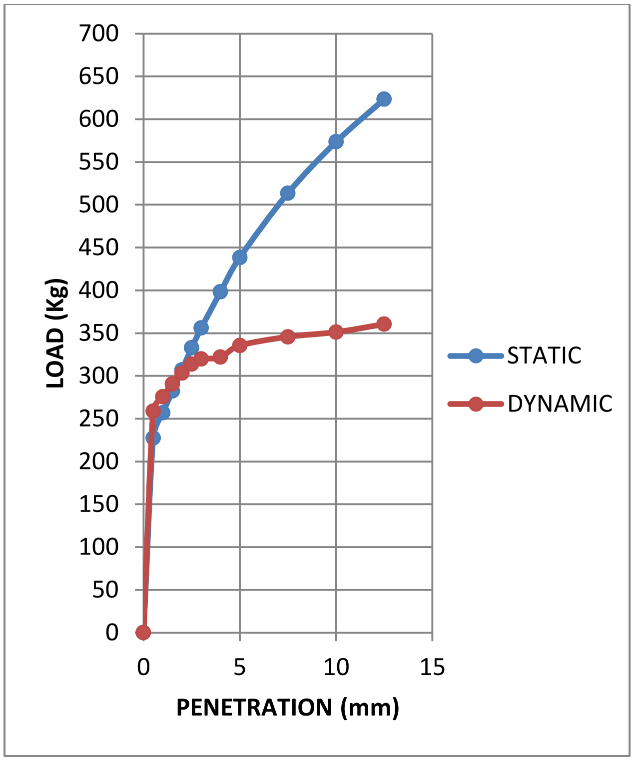

Fig. 4.13: Superimposed curves of CBR test on statically and dynamically compacted soil-sample 5 at OMC-3%

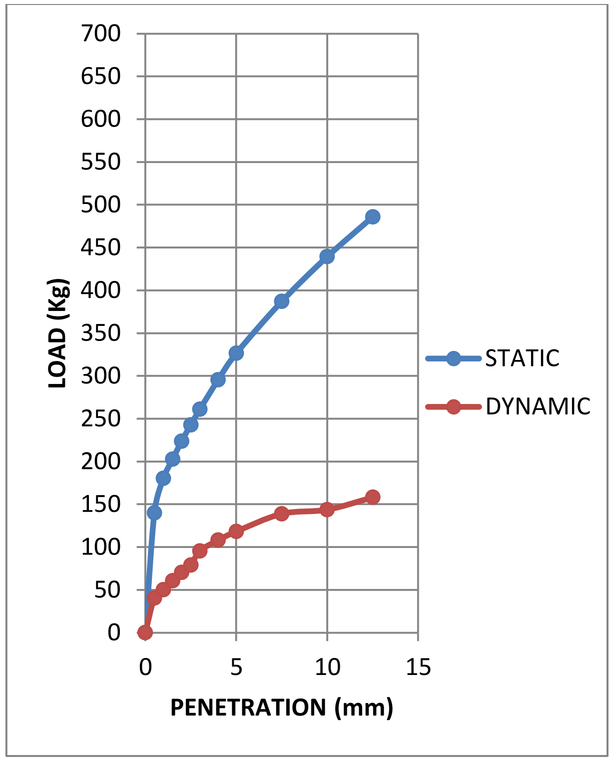

Fig. 4.14: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 5 at OMC

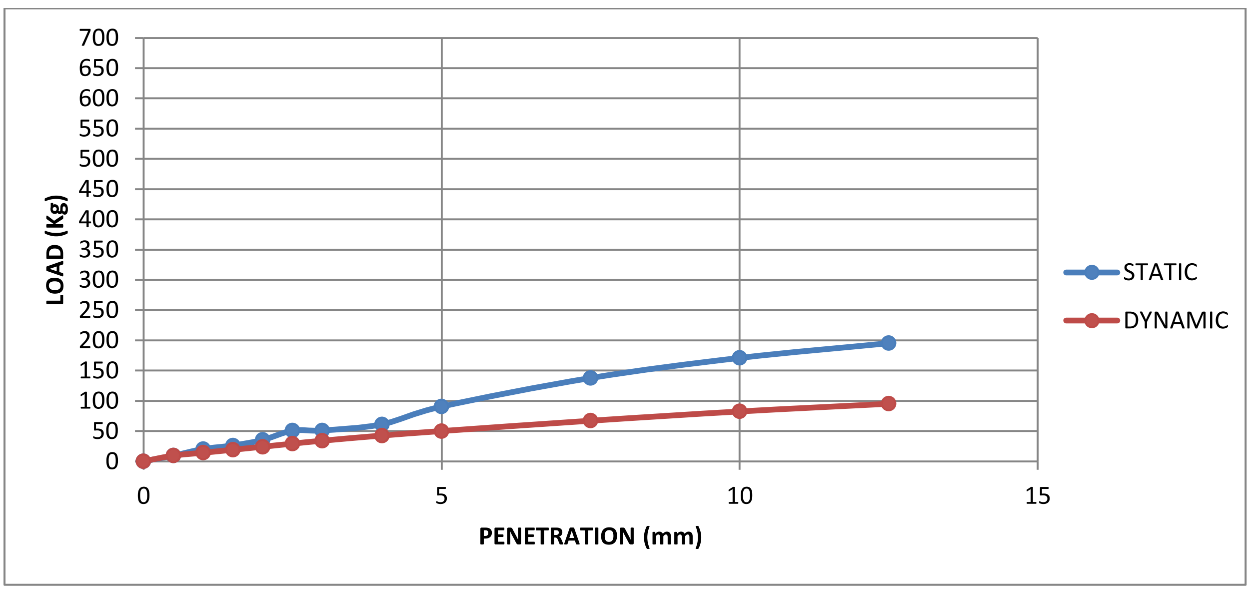

Fig. 4.15: Superimposed curves of CBR test on statically and dynamically compacted soil-sample 5 at OMC+3%

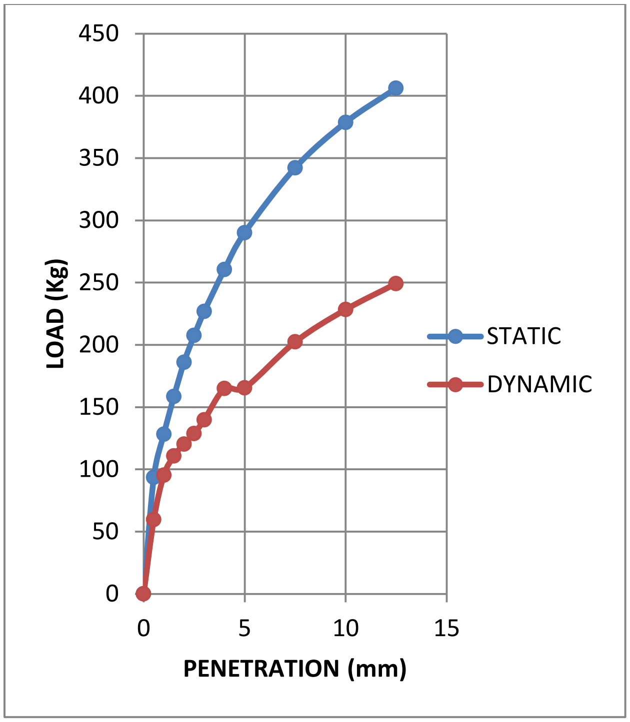

Fig. 4.16: Superimposed curves of CBR test on statically and dynamically compacted soil-sample 6 at OMC-3%

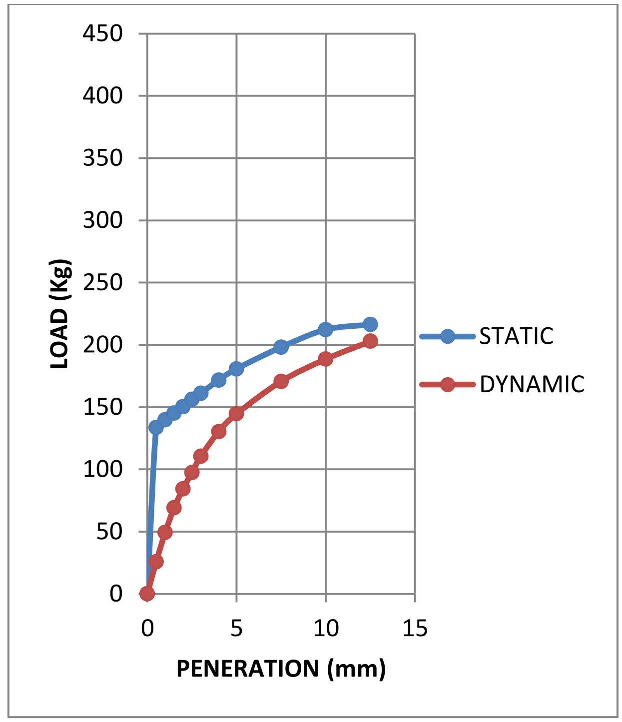

Fig. 4.17: Superimposed curves of CBR test on statically and dynamically compacted soil- sample 6 at OMC

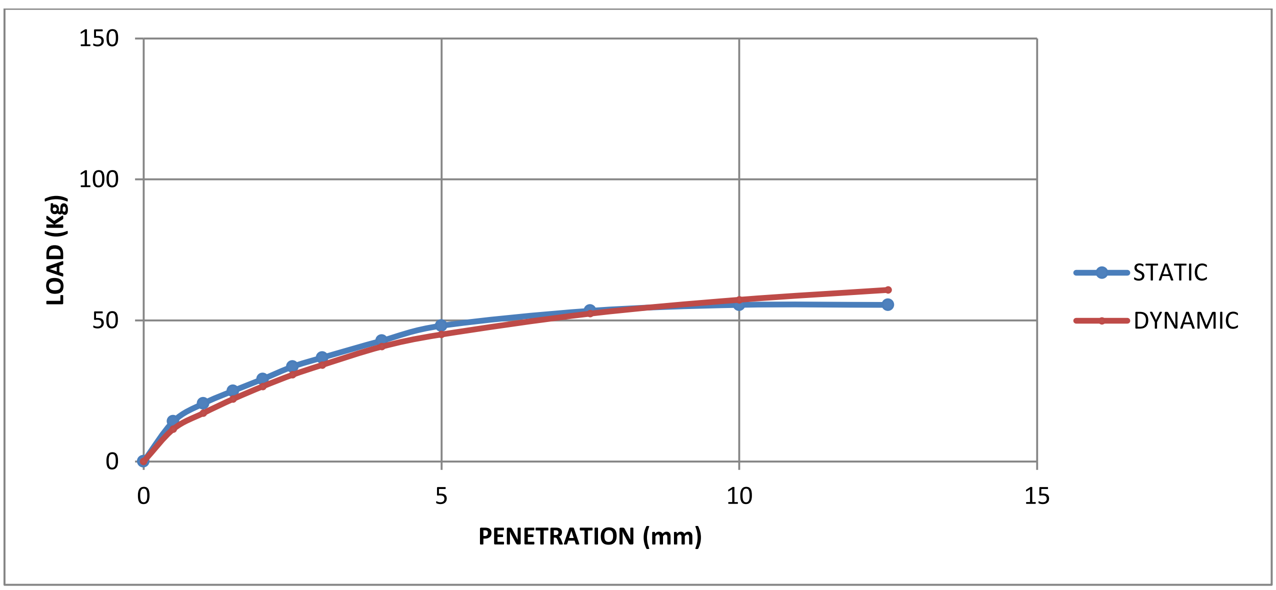

Fig. 4.18: Superimposed curves of CBR test on statically and dynamically compacted soil-sample 6 at OMC+3%

From the superimposed load-penetration curves obtained from the CBR test conducted on statically and dynamically compacted soil specimens, shown in Fig. 4.1 to Fig. 4.18, it can be seen that in all cases, static compaction gives a steeper load-penetration curve than the curves obtained in dynamically compacted specimens. It ascertains that, in comparison to the dynamically compacted soil specimen, the statically compacted soil specimen yields a higher unsoaked CBR value, which is also seen from the CBR values listed in Table 4.1.

The possible cause of this variation could be that the statically compacted soil specimen has better soil particle packing. In the dynamic compaction process, because of the stress gradient created by layer- by- layer compaction, soil specimens typically have a lower density at the bottom and a higher density at the top. Numerous researchers such as **L.Xu et al. (2021), Bui QB et al. (2009)** etc. have noted this finding in various soil studies. As dry density has a significant influence on the mechanical behaviour of compacted soil, this inhomogeneity—caused by dynamic compaction—should be avoided for soil specimens intended for laboratory testing. In contrast, there is a benefit to static compaction, where soil is compacted into one homogeneous layer which eventually increases the mechanical strength of soil. When soil specimens are compacted dynamically, a significant amount of energy is wasted in the compaction process. On the other hand, in static compaction, the entire mass of soil is subjected to displacement and virtually all of the energy is used to densify the soil and no energy is lost. According to the observations made by **Kayabali et al. (2019)** in their study, the compaction energy level needed for the static compaction test is approximately 40% of the standard Proctor method, or 237 kJ/m^3, as per the results of the compaction energy applied to soil samples tested. This could also be a reason for higher strength in soil compacted statically in comparison to a dynamically compacted soil.

Based on the comparison of test results done on two earth materials, **L. Xu et al. (2021)** stated that**,** at the same moisture content, earth samples from static compaction exhibit slightly higher matric suction than those from dynamic Proctor tests. In their study, they observed that for both types of compaction methods, with a decrease in water content, matric suction increases. This observation is a recognized conclusion for earthen materials. So, the effect of matric suction on the strength behaviour of compacted soils can be of great importance.

Based on the results obtained in the study of **Asmani et al. (2013),** they also found that soil samples compacted using static packing pressure yielded higher unsoaked CBR values than samples compacted using Standard Proctor method (dynamic method). They obtained a correlation between CBR value, plasticity index, and optimum moisture content. The summary of their test results is shown below.

Table 4.2: The comparison result of CBR values and (PI/OMC) values of Asmani et al. (2013)

Soil sample	OMC %		CBR Value%		PI/OMC	
	Dynamic	Packing Pressure	Dynamic	Packing Pressure	Dynamic	Packing Pressure
A	18.31	14.32	20.14	22.62	0.37	0.42
B	21.15	18.25	6.72	14.60	0.76	0.86
C	21.10	14.72	2.92	4.71	1.14	1.63

From their test results shown in the table above, they also made an observation that the overall characteristics of soil samples, such as OMC and plasticity index over OMC, have effects on the CBR value of soil both in statically and dynamically compacted specimens. In comparison to soils B and C, soil A had the highest CBR value for both dynamic and packing pressure. Their results showed that the CBR value is influenced by the PI over OMC value, with the soil sample that had a higher PI over OMC value having a lower CBR value. They observed that, the CBR values are influenced by the characteristics of the soil sample and changes in the OMC values. However, these results may be a function of the soil type.

From the above discussion, we can draw the conclusion that static compaction yields a higher CBR value than dynamic compaction, indicating that the static compaction approach is more reasonable and useful than the dynamic compaction method. This conclusion can improve engineering parameters, especially for road construction design, and the higher CBR value can minimize the road design thickness, consequently reducing the cost of road construction.

The following table shows the experimental results of variation of UCS value in static compaction and dynamic compaction of the soil samples tested.

Table 4.3: Relative increase in UCS value:

Soil Sample (1)	Soil type (2)	Water content % (3)	UCS value (kPa) (Static compaction) (4)	UCS value (kPa) (Dynamic compaction) (5)	(4)/(5)	% (silt + clay) (6)	%(sand) (7)
*1	CI	OMC-3%	550	650	0.85	92.65	7.35
		OMC	232	430	0.54		
		OMC+3%	132.9	250	0.53		
*2	CH	OMC-5%	124	180.7	0.69	71.85	28.15
		OMC	124.9	197	0.63		
		OMC+5%	126	247	0.51		
3	CI	OMC-3%	360	351	1.03	83.838	16.162
		OMC	330	219	1.51		
		OMC+3%	128.9	90	1.43		
4	CH	OMC-3%	820	747	1.09	90.17	9.83
		OMC	521	432	1.21		
		OMC+3%	322	230	1.40		
*5	CL	OMC-3%	475	540	0.88	98.04	1.96
		OMC	380	500	0.76		
		OMC+3%	226	260	0.87		
6	CI	OMC-3%	435	320	1.36	95.94	4.06
		OMC	260	136	1.91		
		OMC+3%	113	87.2	1.29		

*Sample is showing higher UCS value when compacted dynamically than statically compacted soil.

The following are the superimposed stress -strain curves that were acquired from the UCS test of specimens of the soil samples that were statically and dynamically compacted:

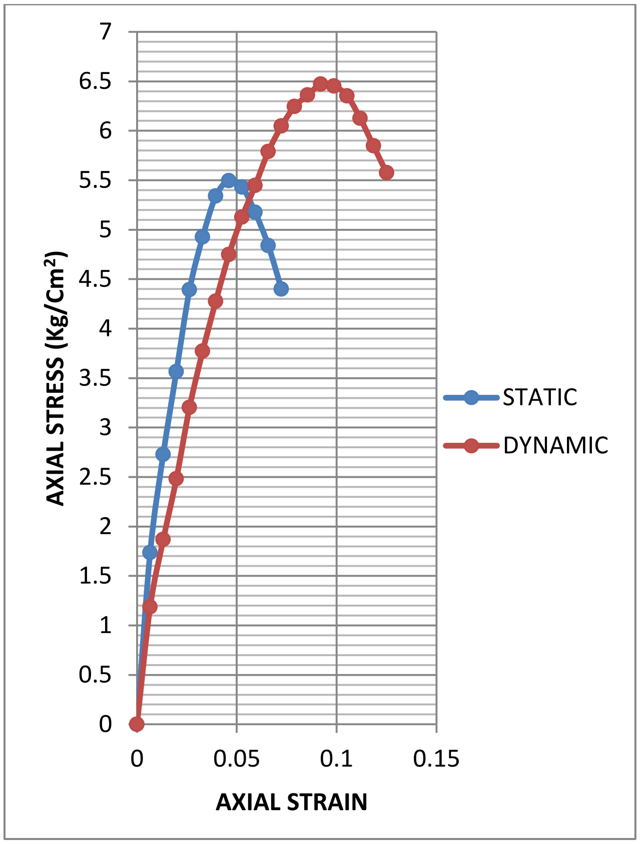

Fig. 4.19: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 1 at OMC-3%

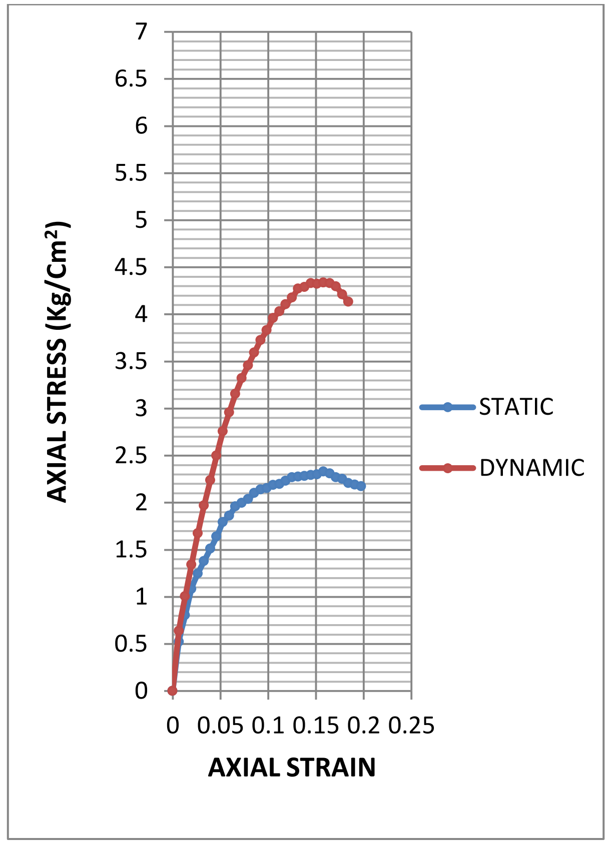

Fig. 4.20: Superimposed curves of UCS test on statically and dynamically compacted soil- sample 1 at OMC

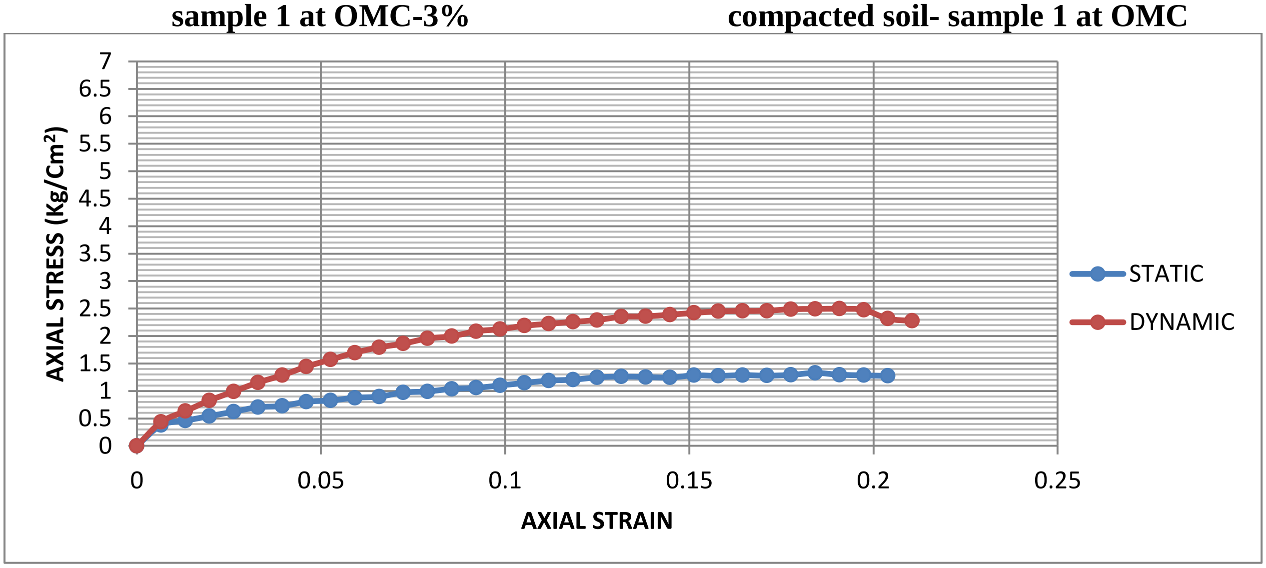

Fig. 4.21: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 1 at OMC+3%

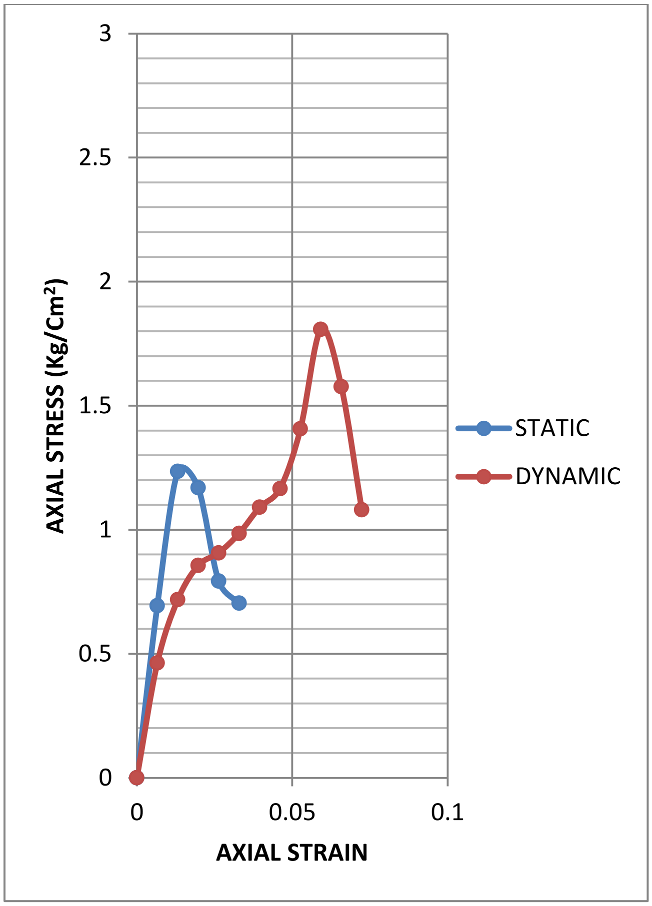

Fig. 4.22: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 2 at OMC-5%

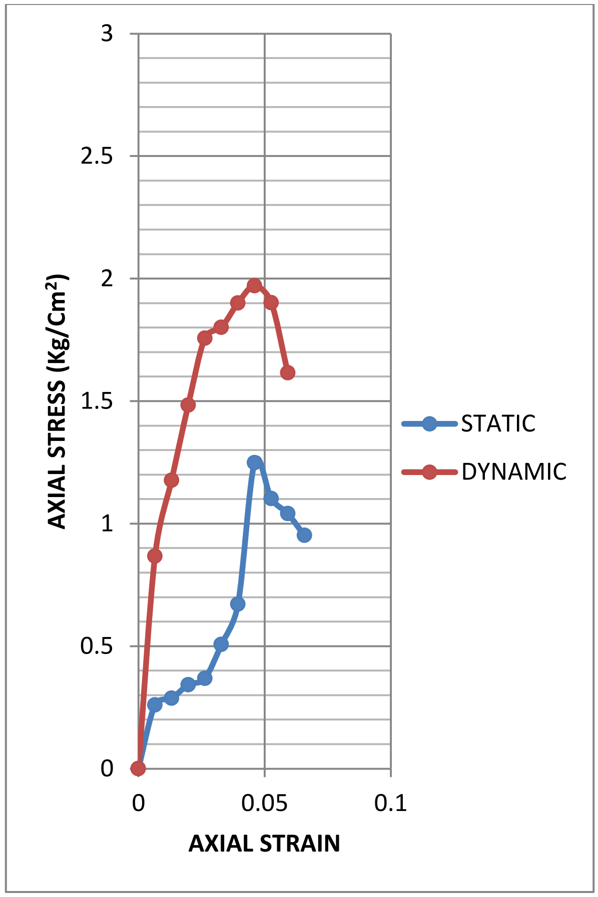

Fig. 4.23: Superimposed curves of UCS test on statically and dynamically compacted soil- sample 2 at OMC

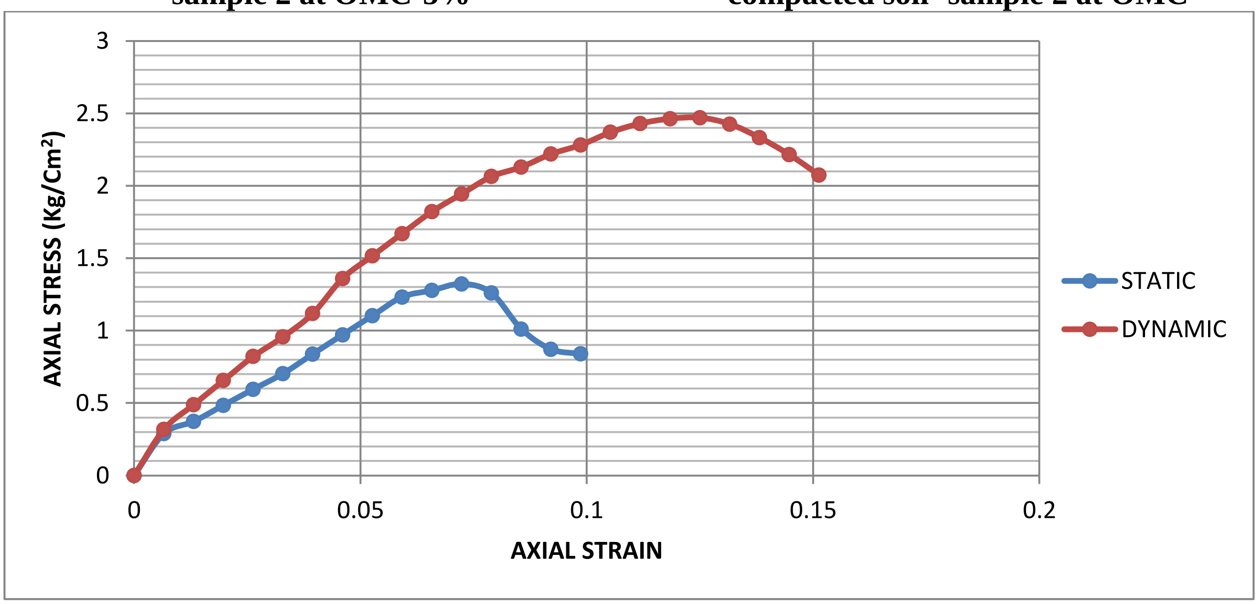

Fig. 4.24: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 2 at OMC+5%

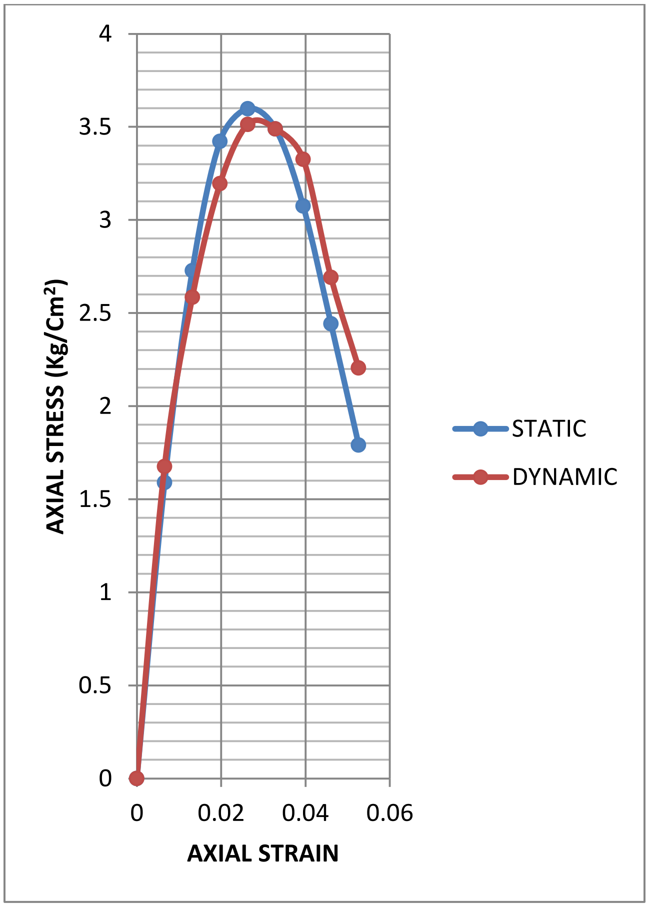

Fig. 4.25: Superimposed curves of UCS test on statically and dynamically compacted soil- sample 3 at OMC-3%

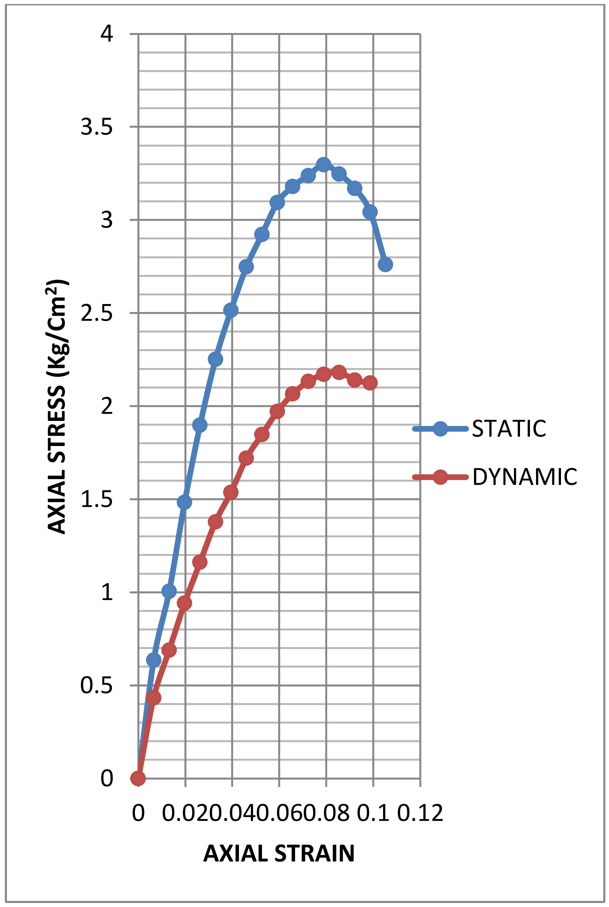

Fig. 4.26: Superimposed curves of UCS test on statically and dynamically compacted soil- sample 3 at OMC

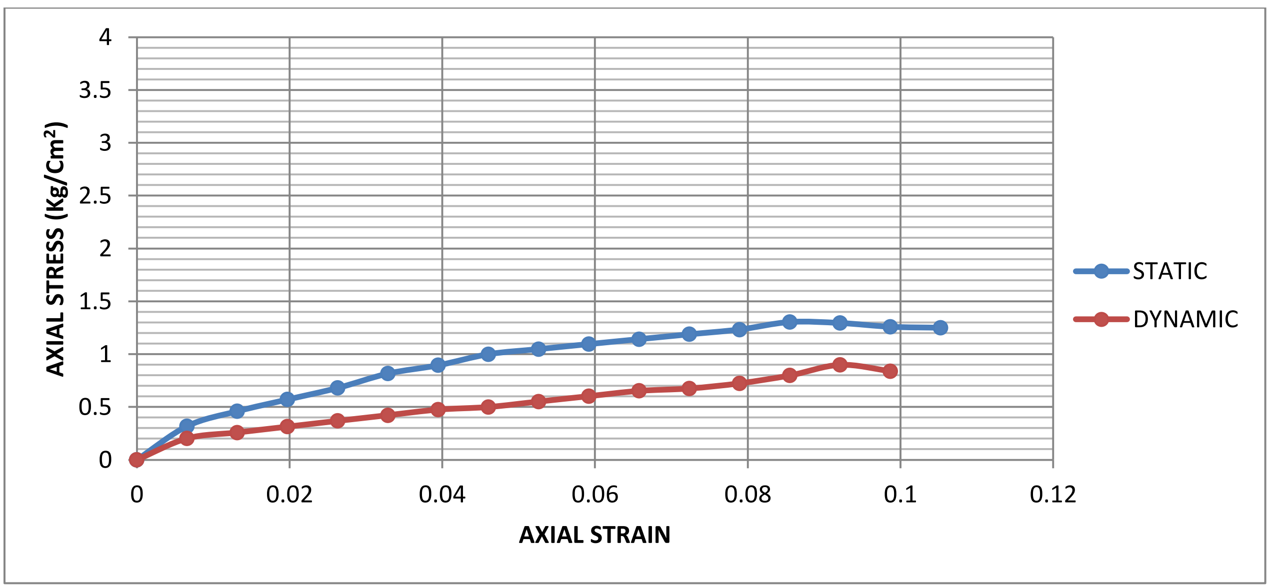

Fig. 4.27: Superimposed curves of UCS test on statically and dynamically compacted soil- sample 3 at OMC+3%

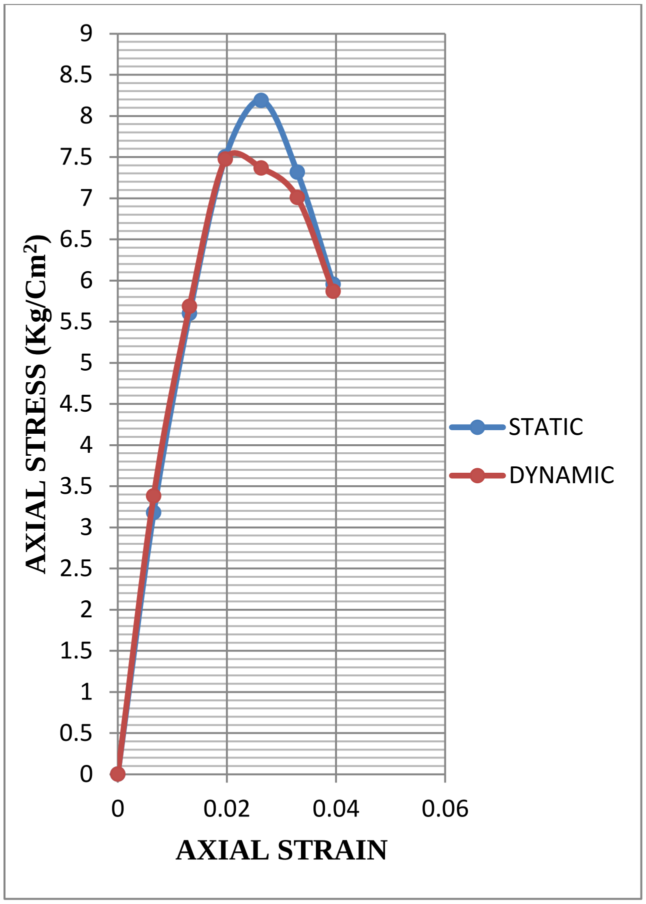

Fig. 4.28: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 4 at OMC-3%

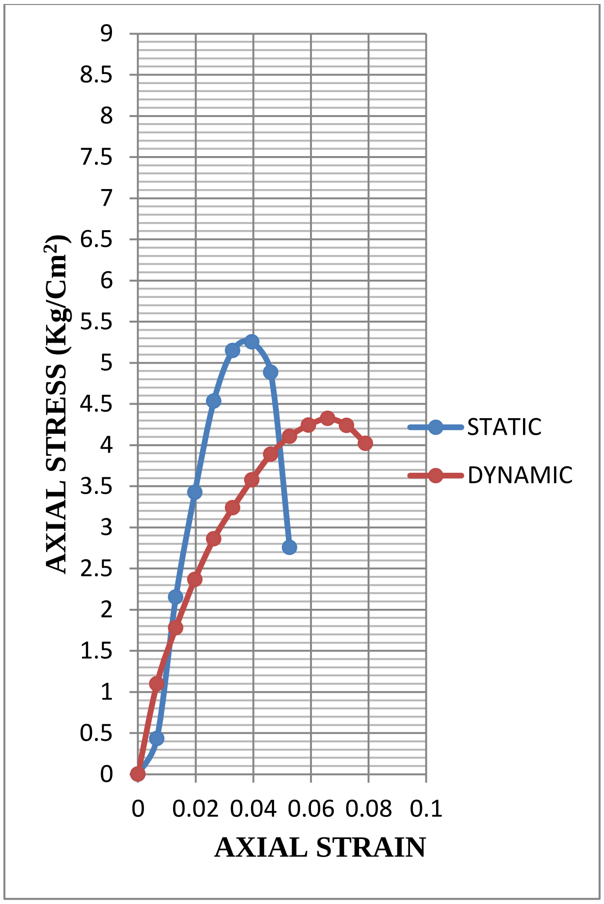

Fig. 4.29: Superimposed curves of UCS test on statically and dynamically compacted soil- sample 4 at OMC

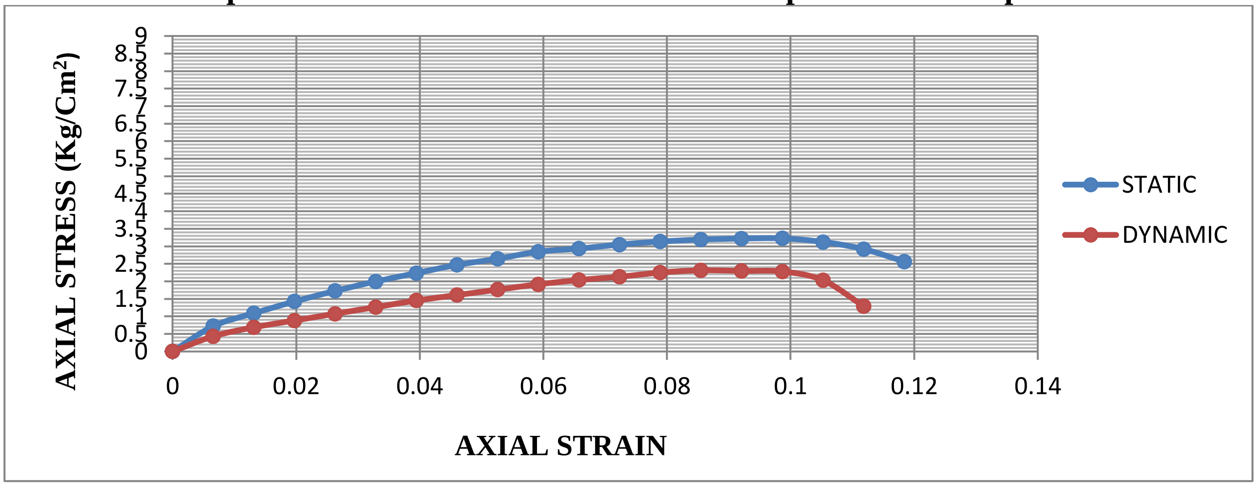

Fig. 4.30: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 4 at OMC+3%

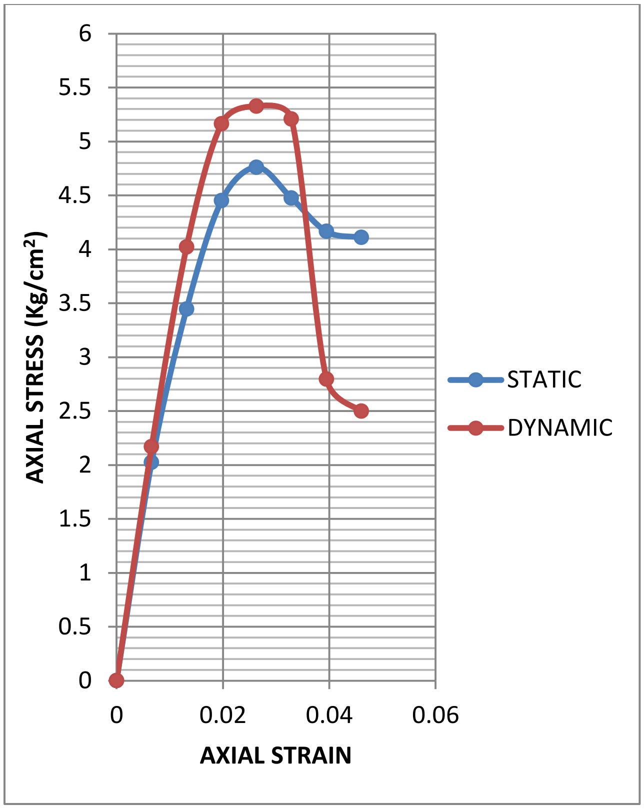

Fig. 4.31: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 5 at OMC-3%

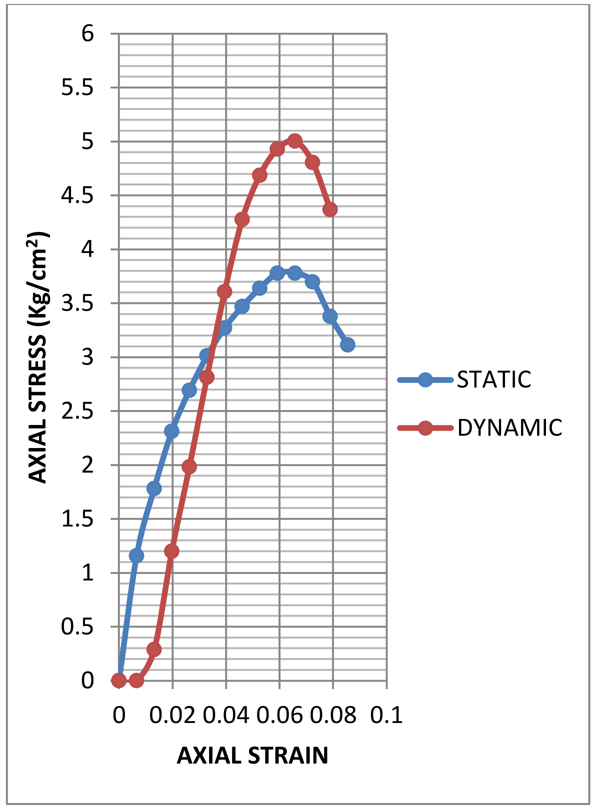

Fig. 4.32: Superimposed curves of UCS test on statically and dynamically compacted soil- sample 5 at OMC

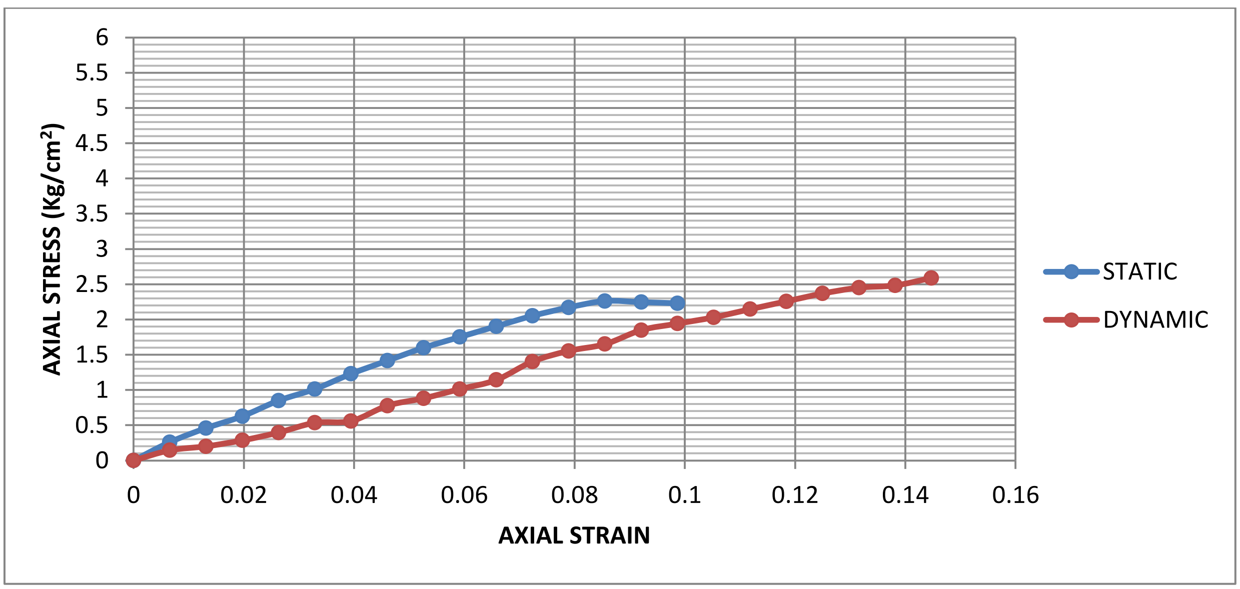

Fig. 4.33: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 5 at OMC+3%

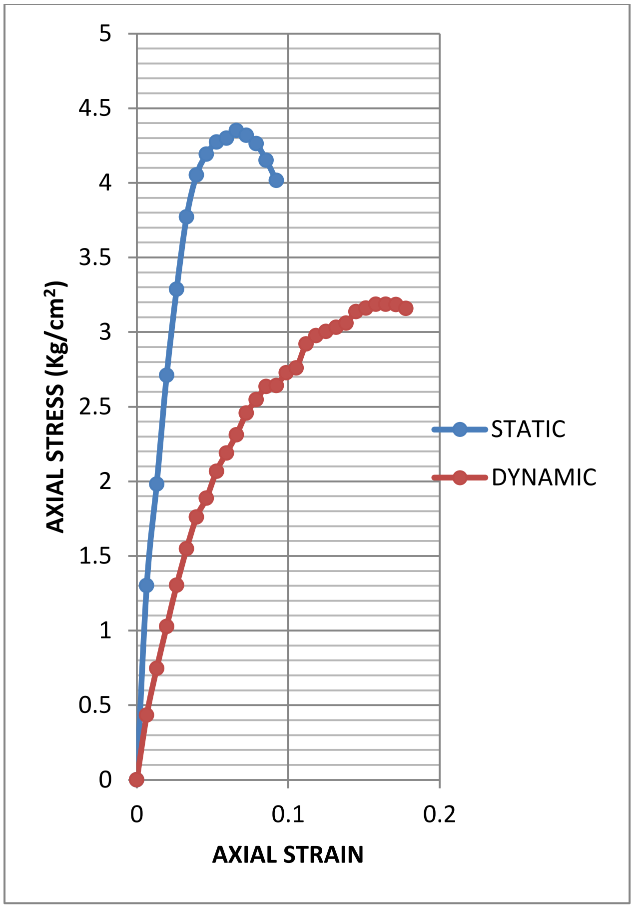

Fig. 4.34: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 6 at OMC-3%

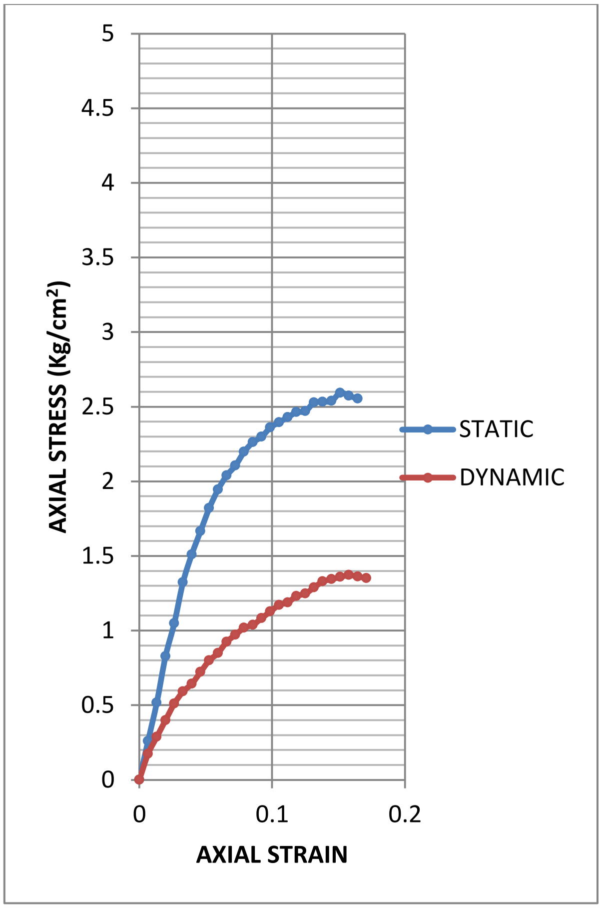

Fig. 4.35: Superimposed curves of UCS test on statically and dynamically compacted soil- sample 6 at OMC

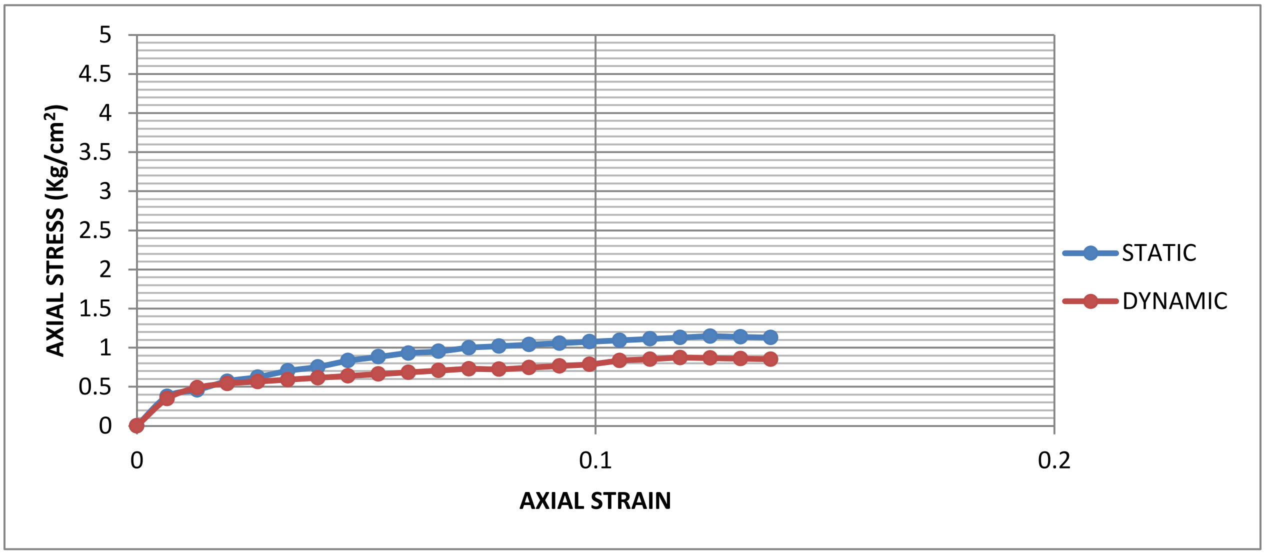

Fig. 4.36: Superimposed curves of UCS test on statically and dynamically compacted soil-sample 6 at OMC+3%

From the stress-strain curves, modulus of elasticity for both static and dynamic curves is calculated. The results are shown in the table below.

Table 4.4: UCS Value and Modulus of elasticity of dynamically and statically compacted soil:

Sample No.	OMC %	UCS value (kPa)			Modulus of elasticity for static compaction (MPa)	Modulus of elasticity for dynamic compaction (MPa)
		Water content	Statically compacted	Dynamically compacted		
1	20.30	OMC-3%	550	650	16.37	10.11
		OMC	232	430	3.34	3.28
		OMC+3%	132.9	250	1.19	2.22
2	23	OMC-5%	124	181	5.81	2.94
		OMC	125	197	1.37	5.37
		OMC + 5%	126	247	2.10	2.44
3	18.60	OMC -3%	360	351	17	15.8
		OMC	330	219	6.25	3.8
		OMC+3%	129	90	2.22	1.18
4	24	OMC -3%	820	747	37.28	37.15
		OMC	521	432	37.15	17
		OMC+3%	322	230	5.26	3.43
5	19.10	OMC -3%	475	540	25.69	25.66
		OMC	380	500	8.98	8.39
		OMC+3%	226	260	3.1	1.7
6	20.80	OMC -3%	435	320	11.25	3.16
		OMC	260	136	2.85	1.32
		OMC+3%	113	87.2	1.54	1.23

From the experimental results shown in Table 4.3, it is seen that three soil samples yield a higher UCS value when statically compacted, and the other three soil samples yield a higher UCS value when compacted dynamically.

Compared to soil specimens prepared by dynamic compaction, those prepared by static compaction are more rigid, resilient, and less plastic. The energy from the falling plunger weight in the dynamic compaction test decays inside the mould, and this energy are further increased by the quick tamping that causes punching shear. This causes the soil mass to become significantly disturbed until the following layer is compacted and cracks appear. Furthermore, a considerable anisotropy is induced by the dynamic compaction, which contributes to the strength degradation. However, because the particles are pressing against one another during loading, there are fewer disturbances in the case of static compaction and there is very little anisotropy and the sample functions as a single layer.

According to observations made by **Asmani et al. (2011)** in their study, static compaction gives a higher shear strength value as compared to dynamic compaction. Other than that, they also observed that, in comparison to the dynamic compaction specimen, the stress-strain graph indicates that the percentage of axial strain for static compaction was almost 10% lower. Therefore, it can be said that crushing a static specimen takes less time than a dynamic specimen. Similar observations can be made in the present study, where the soil samples showing higher strength when compacted statically take less time to crush. Based on that duration, it can be seen that the static specimen has a higher shear strength value and is denser than the dynamic specimen as it takes less time to fail. In short, they observed that, static compaction is found to have higher density and shear strength values than dynamic compaction method based on comparison results between static and dynamic compaction test. The X-ray test further demonstrates the greater structural homogeneity of the static remoulded specimens.

As per the discovery of **Dario et al. (2011)**, for the clayey soil, the static process resulted in specimens with a higher UCS than the dynamic compaction. This behaviour is further supported by observations made using the optical microscopy technique, which shows that specimens of statically compacted clayey soil exhibit original microaggregation features, such as the formation of isolated gaps, fissured and oriented porosity, and original nodules. Conversely, specimens that have been dynamically compacted exhibit minimal original microaggregation characteristics, as nearly all of the porosity has been lost. As demonstrated by Dario et.al (2011) in their work, static compaction results in higher dry density and higher unconfined compressive strength up to a specific water content for CH type of soil. . For the same soil, an opposing trend in dry density and mechanical strength is observed after the particular water content. However, compared to static compaction, dynamic compaction produced higher dry density and mechanical strength values for the SC type of soil, regardless of water content. Therefore, it is clear from the result that the method of compaction significantly affects the mechanical strength of soil.

According to their work, the statically compacted clayey soil specimens at OMC are found to exhibit original microaggregation characteristics, including original nodules, the creation of isolated gaps, and fissured and oriented porosity (about 3%). Conversely, dynamically compacted specimens at this same water content show only a few original microaggregation features, and nearly all of their porosity is lost (about 2%). Dario et al. (2011) state that structures with reduced shear strength may result from the dominance of interparticle forces that were destroyed by the dynamic compaction. Bueno et al. (1992) observed similar behaviour when comparing the mechanical response of a red-yellow latosol under undisturbed field conditions to the effect of dynamic compaction.

However, in this present study, it is seen that three soil samples show higher UCS value when compacted dynamically. When soil is partially saturated, dynamic compaction can lead to temporarily higher strength values because capillary action creates an apparent cohesiveness in the soil, unlike statically compacted soil.

Following are the curves of strength vs. molding water content (i.e. OMC-3%, OMC and OMC+3) for both statically and dynamically compacted soil:

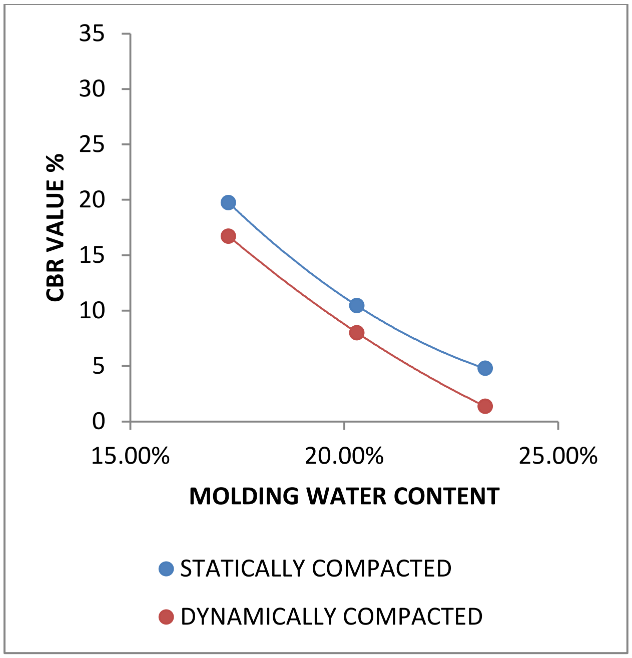

Fig. 4.37: Superimposed curves of CBR values vs. molding water contents of statically and dynamically compacted soil for sample 1

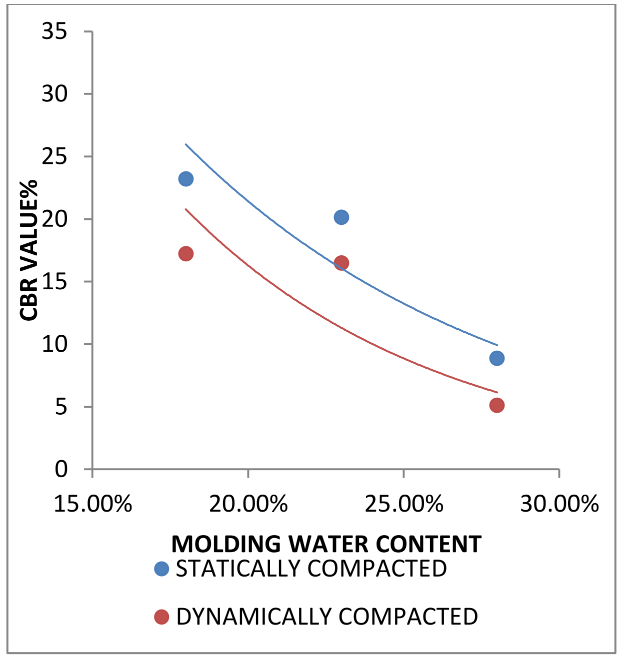

Fig. 4.38: Superimposed curves of CBR values vs. molding water contents of statically and dynamically compacted soil for sample 2

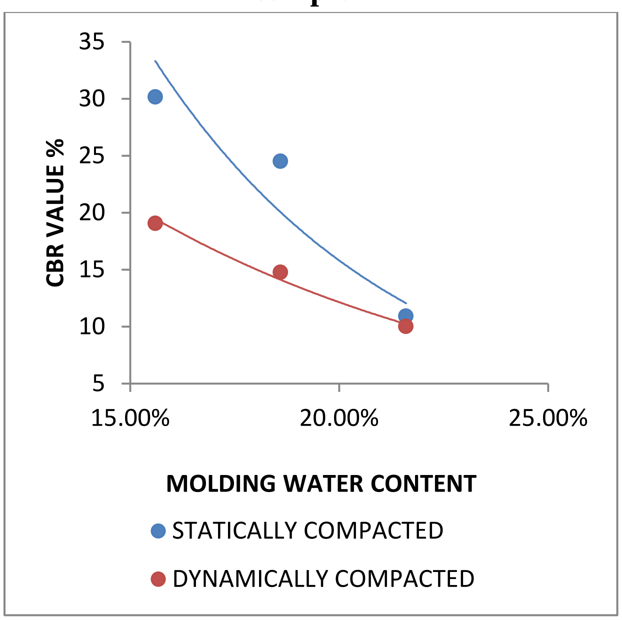

Fig. 4.39: Superimposed curves of CBR values vs. molding water contents of statically and dynamically compacted soil for sample 3

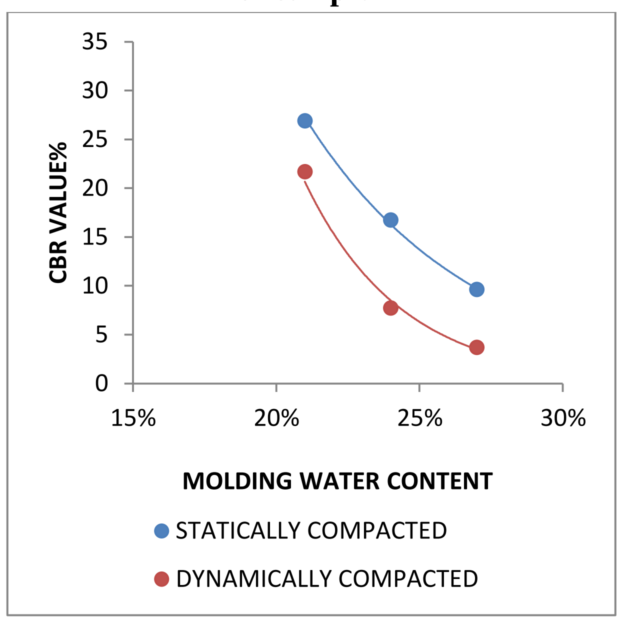

Fig. 4.40: Superimposed curves of CBR values vs. molding water contents of statically and dynamically compacted soil for sample 4

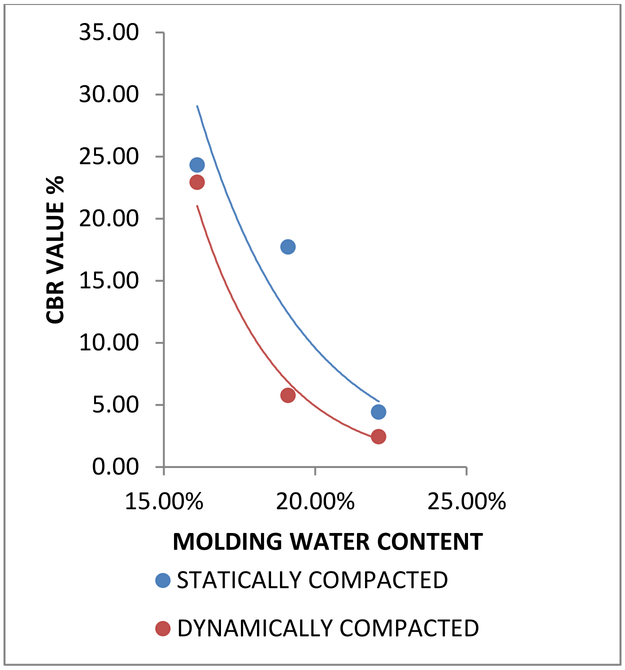

Fig. 4.41: Superimposed curves of CBR values vs. molding water contents of statically and dynamically compacted soil for sample 5

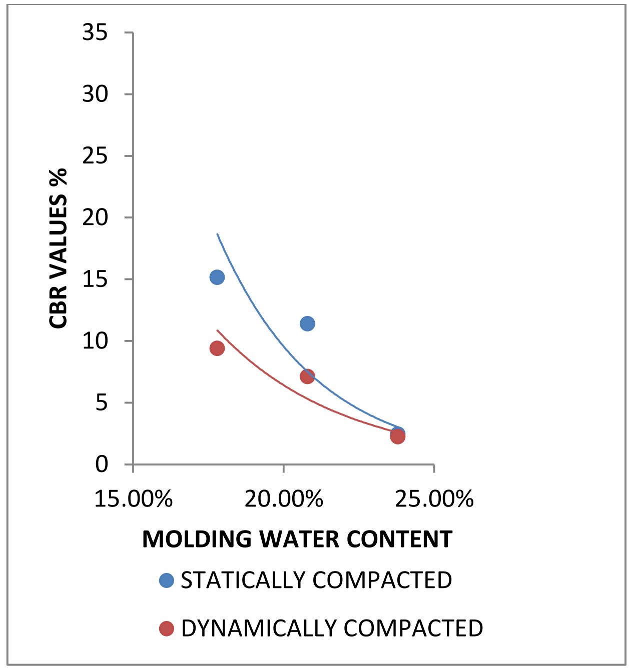

Fig. 4.42: Superimposed curves of CBR values vs. molding water contents of statically and dynamically compacted soil for sample 6

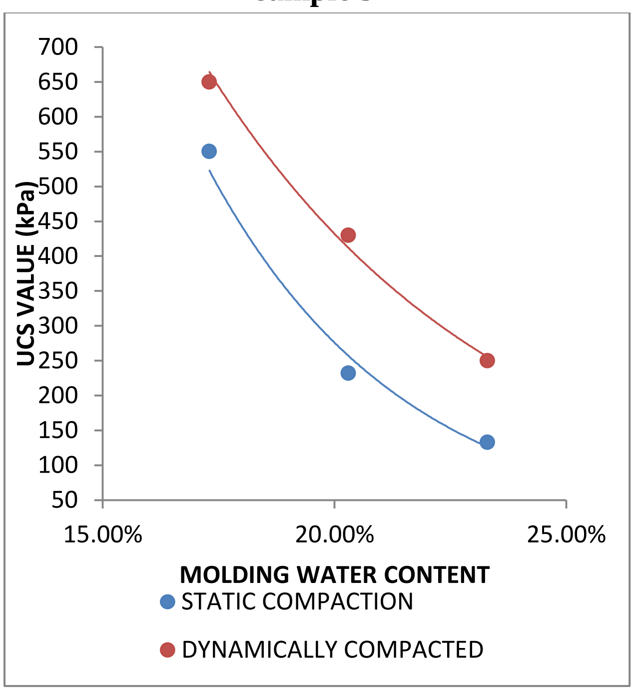

Fig. 4.43: Superimposed curves of UCS values vs. molding water contents of statically and dynamically compacted soil for sample 1

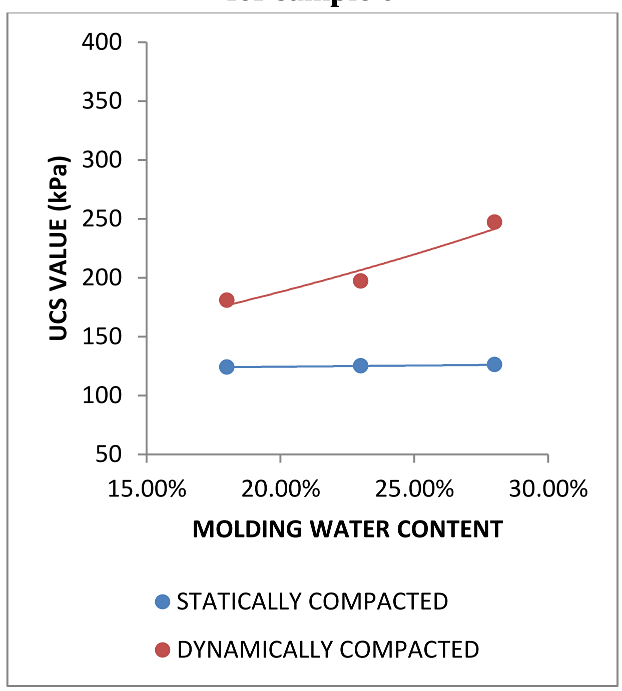

Fig. 4.44: Superimposed curves of UCS values vs. molding water contents of statically and dynamically compacted soil for sample 2

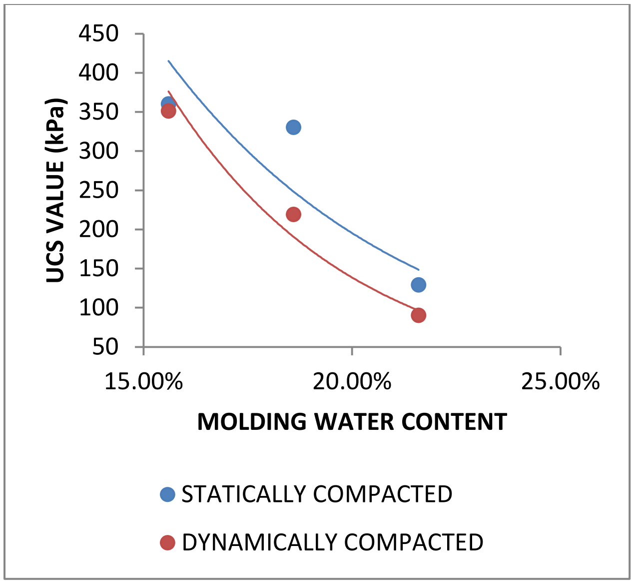

Fig. 4.45: Superimposed curves of UCS values vs. molding water contents of statically and dynamically compacted soil for sample 3

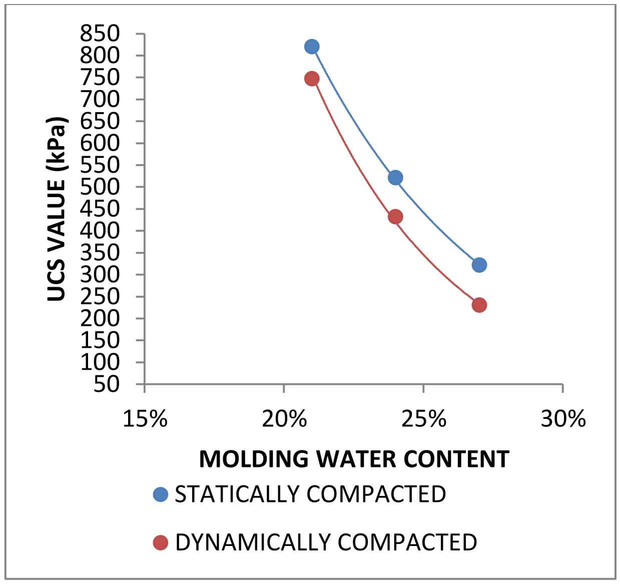

Fig. 4.46: Superimposed curves of UCS values vs. molding water contents of statically and dynamically compacted soil for sample 4

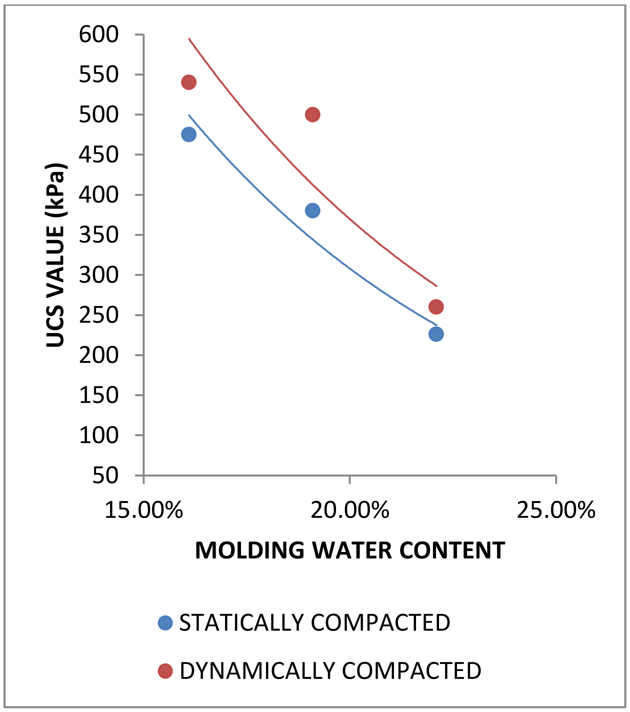

Fig. 4.47: Superimposed curves of UCS values vs. molding water contents of statically and dynamically compacted soil for sample 5

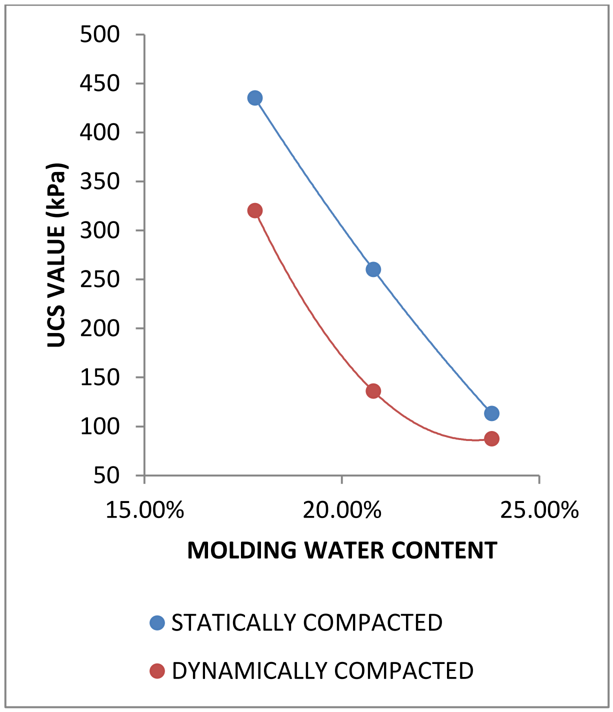

Fig. 4.48: Superimposed curves of UCS values vs. molding water contents of statically and dynamically compacted soil for sample 6

It is seen from Fig. 4.37 to Fig. 4.42 that CBR value decreases with increasing water content for both statically and dynamically compacted soil. This observation is agreement with existing literature such **as Nagaraj et al. (2018), Nagaraj et al. (2012), Sridharan and Prakash (1999),** where it is said that with increasing water content strength of soil has a non-linear decreasing relationship.

Similarly, from Fig. 4.43 to Fig. 4.48, it can be seen that UCS value also has a decreasing relationship with increasing water content except in Fig. 4.44 (sample 2) an opposite trend has been seen. The possible reason for this opposite trend i.e. the high undrained shear strength at lower water content could be due to the occurrence of swelling after saturation (**Lambe and Whitman, 1979**).

From the observations made in this study it can be said that strength in general possess a decreasing relationship with increasing water content. However, the relationship of strength with water content is expected to be different based on the type of soil. To get a broader insight on this, the structure of soil and soil fabric has to be studied.

A possible reason for this variation is the higher suction of soil at dry of optimum than at optimum moisture content. Relevant studies have been done by various research workers on soil suction. It is commonly acknowledged that matric suction, allows soil to retain some shear strength which is regarded as an apparent cohesion. Therefore, matric suction could be a reason for this decreasing strength with increasing water content in the compacted soil. Higher suction on the dry side of the optimum results in stronger internal cohesion, causing aggregates and large inter-aggregate pores during compaction and prevent complete breakdown or remoulding. A thick and massive matrix microstructure forms at OMC as a result of deformability and breakability of the aggregates. Due to hydration and the same amount of clay, the wet side has a larger clay volume and clay paste surrounds the silt grains. This prevents the granular aggregates from breaking down and remoulding, allowing compaction to occur through plastic deformation of the clay paste. When compaction stress is released, water that was under suction in the powder state reaches neutral or positive pressures and might offer some elastic energy.

To have a better understanding of the variation of strength with water content i.e., at dry of optimum, optimum moisture content, and wet of optimum we need to understand the change in soil structure during both static and dynamic compaction processes. The study of soil fabric during compaction process is of great importance.

As stated by **H. Cetin et al. (2007),** compaction techniques have a major impact on both the soil structure and the optimum compaction parameters. From their investigations on the compaction of cohesive soils to examine the orientation of particles, pores, and other constituents, they made the observation that particles, pores, and other components align randomly at lower moisture levels. The number of edge-face contacts rises with increased moisture content, and the pores link together. Compaction and the void ratio decrease as a result of the pores' sizes decreasing more perpendicular to the loading direction than parallel to it. The soil structure exhibits a greater degree of alignment, with more particles aligned between 0° and 10° and a decrease in average angles to the horizontal, at the optimum moisture content. Particles continue to realign and converge at higher moisture levels, which cause a decrease in edge-face contacts and an increase in face-face contact.

According to the study, using electron microscopy, **Sloane and Kell (1966)** investigated the structure of the middle third of compacted kaolinite clay soil specimens at 3% above and below the optimum moisture content in a more direct but qualitative manner and stated that in contrast, the specimens compacted at a moulding moisture content of 3% above optimum show a rather high degree of orientation, while the specimens compacted at a moulding moisture content of 3% below optimum show a rather high degree of randomness in the fabric formed by the kaolin packets, which was in support with **Lambe (1958**).

Using the scanning electron microscope, X-ray orientation determinations or orientation indices, and pore size–distribution measurements, **Diamond (1971)** examined the microstructures of impact on compacted kaolinite and illite clay soils. In conclusion they observed, there is minimal variation between specimens compacted either dry or wet of optimum, and there is only a small degree of overall preferred orientation normal to the axis of compaction. The specimens were compacted by Diamond in a way that was somewhat similar to but distinct from the standard compaction techniques.

In the investigation of the microstructure of a kaolin clay soil compacted at dry of optimum, approximately at optimum, and wet of optimum with the help of a scanning electron microscope, X-ray diffraction or fabric index, and permeability testing equipment, **Yoshinaka and Kazama (1973)** made an observation that as the amount of moulding moisture in the soil increases, so does the parallelism or orientation of the particles in the soil mass overall. According to their observations, curved and folded particle arrangements that form parallel, flow-like arrangements are common on the dry and wet sides of the optimum. Even though preferred parallel arrangement predominates at the optimum moisture content, strongly folded structures are not present. As per Diamond (1971) and Yoshinaka and Kazama (1973), a soil compacted using the standard proctor method has poor or very poor parallelism or orientation of its particles, indicating the effect of compaction method on the soil structure and soil fabric during compaction process.

4.3: Effects of clay minerals on strength of soil:

Besides the effect of compaction on changes in soil structure, it is a well-known fact that the type of clay mineral that is present in the soil greatly influences how the soil behaves structurally. Therefore, XRD test has been done on four samples to identify the clay minerals present in them. The clay minerals present and their CBR and UCS values at respective molding water contents are shown in the table below:

Table 4.5: Clay minerals present in the soil samples with their CBR and UCS values at the respective molding water content

Sample No.	Water Content %	Static CBR%	Dynamic CBR%	Static UCS (kPa)	Dynamic UCS (kPa)	Clay minerals	Soil type
1	OMC-3%	19.74	16.72	550	650	Montmorillonite, Illite ,Chlorite	CI
	OMC	10.45	8.01	232	430		
	OMC+3%	4.78	1.36	132.9	250		
2	OMC-5%	23.19	17.22	124	180.7	Illite ,Chlorite , Kaolinite	CH
	OMC	20.13	16.47	124.9	197		
	OMC+5%	8.87	5.10	126	247		
3	OMC-3%	30.13	19.04	360	351	Illite ,Kaolinite, Chlorite	CI
	OMC	24.49	14.74	330	219		
	OMC+3%	10.90	10.00	128.9	90		
4	OMC-3%	26.89	21.67	820	747	Chlorite, Illite, Kaolinite	CH
	OMC	16.71	7.71	521	432		
	OMC+3%	9.60	3.66	322	230		

Bhuyan R. (2022) also conducted an XRD test on five fine-grained soil samples that were taken for his study to determine the clay minerals present in them. Details of his findings, along with their respective UCS and CBR values, are shown in the table below:

Table 4.6: Clay minerals and their respective UCS and CBR value: (Data taken from Bhuyan R (2022))

Sample	Static CBR (%)	Dynamic CBR (%)	Static UCS (kPa)	Dynamic UCS (kPa)	Clay minerals	Soil type
3	27.34	16.96	242.37	219.42	Illite, Montmorillonite, Chlorite,Kaolinite	CI
4	25.17	15.89	495.92	357.89	Illite, Chlorite, Kaolinite	CL
5	23	12.03	424.68	217.22	Illite, Montmorillonite, Chlorite,Kaolinite	CI
6	25.46	17.78	343.67	318.86	Illite, Chlorite, Kaolinite	CH
10	13.29	4.63	214.91	334.26	Illite, Chlorite, Kaolinit	CL

In physical terms, the type of clay mineral present in a soil determines its absorption capacity at a particular clay mass content. When the specific surface area and surface electric charge density of clay particles rise, so does the water affinity and absorption capacity. Higher surface charge density and larger specific surface area are characteristics of more active clay minerals, which effectively aid in the formation of matric suction.

The minerals found in clay have a major impact on soil strength. For instance, kaolinite-rich soils typically have lower strengths than illite- or montmorillonite-rich soils. This is because kaolinite is less prone to deform under mechanical stress than illite or montmorillonite and contains fewer layers of silicate minerals. Because of their large surface area, clay minerals can hold a lot of water. A soil with a high concentration of clay minerals will have higher water content, be more prone to deformation, and lose strength.

From Table 4.5, it can be observed that samples 3 and 4 have the same clay minerals, which are: illite, chlorite, and kaolinite, both samples are from different categories (CI and CH, respectively) and show a similar trend when the UCS test is done on both statically and dynamically compacted specimens, i.e., a higher UCS value is obtained for both samples when the specimens are statically compacted. On the other hand, samples 1 and 2 are showing a similar strength trend, i.e., a higher UCS value is obtained when the specimens are compacted dynamically than the statically compacted specimens, in spite of the fact that they belong to different categories (CI and CH, respectively) and have different types of clay minerals present in both samples. Sample 1 has montmorillonite, illite, and chlorite, while sample 2 has illite, chorite, and kaolinite in it. However, Sample 3 and sample 5, which have the same types of clay minerals and also belong to the same category of soil (CI), show different trends of strength when compacted statically and dynamically. Furthermore, it can be seen that sample 1, which has montmorillonite and illite in it, is showing a higher strength value than the other samples having kaolinite in them (sample 2 and 3). But sample 4 is showing the highest strength value in spite of having kaolinite (illite and chlorite are also present in sample 4). From this, it can be inferred that the amount of a different type of clay mineral may have an effect on the strength behaviour of soil when compacted both statically and dynamically. So, further investigation of the amount of different types of clay minerals may give a better insight into their effects on strength behaviour.

From Table 4.6 which has been taken from Bhuyan R. (2022), it is seen that, When the UCS test is performed on a statically and dynamically compacted soil sample, soil samples 4 and 10 exhibit opposite strength trends, despite having the same clay minerals (kaolinite, chlorite, and illite) and being CL soils. Despite having different soil types, Samples 4 and 6 with the same clay minerals (kaolinite, chlorite, and illite) exhibit a similar strength trend, meaning that a high strength value is obtained when the UCS test is performed on statically compacted soil. As opposed to this, samples 3 and 5, which belong to the CI category and have the same clay minerals (illite, montmorillonite, chlorite, and kaolinite), are showing a similar trend in strength as samples 4 and 6. Thus, we can conclude that the presence of the same clay minerals does not guarantee that the samples will always exhibit a similar trend in strength. As sample 4 and sample 6 demonstrate, soil may exhibit a similar strength trend even though the same clay minerals are found in different categories.

From the above discussion, it can be said that we must look into the situation more thoroughly, comparing the relative amounts of clay and non-clay minerals, as well as the samples' soil structure fabric, which can help us determine the cause of this variation in strength and the effects of clay minerals on the strength behaviour of soil.

CBR and UCS both are a measure of soil strength. So, their value will definitely depend on the type of clay minerals present in the soil. The interaction of the clay minerals that are present in the soil plays a major role in the mobilization of undrained strength, or soil cohesiveness. When it comes to kaolinite clay particles, the mobilization of net attractive force between them produces enhanced flocculation, which raises the particle-level shear strength in the case of kaolinite-rich soils; As opposed to this, the strength in montmorillonitic soils is a result of the diffuse double layer's contribution to the viscous shear resistance. The strength of soils will increase in response to any factor that increases net attractive forces or encourages the diffusion of a double layer. Conversely, non-clay minerals with larger sizes and a lower surface area, such as mica, feldspar, and quartz, can cause a less compact soil structure and a decrease in compressive strength.

So, with the help of both optical and electron microscopes, different soil micromorphological techniques, including thin sections can be studied to know the structure of soil and its minerological components.

From the above discussions and the experimental results from Chapter 3, however, we can conclude that static compaction is showing better results in the strength of clay at different molding water contents. The engineering parameter can be improved by using the static compaction test, particularly when determining the laboratory's degree of compaction value and comparing it to field data. In comparison to the dynamic concept, static compaction can also be characterized as a quicker, simpler, and easier method that can be completed in the laboratory in a short amount of time. The static compaction method is more sensible and practical than the dynamic compaction method, according to the laboratory results. However, long-term strength tests must be performed in order to comprehend the overall strength behavior both in statically and dynamically compacted clay at different molding water contents.

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE STUDY

5.1: INTRODUCTION:

This concluding chapter reflects upon the key findings drawn from this present study on strength characteristics of soil by static and dynamic compaction method. Conclusions which are drawn from the present study, along with some suggestions for further study are incorporated below.

5.2 Conclusions:

Conclusions which are drawn from the study on statically and dynamically compacted soil are:

1. It is found that the unsoaked CBR value for the statically compacted soil specimen has a higher value than the value for the dynamically compacted soil specimen. When the unsoaked CBR value from the two compaction modes is compared, it turns out that, depending on the type of soil, the statically compacted soil specimen typically yields a CBR value that is on an average 1.7 times higher than the dynamically compacted soil specimen.
2. Three soil samples exhibit higher values for the unconfined compressive strength (UCS) for statically compacted soil specimens. But the other three soil samples exhibit higher values for unconfined compressive strength when the soil specimens were compacted dynamically.
3. A non-linear decreasing relation of strength with increasing water content has been observed for both CBR and UCS tests when the water contents lie at dry of optimum, optimum moisture content, and wet of optimum for both static and dynamic modes of compaction. Strength generally decreases with increasing water content, but the relationship may vary depending on the type of soil.
4. In general, the modulus of elasticity of soil for a statically compacted specimen is found to be higher than for a dynamically compacted specimen.
5. Static compaction yields a higher CBR value than dynamic compaction, making it more reasonable and useful for the improvement of engineering parameters, especially in road construction design, reducing road design thickness and, in turn, its cost of construction.

6. Based on the laboratory results of this study, we can conclude that static compaction would perform better in terms of strength for applications where greater strength is required. However, long-term strength tests must be performed in order to validate this statement.

5.3 Scope for Future Study:

This study of the strength characteristics of soil may be extended by taking into account the subsequent points.

1. To investigate the strength characteristics of statically and dynamically compacted soils, only a limited number of soil samples have been tested in this study. To strengthen and validate the reliability of test results, more testing would have to be done with soil of different physical properties and different geological origins.
2. An investigation of the matric suctions present during both the static and dynamic compaction process needs to be done.
3. Thin sections and other soil micromorphological techniques can be used to quantitatively study the soil's structure and soil fabric under both optical and electron microscopes.
4. Variation in strength can be studied while the water content of the specimens lies further away from optimum, say, 6% above and below optimum moisture content.
5. An investigation of the soaked CBR value can be made by preparing the soil specimens using both static and dynamic compaction methods to correlate with the unsoaked CBR value under the same test conditions.
6. The proportion of clay and non-clay minerals can be investigated to determine their effects on soil strength.
7. An attempt could be made to examine the variation of permeability with the variation of strength characteristics at respective molding water content.

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