A COMPARATIVE STUDY ON UNCONFINED COMPRESSIVE STRENGTH OF STATICALLY AND DYNAMICALLY COMPACTED SOIL UNDER VARIOUS STRAIN RATES

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

MASTER OF TECHNOLOGY
In
CIVIL ENGINEERING
(*With specialization in Geotechnical Engineering*)
Of
Assam Science & Technology University
Session: 2022-2024

By
DIPANJAL DAS
Roll No: PG/C/04
ASTU Registration No: 176004116
ASTU Roll No: 220620062004

Under the Guidance of
DR. MALAYA CHETIA
Professor, Assam Engineering College
Department of Civil Engineering

ASSAM ENGINEERING COLLEGE
JALUKBARI, GUWAHATI-13, ASSAM

DECLARATION

I hereby declare that the work presented in this report entitled "**A COMPARATIVE STUDY ON UNCONFINED COMPRESSIVE STRENGTH OF STATICALLY AND DYNAMICALLY COMPACTED SOIL UDNER VARIOUS STRAIN RATE"** in the partial fulfillment 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 for twelve months under the supervision of Dr Malaya Chetia, 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.

Date:

Place:

DIPANJAL DAS
M. Tech 4TH Semester
Roll No: PG/CE/04
ASTU Registration No: 176004116
Department of Civil Engineering
Assam Engineering College
Jalukbari, Guwahati-781013

CERTIFICATE

This is to certify that the work presented in this report entitled "**A COMPARATIVE STUDY ON UNCONFINED COMPRESSIVE STRENGTH OF STATICALLY & DYNAMICALLY COMPACTED SOIL UDNER VARIOUS STRAIN RATE**" is carried out Dipanjal Das, Roll No: PG/C/04, a student of M. Tech 4^{th} semester, Department of Civil Engineering, Assam Engineering College, under my guidance and supervision and submitted in the partial fulfillment of the requirement for the award of the Degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

Date:

Place:

DR. MALAYA CHETIA
Professor
Department of Civil Engineering
Assam Engineering College
Jalukbari, Guwahati-781013

CERTIFICATE FROM HEAD OF THE DEPARTMENT

This is to certify that the project report entitled "**A COMPARATIVE STUDY ON UNCONFINED COMPRESSIVE STRENGTH OF STATICALLY & DYNAMICALLY COMPACTED SOIL UDNER VARIOUS STRAIN RATE**" has been submitted by DIPANJAL DAS, bearing Roll No: PG/C/04, a student of M.Tech 4th Semester, Geotechnical Engineering (Civil Engineering Department), Assam Engineering College, in partial fulfillment of the requirements for the award of the degree of Master of Technology in Geotechnical Engineering of Assam Science & Technology University.

Date:

Place:

DR. JAYANT A PATHAK

(Professor & Head of the Department)

Department of Civil Engineering

Assam Engineering College

Guwahati-781013

ACKNOWLEDGEMENT

I would like to extend my sincere appreciation to Dr. Malaya Chetia, Professor in the Department of Civil Engineering at Assam Engineering College, for her extensive support and encouragement throughout the project. Her guidance, constant supervision and provision of necessary information were invaluable to me. Working under her was an inspiring and great experience, and I am highly indebted to her.

This project would not have been possible without the help of my seniors; laboratory assistants and staffs, for their guidance in various ways. Without their guidance and support it would have not been possible for me to prepare and complete this study.

I am also grateful to Dr. Jayanta Pathak, Professor and Head of the Department of Civil Engineering at Assam Engineering College as well as the entire community of the Department of Civil Engineering at Assam Engineering College for providing us with the necessary infrastructure and comfort throughout the course, particularly during my project.

Date:

Place:

DIPANJAL DAS

M.Tech 4th Semester

Department of Civil Engineering

Assam Engineering College

Jalukbari, Guwahati-781013

ABSTRACT

The unconfined compressive strength (UCS) of soil is a critical parameter influencing the stability and load-bearing capacity of various civil engineering structures. This study investigates the disparities in UCS between statically and dynamically compacted soils. Statically compacted soil, traditionally employed in construction projects, undergoes compaction through static pressure application. Conversely, dynamically compacted soil, an emerging technique, involves dynamic energy application through methods like vibro-compaction or dynamic compaction. But the notable variations in the mechanical and physical characteristics of the two compaction techniques that have been documented in the literature were restricted to clay or sand. This work investigates the impact of the compaction method on the microstructure, density, and unconfined compressive strength (UCS) of soil by an extensive literature review and experimental analysis. Various soil types, clay, silty clay, collected from various sites are considered to assess the generalizability of findings. Factors such as moisture content, dry density, strain rate, and compaction energy are analyzed to understand their impact on UCS. The results indicate notable differences in UCS between statically and dynamically compacted soil specimens under different strain rate. It must be concluded that to obtain significant increases in strength or modulus of deformation, at a given moisture content and density, it takes a rate of strain approximately equivalent to fast transient conditions. Furthermore, when the water content is reduced, the most effective method to enhance the strength of both CI & CL-ML soil is by increasing the rate of strain. Moreover, as the rate of strain increases, the strain at failure decreases. Unconfined compression strength of dynamically compacted soil specimen exhibited higher values than statically compacted soil. However, Dynamic compaction at OMC, where the soil is partially saturated, may result in temporary higher strength values due to capillary action creating an apparent cohesion in the soil, compare to statically compacted soil. In conclusion, this research provides valuable insights into the performance of statically and dynamically compacted soils regarding UCS. The findings contribute to optimizing soil compaction techniques for diverse engineering projects, emphasizing the importance of considering dynamic compaction methods for enhanced long-term stability and resilience against dynamic loading conditions

LIST OF TABLES

LIST OF FIGURES

CONTENTS

CHAPTER 1

INTRODUCTION

Soil is a crucial material in civil engineering, as most of the structures are built on soil ground. The failure of the ground and collapse of the buildings are often associated with soil shear strength. Under different loading conditions the soil shear strength, or the shear resistance, is dependent on the cohesion, friction, and interlocking between particles. The mechanical property of soil is complex due to the fact that soil often contains different particle sizes, high water content, and large voids.

Soil shear strength is dominated by basic parameters such as soil mineralogy, overburden pressure, water content, density, capillary action, strain rate & void. Commonly, the soil shear strength is calculated by determining the effective stress and soil parameters, such as internal friction angle and cohesion. These soil parameters can be determined in the field by Standard Penetration Test (SPT) or shear vane test and in the laboratory by conducting direct shear test, ring shear test, triaxial test, and unconfined compression**.**

Unconfined Compressive Strength of Soil: Complementary to shear strength, the Unconfined Compressive Strength (UCS) of soil measures its ability to withstand axial loading in an undrained condition. The UCS test is particularly useful for cohesive soils, providing information on the material's strength and its susceptibility to deformation under compression. Understanding the unconfined compressive strength is crucial in designing foundations and assessing the load-bearing capacity of soil in construction projects.

This project aims to conduct a comprehensive comparative analysis of the shear strength characteristics of soil using Unconfined Compressive Strength Test. By juxtaposing the results obtained from this distinct testing method, we seek to elucidate any variations in the measured shear strength parameters and explore the implications for geotechnical engineering applications.

The main purpose of this comparative study was to examine the shear strength behavior of soil under different compaction method and different dry density at different water content under different strain rate. The soil compaction is widely known as one of most important mechanical method to improve the soil strength. The basic concept of the soil compaction depends upon densify the soil to improve soil strength (Das and Sobhan, 2014). This densification can be achieved by replacing the air voids with water or solid particles (Das and Sobhan, 2014). However,while the compaction is a mechanical method to strengthen the soil.

The Unconfined compressive strength Test which to evaluate the shear strength of soil. The shear strength, and cohesion are the main parameters to evaluate the soil strength (Das and Sobhan, 2014; Wang et al., 2015). The measured shear strength parameters (i.e. shear strength, and cohesion) depends on several factors which can be related to soil properties (e.g. fine content, moisture content, dry density, particle size and shape) (Chen et al., 2015; Li, 2013) or the shear mechanism.

The UCS test is performed for quick determination of UCS for both remoulded and undisturbed soils. Though a lot of studies have been conducted to determine the UCS of different soil at different compaction method, the highlight of effect of strain rate under different compaction method at different dry density and moisture content is found to be very few. The effect of loading duration and strain rate on the UCS of compacted clay was documented by Seed et al. (1983). It was discovered that the UCS first reduced and then gradually increased. Three distinct strain rates were used in the UCS test by Awoleye et al. (1991) for highly plastic clay: 2 mm/min, 1 mm/min, and 0.08 mm/min for both undisturbed and remolded specimens. The findings showed that the UCS of both undisturbed and remoulded soil increases as the strain rate increases. Sensitivity increased as a result of this increase, which was more pronounced in the undisturbed cases than in the remolded ones.

Many projects in geotechnical and pavement engineering involve unsaturated soils at shallow depths (i.e. stability of natural, expansive or embankment slopes and pavement design) (AASHTO 1993, Whenham et al. 2007, Li and Zhang 2015). However, determining the unconfined compressive strength of an unsaturated soil for different matric suction values is time consuming. Several empirical or semi-empirical methodologies/approaches developed to predict the variation of unconfined compressive strength of unsaturated soils with respect to suction (Won Taek Oh et al. 2017)

1.1 Motivation for the study:

The fact that the compressive strength of a soil is a function of the time required to reach the failure load has long been recognized. However, this area of soil mechanics has not been extensively explored and much work remains to be done, in order that the effects of this phenomenon can be properly evaluated. There are some specific area where this information would be greatest benefit. In areas where there are possibilities of earthquakes, it is crucial to look into the stability of slopes, both natural and man-made, under temporary circumstances in regions where earthquakes may occur. An examination of this kind is particularly required when the slope in question has the potential to fail catastrophically. Critical slopes in these locations should be developed and assessed with the understanding that earthquake shocks created in the earth represent transitory loading conditions. Again, the stress-strain characteristics of pavements are a function of the rate of strain .The variation in travel speed creates significant influence on pavement material. Therefore, a thorough investigation is to be needed, how soil behavior is impacted by strain rate, compaction effort & dry density and moisture content. These are only a few of the reasons that, from an engineering perspective, a study to learn more about the impact of loading duration on soil strength is readily justified. As a result, the main goal of the research presented here was to look into the strength characteristics of silty clay and clay under temporary loading. The specific goal was to try and determine the link between unconfined compressive strength and rate of strain at different densities and moisture contents & compaction energy. So, there is need of this comparison, Again there is no studies were made between effect of compaction energy and strain-rate variation on unconfined compressive strength of soil. Many research works have been carried out on unconfined compressive strength of soil but no comparison have been made effect of strain rate on various density and moisture content. Furthermore, a relationship between the aforementioned variables and the modulus of deformation was intended.

CHAPTER 2

LITERATURE REVIEW

2.1 General:

The comprehensive review of literatures have been shown in this chapter related to the determination of unconfined compressive strength of soil and the effect of strain rate ,compaction energy, dry density & moisture content on compressive strength of clay and silty clay.

2.2 Literature Review:

Alshameri et al. (2017): They studied a large number of soil samples from six different sand-kaolin soil combinations with varying fine contents were examined in order to find out how density and fine content affected the shear strength characteristics.

The following are the outcomes:

The link between density and the influence of fine material on cohesiveness is dissonant. When the fine content increased, cohesion increased as well; nevertheless, cohesion reduced as density increased. The properties of the sand-kaolin combination are affected in multiple ways by the presence of fine grains. An increase in fine content led to a decrease in density, modifications to the area of friction surface, and adjustments to the shear strength values. The influence of fine materials when the present a relative is explained by the intergranular void ratio.

Kang et al. (2022): They studied and examine the sitly clay, which has a higher powder group than sand group. Particle gradation, dry density, and moisture content are the key factors affecting its shear strength. Through indoor direct shear experiments, the deformation characteristics of silty clay under various normal pressure situations were examined in this study from the standpoint of control variables. The study's findings demonstrate that, given an identical guaranteed moisture content, the fitted curves demonstrate that, as dry density increases, soil particle arrangement becomes more compact, cementation between particles strengthens, shear strength rises, occlusal friction rises as a result of the altered arrangement between particles, and the angle of internal friction and cohesion are larger; in addition, when the dry density is the same, with the increase of moisture content, the soil becomes softer, and the form of water in the soil particles changes. In addition, when the dry density is the same, as the moisture content increases, the soil becomes softer, the presence of water between the soil particles changes, resulting in the weakening of the occlusion between the soil particles, the shear strength decreases, and the cohesion and the angle of internal friction relatively decrease.

E.Cokca et al. (2004): examined how compaction moisture content and soaking affect the unsaturated shear strength of a clay soil. Tests were conducted on samples compacted at different moisture levels, both above and below the optimal level of 24%, as well as on a soaked sample. The study found that the relationship between log suction and water content for the compacted clay is linear on the dry side of the optimal moisture level. The soil suction is roughly 230 kPa when the optimal moisture level is reached and then decreases slightly as moisture increases. This suggests that the clay behaves like a saturated clay at around the optimal moisture content. Additionally, the angle of friction decreases rapidly as moisture content increases and suction decreases up to the optimal moisture level. The peak value of cohesion component of shear strength is observed at around optimal moisture content and then decreases. Furthermore, it was found that soaking does not have much effect on the angle of friction at optimal moisture content, but it causes almost threefold reduction in the cohesion component of shear strength.

Poudel et al. (2019): The findings indicate that the shear strength of Red clay soil (local name: Ratomato) is greater than that of Black cotton soil (local name: Kalomato) and White soil (local name: Kameromato). Since kameromato is insensitive, there is no need to investigate its thixotropic characteristics.In comparison to the findings of the unconfined compression test, it was found that the Vane shear test typically produced greater values of un-drained shear strength. In their instance, the shear strength result increases by 5% from UCS to VST. Ratomato showed a stronger thixotropic strength return in strength percent of original undisturbed strength than Kalomato, but both have a same thixotropic strength ratio. Quantification, Mohs values, and detailed mineralogical identification show that quartz content is higher in ratatopes and lower in kameromatoes. major minerals in Ratomato are hard, while for Kalomato it is intermediate hard and soft for Kameromato as major mineral (chlorite) has low Mohs value.

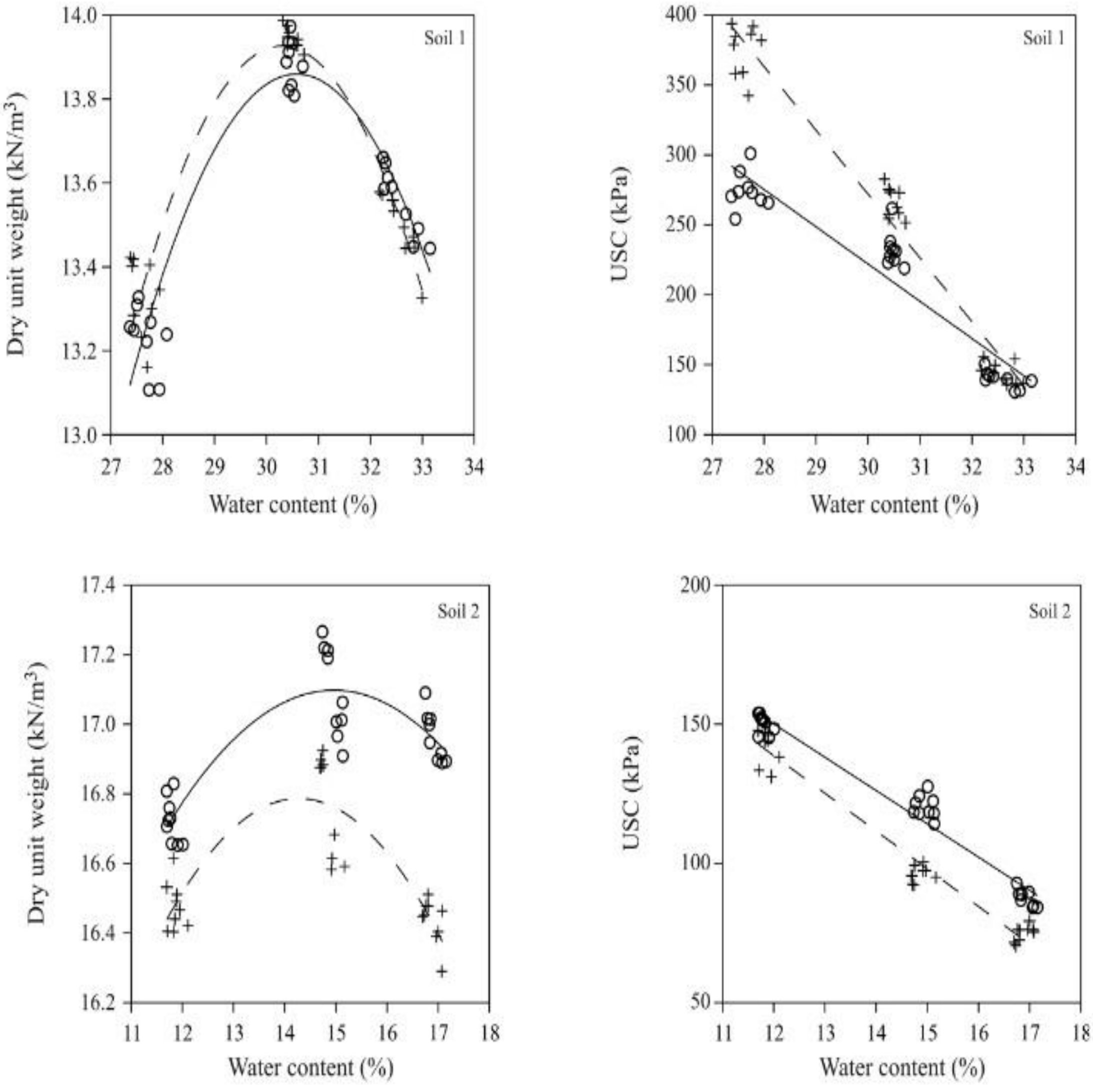
Dario et al. (2011): investigated the influence of the static and dynamic laboratory compaction procedures in the compaction curves. They have also addressed the mechanical strength of two residual soils from the Zona da Mata Norte, in the state of Minas Gerais, Brazil. Laboratory testing is done on two types of residual soil namely silty-sandy clay (soil 1) and clayey silty sand (soil 2). They have compacted the soil specimens at the standard Proctor compaction effort both at and near OMC. Determination of the unconfined compressive strength of the compacted specimens, micro morphological analysis of thin sections of the compacted specimens using optical microscopy and statistical analysis of the laboratory testing program data is also included as a part of the research. In an attempt to reproduce the compaction effort and water content commonly used in the field compaction of landfills and sub-grade soil layers, all specimens were compacted at the standard Proctor compaction effort adopting nine repetitions of the compaction curve at water contents equal to and close to OMC.

The compaction tests were carried out through dynamic and static compaction laboratory procedures. Dynamic compaction is done as per Standard Proctor compaction test adopting nine repetitions of the compaction curve at the optimum water content (w_{ot}); optimum minus 3% (w_{ot} -3%); and optimum plus 2%(w_{ot} +2%) to determining the dry unit weight (γ_d) at each selected water content.

Static compaction is done with the help of a hydraulic pump where sufficient pressure is imposed to each layer of three-layered specimen so that the desired dry density corresponding to dynamic compaction can be achieved at selected water content. In the static compaction procedure, there was no control of the applied force to the specimen; therefore, only the mass and height layers were controlled. The acceptance criteria adopted for specimen preparation was water content maximum deviation of ± 0.3%.

The unconfined compression strength (UCS) of the compacted specimens was determined following the Brazilian Association of Technical Standards, ABNT (1992) at the deformation rate of 1.25 x 10-5 m/s. The statistic tests t and F were applied to the UCS data in order to evaluate the influence of the compaction procedures in the soil's structures, considering the 5% probability level in all analysis.

Figure 2.1 shows the compaction curves and unconfined compression data from laboratory tests performed in specimen of soils 1 and 2 respectively.



+++++++ - static compaction
oooooooo - dynamic compaction

Fig 2.1: Compaction curves and unconfined compressive strength (UCS) of soils 1 and 2 (Dario et al. -2010)

From the graph it is clear that static compaction produces higher dry density and higher confined compressive strength for fine-grained soil sample-1 of CH-category upto a particular water content (in the wet side of optimum) as shown in Fig.2.1 After the specific water content, an opposite trend of dry density and mechanical strength is observed for the same soll. But for the SC type of soll, dynamic compaction was giving higher value of dry density and mechanical strength irrespective of water content as compared to static compaction. Thus, from the result it is evident that the mode of compaction has significant influence in the mechanical strength of soil.

Figure 2.2 shows relative differences between the mean values of the parameters and UCS of soils 1 and 2, adopting the dynamic compaction data as reference. For practical engineering applications, the relative differences between the γ_d mean values are not significant, not over 1% for soil 1 and 3% for soil 2; on the other hand, regarding the UCS mean values, the relative differences are higher, reaching approximately 37% for soil 1 and 20% for soil 2, which emphasizes the significant influence of the compaction procedure on soil mechanical strength.

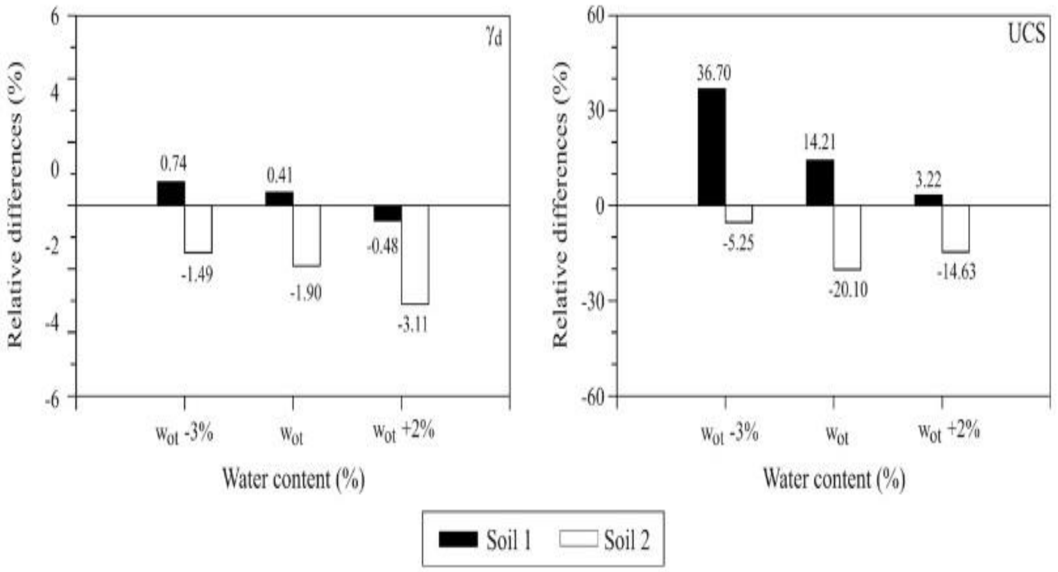


Fig 2.2: Relative differences between mean values of the parameters γ_d and UCS of soils 1 and 2, adopting the dynamic compaction data as reference (Dario et al. 2010)

Applying statistical analyses γ_d to and UCS data from soils 1 and 2 at the 5% significance level it can be concluded that regarding the parameter γ_d, there are significant statistical differences between the data from the static and the dynamic compaction procedures, except for specimens of soil I compacted at the water content w_{ot} + 2%; on the other hand, considering the UCS parameter the results of the statistical analysis confirm that the compaction procedure affects the soils mechanical strength, except for specimens of soil 1 compacted at the water content wot + 2%.

Using the optical microscope, the micro morphological analysis was carried out on thin section of specimen which is compacted statically and dynamically at the water contents War- 3% and War+3% and respective porosity data is determined using the QUANTIPORO software

At OMC, fig.2.3a shows that the statically compacted specimens of soil I present features of original micro aggregation, noticing original nodules, formation of isolated gaps and fissured and oriented porosity, and low porosity, around 3%. On the other hand, at this same water content, Fig.2.3b suppots that dynamically compacted specimens present a few original micro aggregation features, with porosity almost all lost, around 2%.

On the dry side of optimum, at water content Wot -3%, as observed in Fig.2.3c and fig.2.3d the static compaction applied to soil I produced structure with strong features of original micro aggregation and gaps, and porosity around 11%. From another standpoint, the dynamic compaction produced partially bonded micro structured argillaceous plasma, with the original micro aggregation destroyed, and porosity reaching around 2%, which is much lower than the one imposed by the static compaction

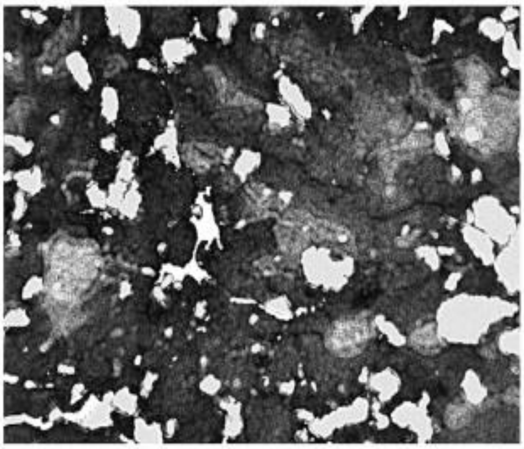


Fig.(a) static compaction at OMC

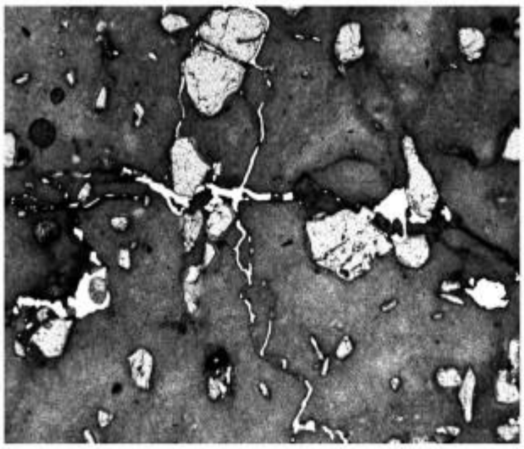
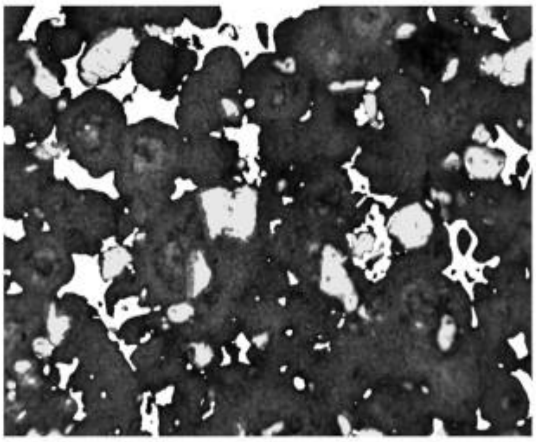


Fig.(b) Dynamic compaction at OMC



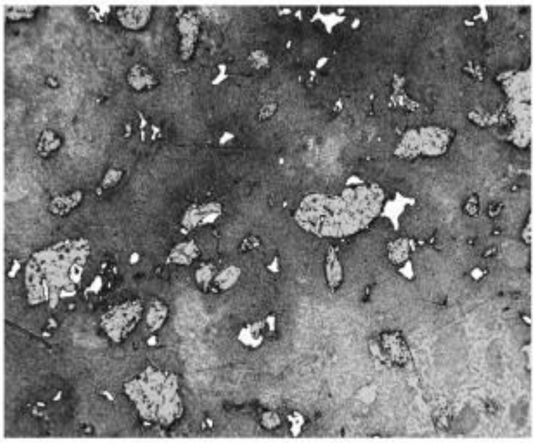


Fig.(c) static compaction at OMC **Fig.(d) static compaction at OMC**

Fig.2.3: Photomicrographs taken from thin section obtained from of soil specimen 1 (Dario et al. 2011)

Byeongsu Kim et al.(2009): They studied the uses unconfined compression tests to assess how matric suction affects the strength and deformation properties of silt soils that have been compacted both statically and dynamically. The relationship between suction stress and unconfined strength is established, and the change in suction and volume of the soil samples are measured in order to estimate the suction stress. A distinct soil-water characteristic curve can be used to represent the connection between suction and the degree of saturation at failure under various initial saturation and dry density conditions in soils. This result demonstrates a tendency that is comparable to an equation that was predicted using the same parameters for the characteristic curves of soil and water. Additionally influencing the unconfined compressive strength.

They used silty soil known as ‘DL clay” in Japan for the test. The soil samples tested are classified into two groups as, Group (A) consists of the dynamically compacted samples under the constant compaction energy, and Group (B) consists of the statically compacted samples under constant dry density as shown in Fig 2.4

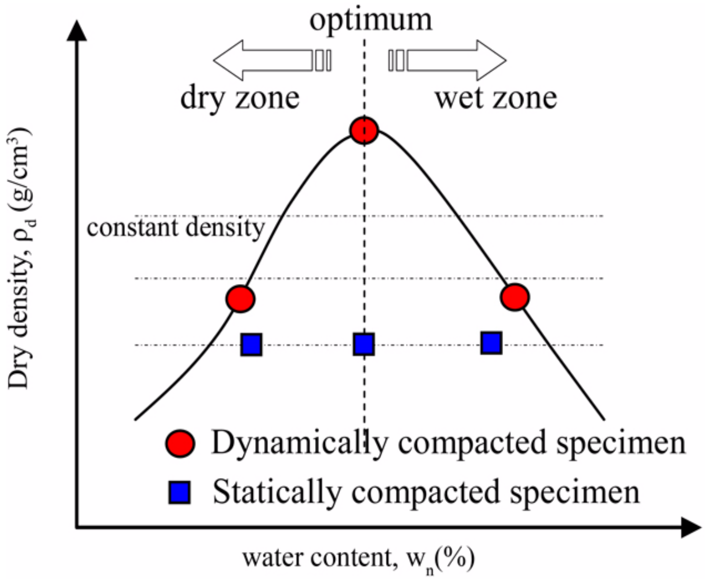


Fig 2.4: Specimen Conditions for a series of unconfined compression (Byeongsu Kim et al. 2009)

The result were classified into two main groups 1) Group (A), index of ○, □ , △ specimens made by constant compaction energy, on which are located the compaction curve, and 2) Group (B), other index; specimens made by constant dry density below the compaction curve. As shown in Fig. 2.5

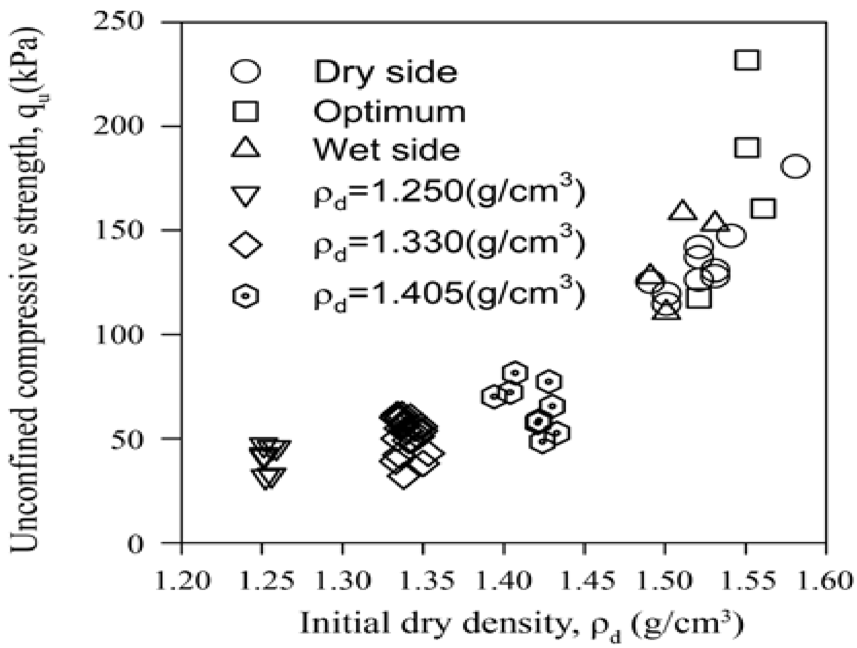


Fig 2.5: Relationship between Initial Dry Density and Unconfined Compressive Strength (Byeongsu Kim et al. 2009)

From the Fig they found increase in unconfined compression strength is quite small for group (B), while an increase in unconfined compressive strength coincides with an increase in dry density for group (A). comparing the result of group (A) and group (B), the other factors may affect the unconfined compression strength as well as the dry density.

They also evaluate the relationship between suction and unconfined compression strength which is shown in Fig 2.6

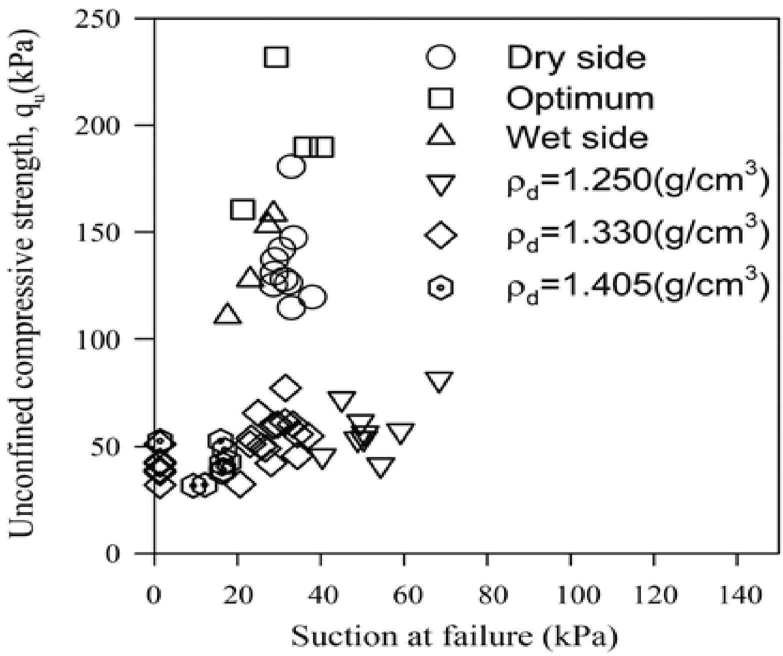


Fig 2.6 : Relationship between Suction and Unconfined Compressive Strength Failure (Byeongsu Kim et al. 2009)

From the Fig, In group (A), the unconfined compression strength at failure is relatively larger than that of group (B). This result may imply that the constant compaction energy and a certain level of density condition will be significant during an embankment construction.

They also studied the effect of initial degree of saturation on unconfined compressive strength. The unconfined compression strength in group (A) tended to increase with an increase in the initial degree of saturation, although the unconfined compression strength in group (B) is not insensitive to the initial degree of saturation. There is a clear difference in the increase in shear strength between the dry and wet sides of group (A), with the dry side of Group (A) specimens having a much larger shear strength than the wet side. Which is show in Fig 2.6

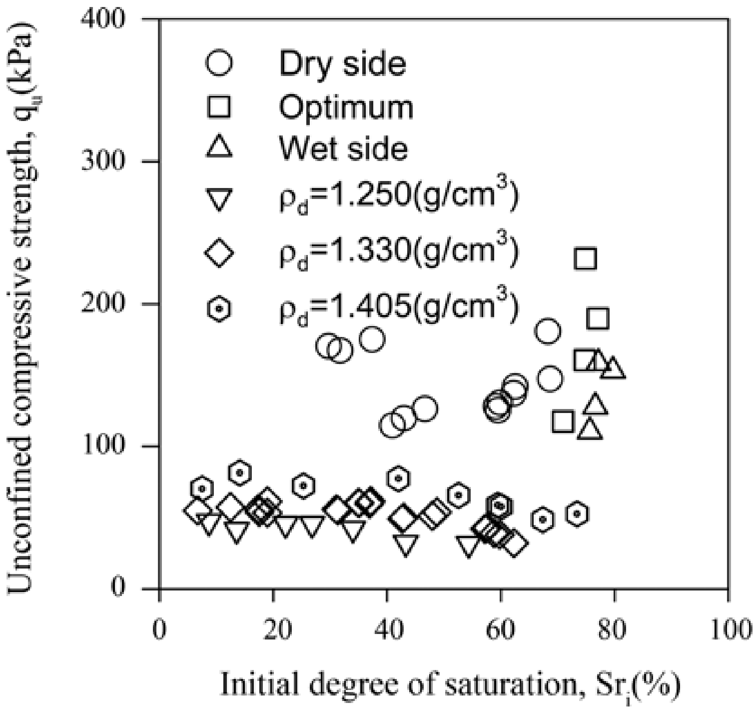


Fig 2.7: Relationship between Initial Degree of Saturation and Unconfined Compressive Strength (Byeongsu Kim et al. 2009)

From the studied they found out unconfined compression strength is influenced by the suction and the degree of saturation as well as by the dry density of soils.

Hampton et al. (1958): Investigated two remoulded soil samples using various strain rates: 0.55 in/min to 1768 in/min, using UCS test. Results indicated that the effect of rate of strain is greater when the compaction effect was lesser. The factors of moisture content and dry density were also of prime importance. Three compactive efforts were used and specimens were molded and tested on both sides of the optimum moisture content, O.M.C., of each compactive effort. The study found that the rate of strain was the most important variable, and the modulus of deformation was the slope of a line from the origin through the point on the stress vs. strain curve at which the stress is one-half of the compressive strength. The effect of rate of strain on unconfined compressive strength. The effect of strain rate on unconfined compressive strength of silty clay graphically presented below in Fig 2.8

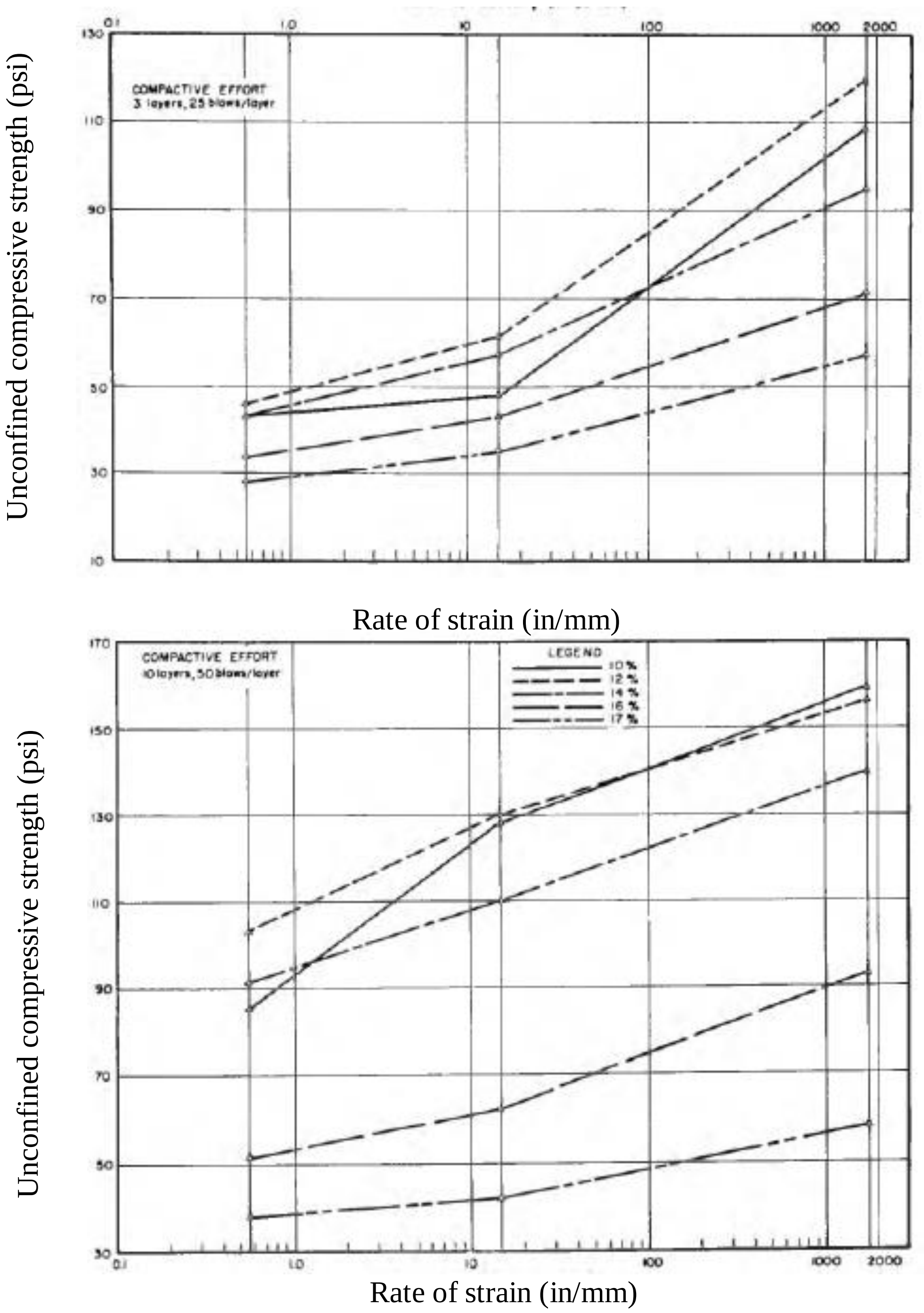
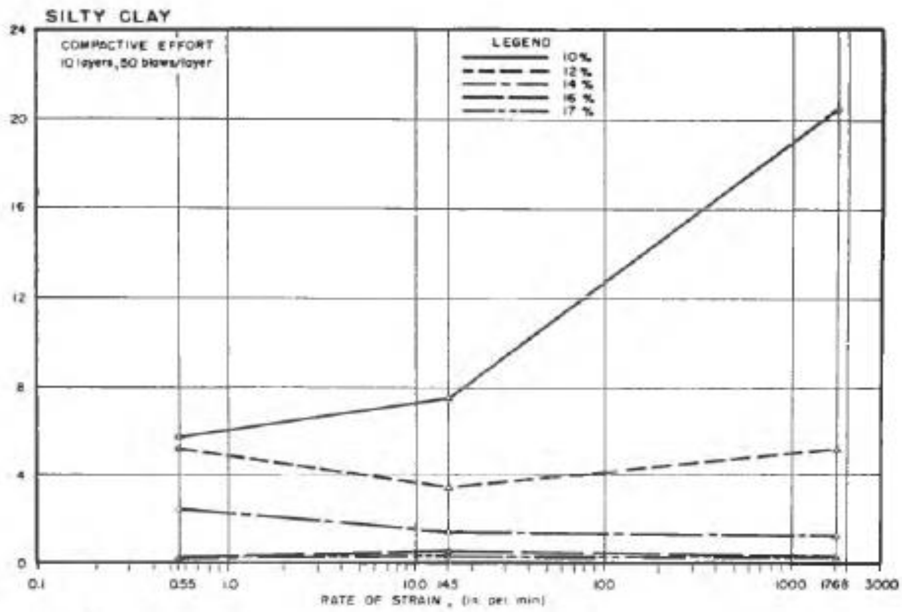


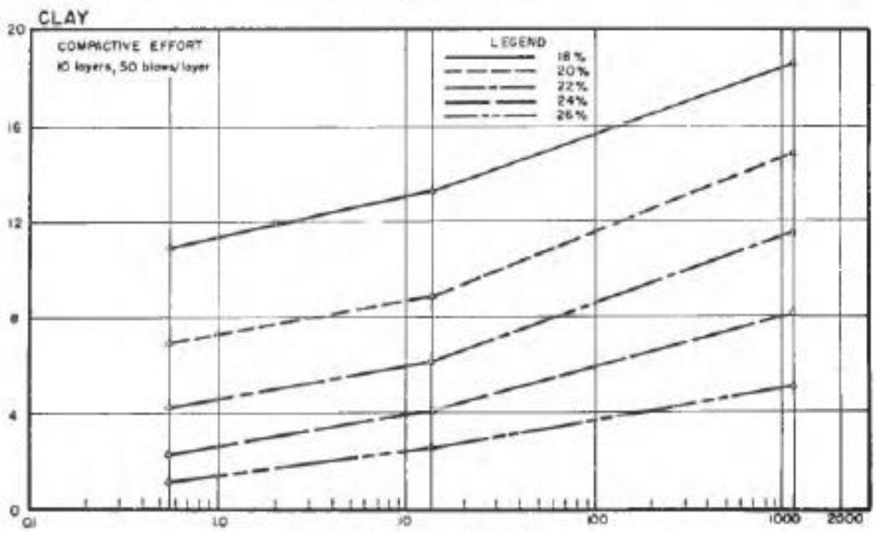
Fig.2.8: Rate of strain vs. unconfined compressive strength—silty clay. (Hampton et al. 1958)

raising the strain rate resulted in a notable improvement in the soils' strength. An examination of the previously given figure demonstrates that variations in moisture content had an increasingly notable impact on the unconfined compressive strength as the compactive effort was raised. For the range of moisture levels evaluated, the strength ratios for the lower compactive effort in both soils were higher than those for the intermediate and greatest compactive effort. For instance, it was discovered that the slower transient test specimens made under the identical parameters of moisture content and density consistently had a strength greater than 100% of the lower compactive effort specimens tested under rapid transient conditions. Nonetheless, the highest and intermediate compactive efforts shown a significantly less variation in strength across the same range of strain rates (highest increase of 89% but frequently much less). Regardless of the rate of strain or the compactive effort, the maximum strength for both soils was reached at a moisture content below the ideal level. Additionally, once the optimal strength was reached, there was a quick decline in strength for a given rise in moisture content. On the strength ratios for the clay and silty clay, however, an increase in moisture content had the reverse effect. For clay, the strength ratio tended to rise with increasing moisture content; for silty clay, the opposite was true. The strength ratio's decline with increasing moisture content, for example On the strength ratios for the clay and silty clay, however, an increase in moisture content had the reverse effect. For clay, the strength ratio tended to rise with increasing moisture content; for silty clay, the opposite was true. For the silty clay, the drop in strength ratio with increasing moisture content was most likely caused by the increased influence of pore water pressures, which would normally tend to reduce the samples' strength. The 10% curves are not consistent with the remaining data, as can be shown by looking at Figure 5. This is most likely because the specimens were collapsing instead of failing, at least in partially at least, by crumbling rather than shear, due to their low moisture content.

They also studied the effect of strain rate and modulus of deformation for clay and silty clay and it was found that, the modulus of deformation of silty clay and clay varied significantly depending on the rate of strain. Which is shown if Fig 2.9



Rate of strain (in/mm)



Rate of strain (in/mm)

Fig.2.9: Rate of strain vs. modulus of deformation
(Hampton et al. 1958)

For the silty clay, Figure 6, it appears a significant increase in modulus of deformation, due to an increase in rate of strain, was obtained only for the specimens compacted at approximately 10 per cent moisture, this was true for all compactive effort. It appears that an increase in the rate of strain will not result in a noticeably higher modulus of deformation when the moisture content is 12 percent or more. In fact, it was discovered that a modest drop in modulus of deformation occurred with an increase in strain rate at high moisture levels and densities.

For a given increase in moisture content and a given rate of deformation, there was also a significant decrease in the modulus of deformation for the clay soil in Fig 6.The stronger the compactive effort, the more noticeable this condition was.

Figure 6 shows how the moisture content and strain rate affect the modulus of deformation. It is clear that, in contrast to the silty clay, the rate of strain plays a significant role in determining the clay specimens' modulus of deformation. This held true for every evaluated moisture content and compactive effort. Lastly, there was a propensity for the clay, as opposed to the silty clay, to show an increase in MD ratio with an increase in moisture. For the silty clay, the opposite held true.

Based on the results of these experiments, it is necessary to draw the conclusion that, for a given moisture content and density, significant improvements in strength or modulus of deformation require a rate of strain that is roughly similar to fast transient conditions. Additionally, at low densities, increasing the rate of strain was the most effective way to increase soil strength, and as the rate of strain grew, the strain at failure reduced as well. The phenomenon under investigation is caused by time lag, or the need for a specific amount of time for the shear planes to grow before failure occurs.

Chetia et al. (2020): They studied the strain rate effect on unconfined compressive strength (UCS) of compacted bentonite and sand (*B*:*S*) mixes. For this, various amounts of bentonite were combined with 60, 70, 80, and 90% sand, and the UCS of each mixture with a varied strain rate was calculated. In this investigation, three distinct strain rates were used: 1.5 mm/min (slowest), 1.75 mm/min (middle), and 2 mm/min (fastest). The findings show that the UCS progressively rises with increasing strain rate for all B:S combinations. The blend B:S = 40:60 showed the largest rise in UCS as a result of an increase in strain rate. The UCS of B:S mixes progressively rises for all strain rates up to a 30% bentonite concentration, beyond which the UCS of the mixes decreases with further bentonite content. Mix B:S = 30:70 can therefore be regarded as the ideal combination. The UCS The UCS of the mix B:S = 30:70 was found to be maximum when the highest strain rate of 2.00 mm/min was applied.

2.3: Summary and critical appraisal of literature review:

The literature review indicates that a vast amount of research and study have been carried out on unconfined compressive strength of soil and how it gets affected by strain rate, moisture content, soil mineralogy, dry density and compactive effort. Different testing methods are used across studies, including laboratory tests (e.g., triaxial compression tests) and in situ tests (e.g., cone penetration tests), each offering insights into UCS under different conditions. The review categorizes findings based on soil types (e.g., clay, sand, silt) and discusses how each type responds differently to unconfined compression. Practical applications of UCS in geotechnical engineering are highlighted, such as slope stability analysis, foundation design, and earthwork construction. Hampton (1958) investigated two remoulded soil samples using various strain rates: 0.55 in/min to 1768 in/min, using UCS test. Results indicated that the effect of rate of strain is greater when the compaction effect was lesser. Chuannian et al. (2003) performed UCS test on saturated clay with different dry density at various strain rates. Test results indicated that the UCS of frozen clay increases with increasing strain rates. None other had shown any comparison of unconfined compressive strength of statically compacted soil under different strain rate. Also there is few comparison of unconfined compression on silty clay under different dry dry density and moisture content under different compactive effort. The review highlights the methodological diversity among studies, which affects the comparability and generalizability of findings. Standardization in testing protocols and reporting parameters is often lacking, limiting the synthesis of results across different studies. Despite the theoretical insights provided, the review could further emphasize practical implications for engineers and practitioners. Clear guidance on interpreting UCS values in real-world applications and mitigating uncertainties would enhance the review's utility.

Overall, the literature review on UCS of soil provides a comprehensive overview of current research trends, methodological approaches, and factors influencing soil strength under unconfined conditions. While offering valuable insights, the review also underscores the need for standardized methodologies, robust data collection, and enhanced practical implications to further advance understanding and application in geotechnical engineering practices.

2.4 Objective and scope of the work:

The main objective of this investigation is to comparative study on unconfined compressive strength of statically and dynamically compacted caly and silty clay under various strain rate .Consequently, the primary purpose of the research reported herein was to investigate the strength properties of a clay and silty clay under conditions of transient loading under different dry density and moisture content. Specifically, the aim was to attempt to ascertain the relationship between rate of strain and unconfined compressive strength at various moisture contents and densities. The following are the scopes of this project work:

1. To study the effect on unconfined compressive strength of dynamically compacted soil under different strain rate.
2. To study the effect on unconfined compressive strength of statically compacted soil under different strain rate
3. To compare the UCS value under different strain rate.
4. To study the effect of moisture content and dry density on unconfined compressive strength.

CHAPTER 3

EXPERIMENTAL PROCEDURE AND RESULTS

3.1 Introduction

The description of different test program which are conducted in the laboratory to examine properties of soil is discussed in this chapter.

3.2 Test program:

The experimental study is done to evaluate the shear strength of fine-grained soil under static and dynamic mode of compaction at different dry density and moisture content. To determine and compare the shear strength parameters by unconfined compressive strength (UCS) test.

In the laboratory, the general soil index properties of the materials were determined in order to perform classifications. For this purpose, liquid limit, plastic limit, optimum moisture content and maximum dry unit weight of the specimens were determined according to Indian Standard specifications along with the strength tests. The test programe is divided into the following phases as depicted below-

1) Collection and preparation of soil sample.
2) Determination of physical properties of soil.
3) Determination of the compaction properties of soil Standard Proctor compaction Test
4) Determination of UCS value of soil by static and dynamic method of Compaction under different strain rate.

3.2.1 Collection of soil sample:

The materials tested in this study are disturbed soil samples to perform the necessary tests the soil sample was collected from deepoor beel area of Kamrup district & another from Barpeta district.

For collecting the fine-grained soil samples from the sites, the top (30-60) cm of the soil is removed so that there is no trace of organic matter amalgamated with the soil specimen About 30 kg of soil sample is collected from a square trench of area 1m x 1m.

The collected soil is allowed to dry in the room temperature followed by pulverization and removal of stones before testing. Soil containing much organic matter and heavy clay material, irreversible changes may take place during oven drying and anomalous results may produce in the subsequent tests. So, to avoid the risk of alteration of soil structure, soil is allowed to air dry instead of oven drying at 105°C.

3.2.2: Determination of the physical properties of the soils:

3.2.2.1: Specific gravity:

The specific gravity (G) of the sample were determined as per IS: 2720-III (1980). Average specific gravity was obtained from among the matching results of four trials and the values are listed in Table 3.1. For soil sample 1 and 2.Pycnometer bottle was used for determination of specific gravity.

3.2.2.2: The particle size distribution of the samples was determined as per IS: 2720-IV (1975).The percentage size fractions of the samples are listed in Table 3.1:

Table.3.1 Percentage size fractions of the samples:

Particle size characteristics (%)	Soil sample 1 (Deepor beel)	Soil sample 2 (Barpeta)
Sand (4.75-0.075 mm)	5.64	4.74
• Coarse sand (4.75-2.00 mm)	0	0
• Medium sand (2-0.425 mm)	2.779	0.033
• Fine sand (0.425-0.075 mm)	2.8595	4.71
Fines (<0.075 mm)	-	-
• %(silt+clay)	94.36	95.257

3.2.2.3: Atterberg limits:

The consistency limits of the clay samples were determined as per the guidelines provided by IS: 2720-V (1985) for liquid limit (w_L) by cone penetration method and plastic limit (w_P) by thread rolling method. The details of the test results are presented in Table 3.2.

3.2.3: Geotechnical characterization: Compaction characteristics

The compaction characteristics of soil sample 1 and soil sample 2 were obtained using light compaction as per IS: 2720-VII (1974). The compaction characteristics are presented in the form of relationship between dry density (d**)** and moisture content (w), as shown by the compaction curves in Fig. 3.1, where Z.A.V.L. represents zero air void line. Moisture content and dry density values for compaction curve are shown in Table 3.2 for respective samples. The maximum dry density (MDD), optimum moisture content (OMC) and degree of saturation (Sr) at OMC of the samples are listed in Table 3.4.

Table 3.2 Moisture content and dry density values for samples used in the study

Sample 1 (Depoor beel)		**Sample 2 (Barpeta)**	
w(%)	**ρ_d (gm/cm^3)**	**w(%)**	**ρ_d (gm/cm^3)**
16.87	1.603	9.88	1.662
18.67	1.620	12.48	1.693
19.14	1.607	15.29	1.673
20.25	1.574	18.40	1.606

3.2.4 Determination of Unconfined compressive strength (UCS) Value:

The unconfined compression test are done on soil specimen collected from deepor beel site & barpeta district as per IS:2720 (part10)-1991 with diameter (d) equal to 38 mm and length (l) to diameter ratio of 2. The type of soil specimen used for the determination of unconfined compressive strength is compacted dynamically and statically at different dry density and moisture content under strain rate 1.25mm/min & 1.5 mm/min.

3.2.4.1 Preparation of test specimen by dynamic compaction: In dynamic method of compaction, a representative sample of the soil (air dried) weight approximately 2.5 kg passing through 4.75 sieve is mixed thoroughly with different water content at different dry unit weight and the sample is kept in a desiccator for a period of 25 hours for maturation.

Water content and dry unit weight were obtained from standard proctor test. The mass of wet soil at the optimum moisture content and mass of soil corresponding dry side of the compaction curve and wet side of the compaction curve and the line corresponding to 100% degree of saturation (ZAVL), calculated by the following expression

$$\gamma_d = \frac{\gamma_w}{(\frac{1}{G_s}) + w}$$

γ_d = dry unit weight at degree of saturation

γ_w = unit weight of water

w = water content , Gs = specific gravity

Now sufficient amount of air dried sample is taken and calculated amount of water is mixed thoroughly. After keeping the wet sample for a maturation period of 24 hours in the desiccator, soil is put into the mould (standard proctor mould) with the extension collar attached is clamped to the base plate.

The soil-water mixture is compacted into the mould in accordance with the methods applicable to the 101.6 mm diameter mould specified in IS: 2720 (Part 7) -1974 i.e. the test specimen is compacted in 3 layers using a 2.6 kg rammer with a free fall of 31cm by giving 25 number of blows on each layer. The extension collar is removed and the compacted soil is trimmed carefully by means of a straightedge. Then the soil specimen for UCS test was extracted by soil extruder.

3.2.4.2 Preparation of test specimen by static compaction: In static compaction the soil specimen preparation was same as dynamic compaction discussed above.

In here the soil-water mixture is fill into the mould in accordance with the methods applicable to the 101.6 mm diameter mould specified in IS: 2720 (Part 7) -1980. Now, the spacer disc and a surcharge load 2.5 kg is placed on the top of the mould and the whole assembly is kept in the compression set up so that the soil get compacted to desired dry density. The depth of compaction is constantly monitored and the load is applied till the specimen reaches desired depth of compaction.

Then the extension collar is removed and the compacted soil is trimmed carefully by means of a straightedge. Then the soil specimen for UCS test was extracted by soil extruder.

3.3 Test results:

The experimental results obtained from the various tests performed are shown below in the form of tables and graphs.

3.3.1 Test results of the physical properties:

Table 3.1 gives the test result of the physical properties for the deepor beel & Barpeta soil samples The classification of the soil sample on the basis of Atterberg limits and plasticity chart has also been incorporated in Table below 3.3.

Table 3.3: Physical properties of the soil sample:

Soil sample	Depth from G.L (m)	Colour	Odour	Specific Gravity (Gs)	Plastic Limit Wp (%)	Liquid Limit W_L (%)	Plastic Index PI	Soil Type	% of (Silt +clay)
1.Depoor Beel site	0.5	**Grey**	NIL	2.64	23.26	46.06	22.8	CI	94.36
2.Barpeta	0.5	**Grey**	NIL	2.61	10.25	26.14	26.14	CL-ML	95.26

3.3.2 Test results of compaction properties of the soil:

The dynamic compaction test of the soils was performed by the standard Proctor's test. The experimental results of Proctor compaction for the sample one have been presented in Table 3

Table 3.4: Results of Optimum moisture content and Maximum dry density by standard Proctor compaction test.

Sample No.	Site location	(MDD) (kN/m^3)	(OMC) (%)	S_r(%)
1	Deepor Beel	16.2	18.67	78.2
2	Barpeta	16.94	12.48	60

The dynamic compaction curves of sample one is shown below-

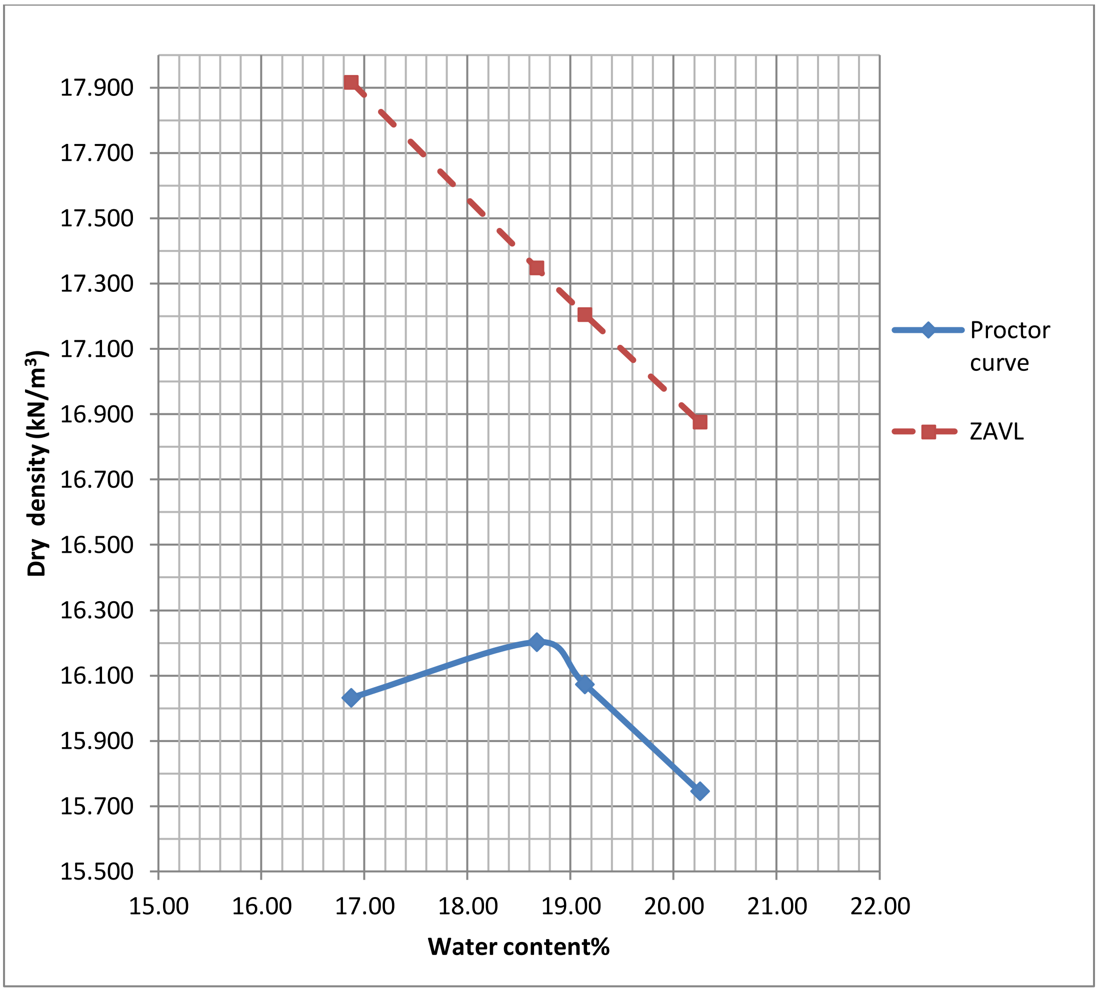


Fig 3.1 Dynamic compaction curve for sample 1

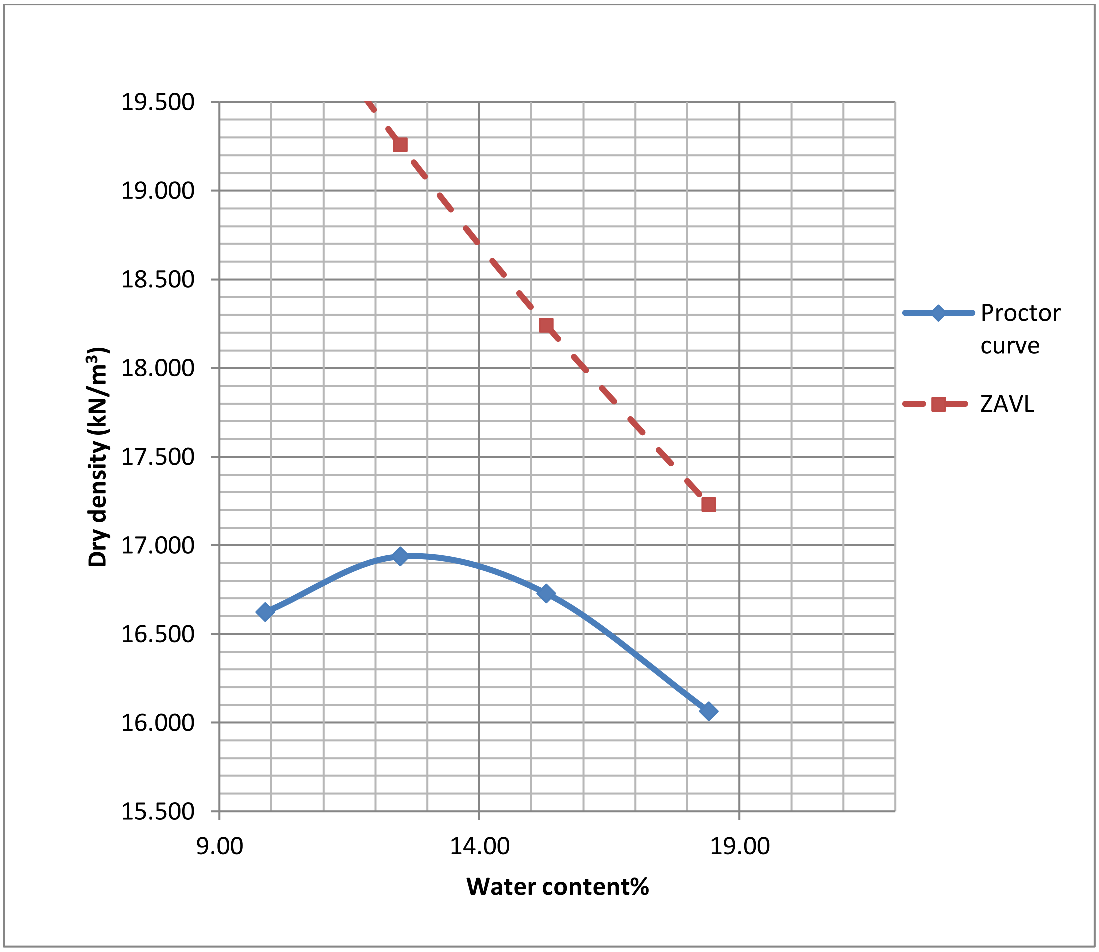
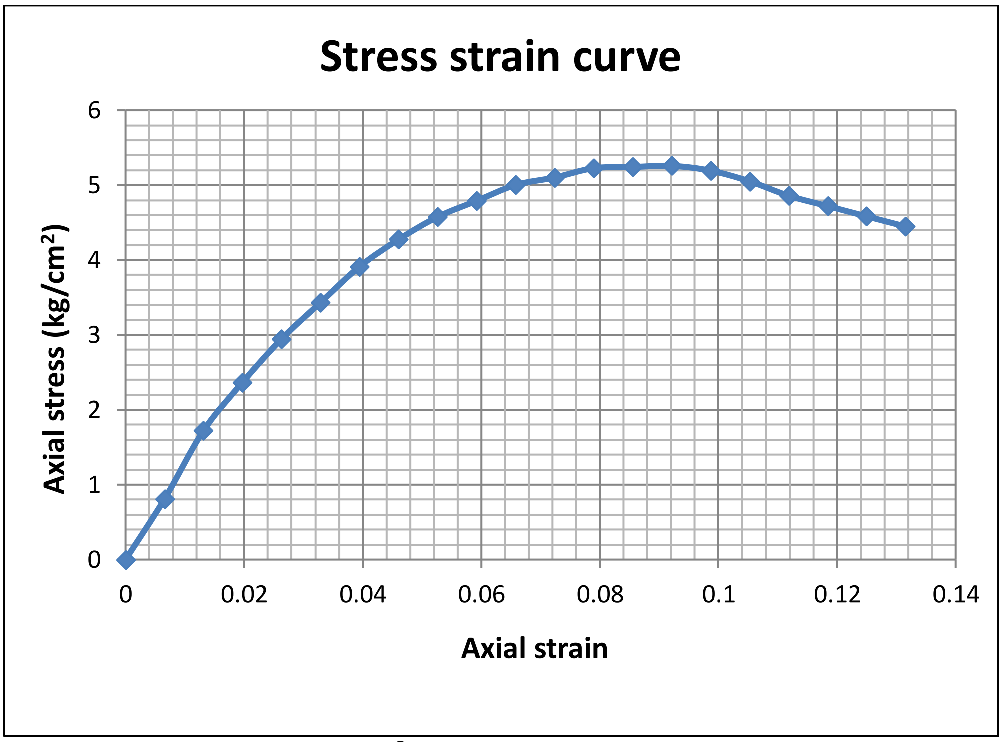


Fig 3.2 Dynamic compaction curve for sample 2

3.3.3 Determination of unconfined compressive strength of soil samples:

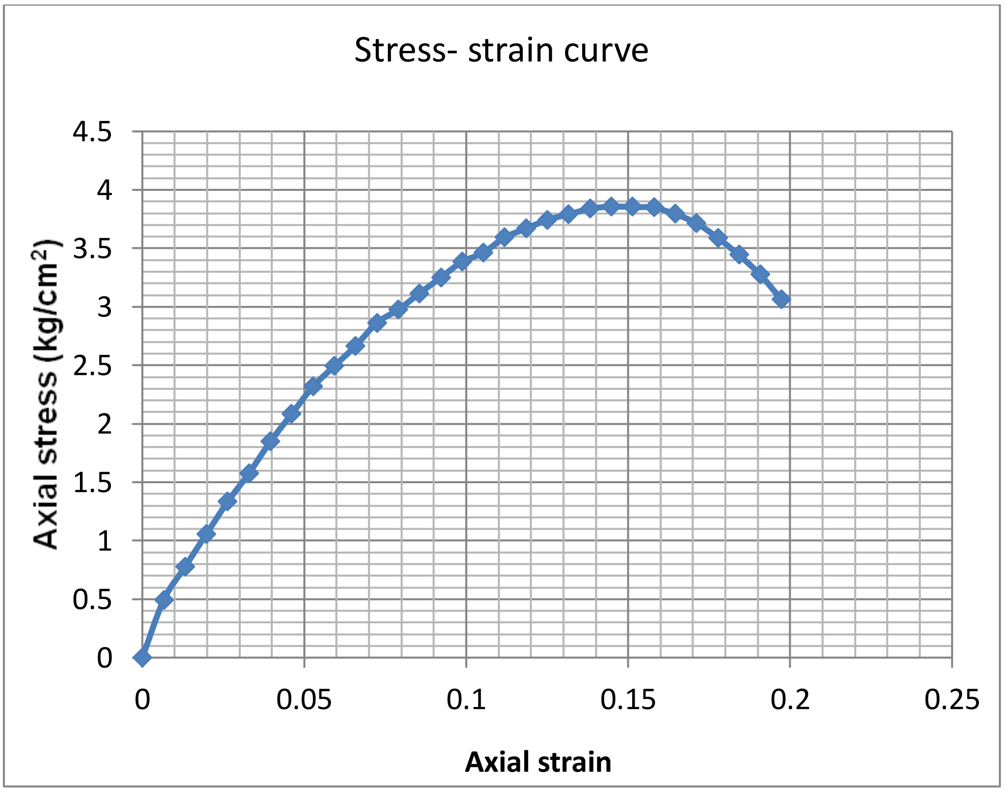
The unconfined compression tests are done on soil sample1 & 2 to determine the unconfined compressive strength on statically and dynamically compacted soil at different dry density and moisture content under different strain rate.

3.3.4. Stress - strain curve for soil sample 1 and 2:



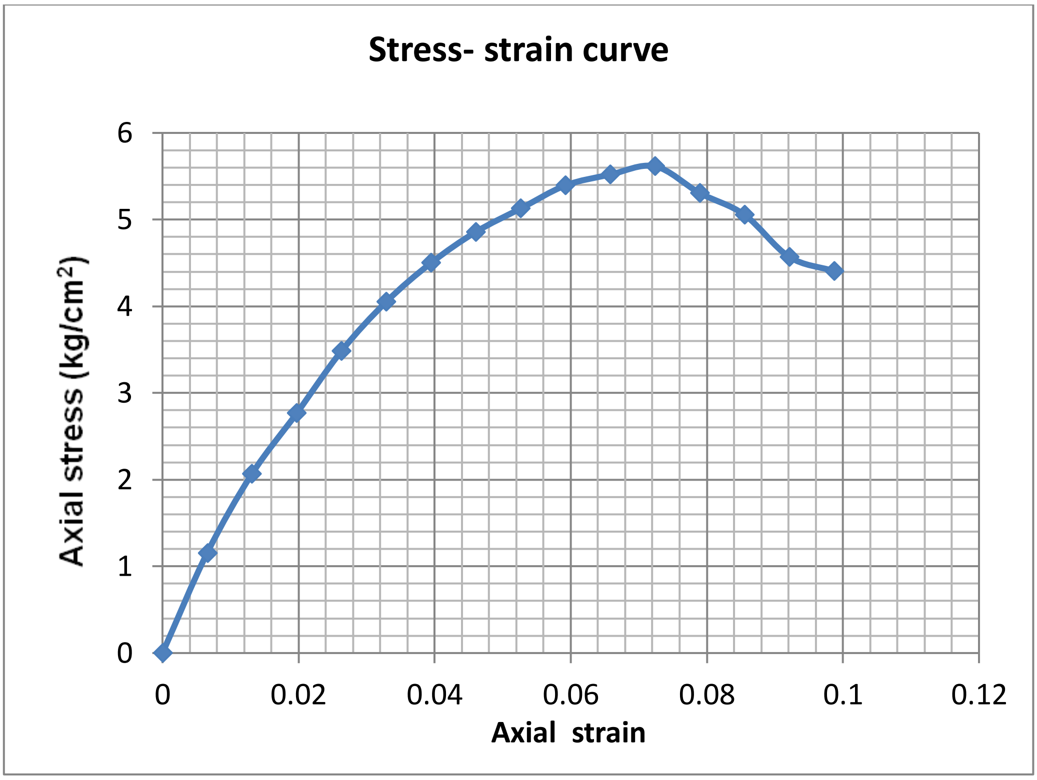
(MDD-16.2 kN/m^3, OMC- 18.67%, @ 1.5mm/min)

Fig.3.3: Stress-strain graph of UCS test for sample 1 (dynamically compacted)

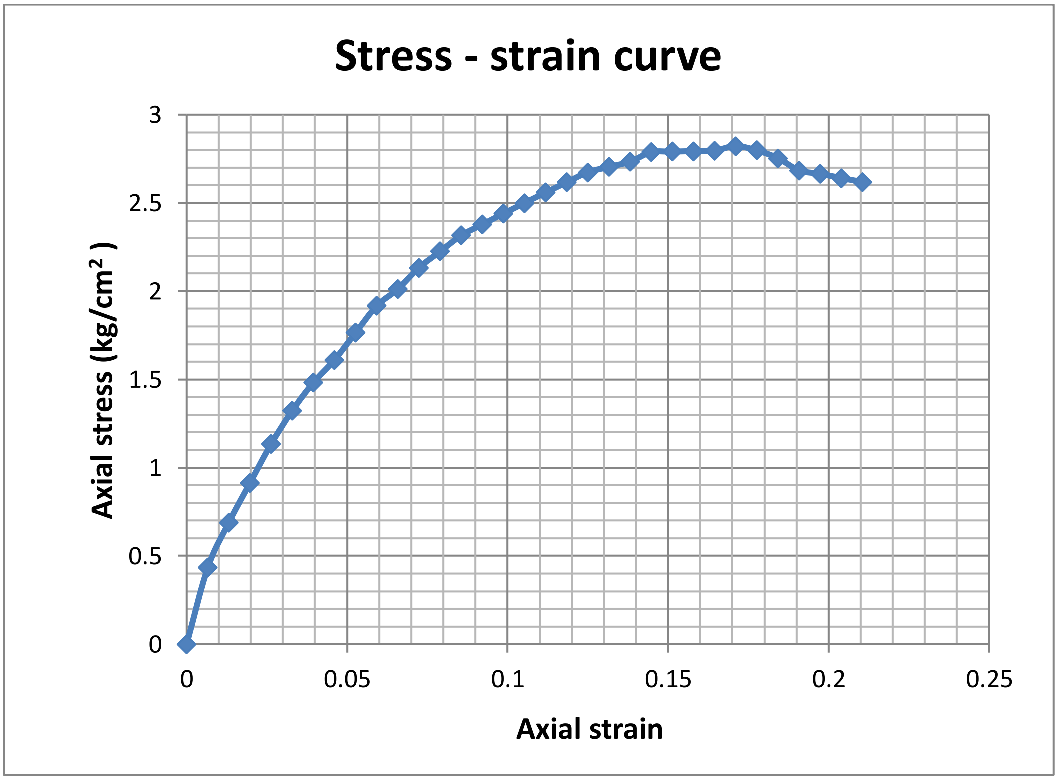


(dry density-17.3 kN/m^3, w.c.-20%, @1.5mm/min)

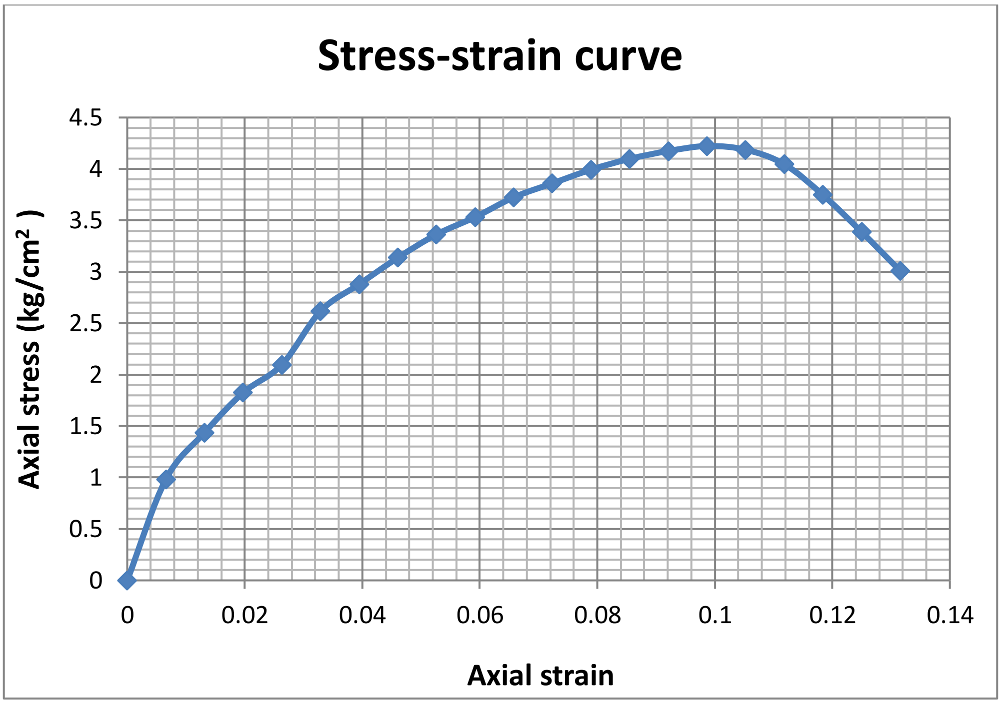
Fig.3.4: Stress-strain graph of UCS test for sample 1 (dynamically compacted)



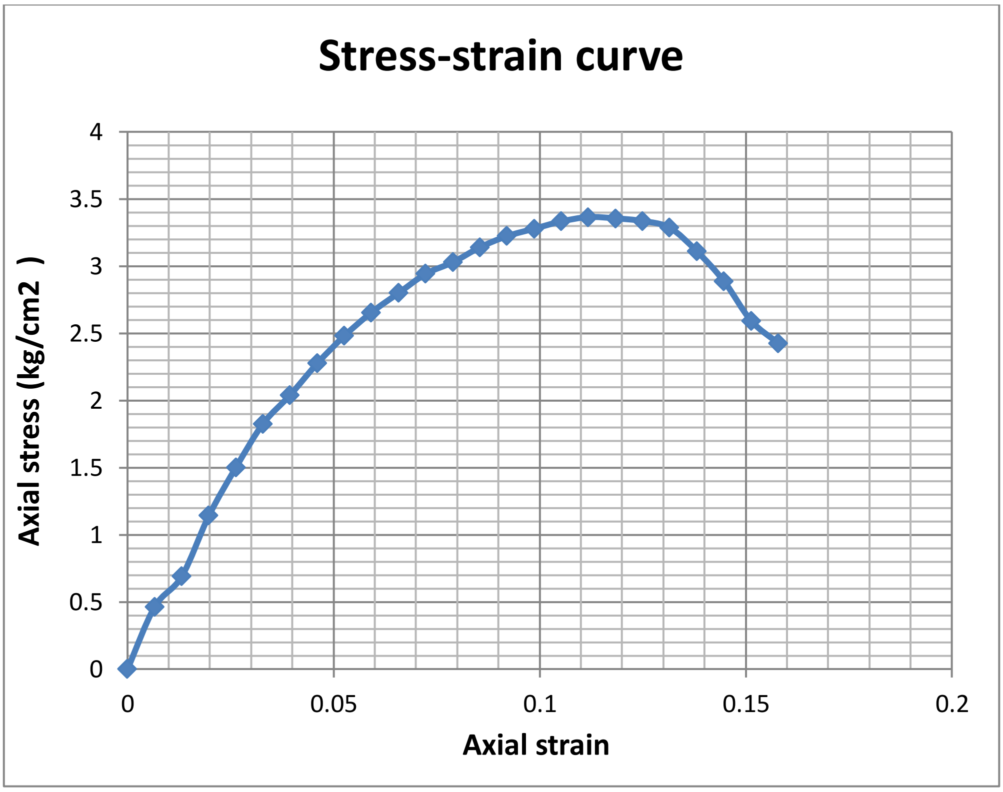
(dry density-18 kN/m^3, w.c.-17.67%, @1.5mm/min)
Fig.3.5: Stress-strain graph of UCS test for sample 1 (dynamically compacted)



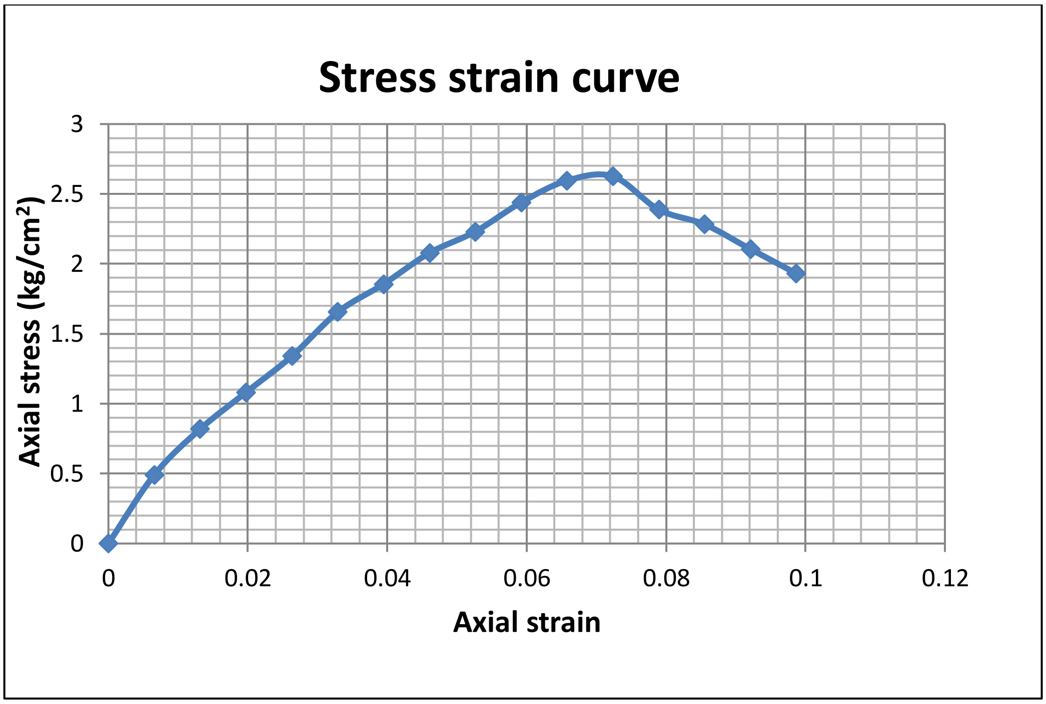
(MDD-16.2 kN/m^3, OMC-18.67%,@ 1.5mm/min)
Fig.3.6: Stress-strain graph of UCS test for sample 1 (statically compacted)



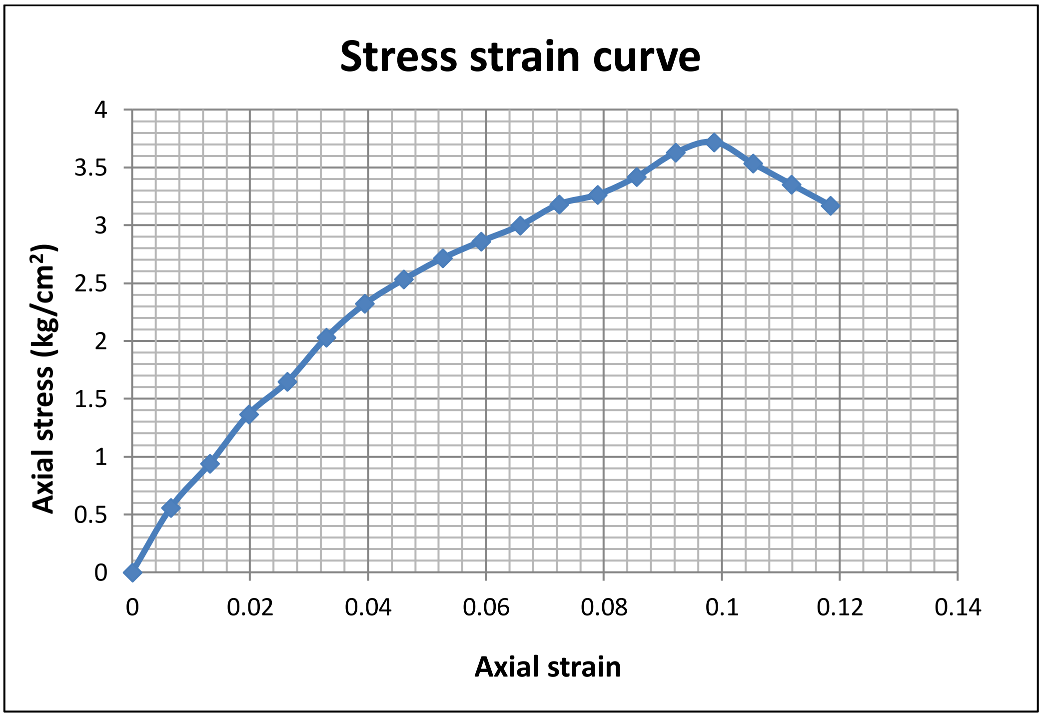
(dry density-17.3 kN/m^3, w.c.-20%,@ 1.5mm/min)
Fig.3.7: Stress-strain graph of UCS test for sample 1 (statically compacted)



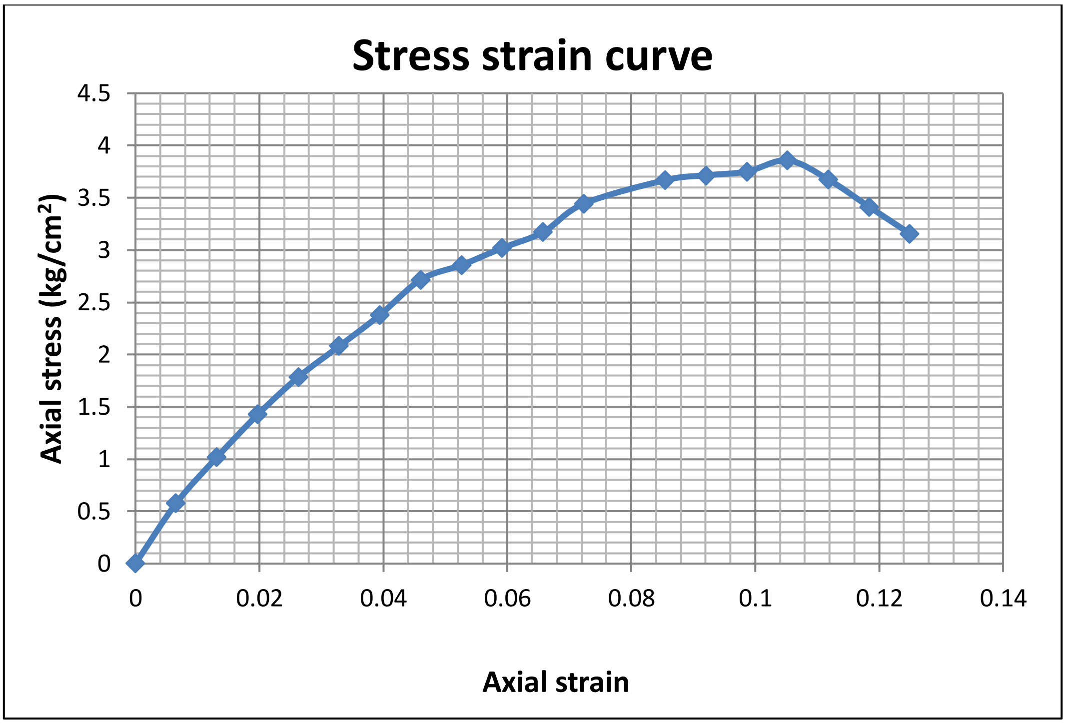
(dry density-18 kN/m^3, w.c.-17.67%,@ 1.5mm/min)
Fig.3.8: Stress-strain graph of UCS test for sample 1 (statically compacted)



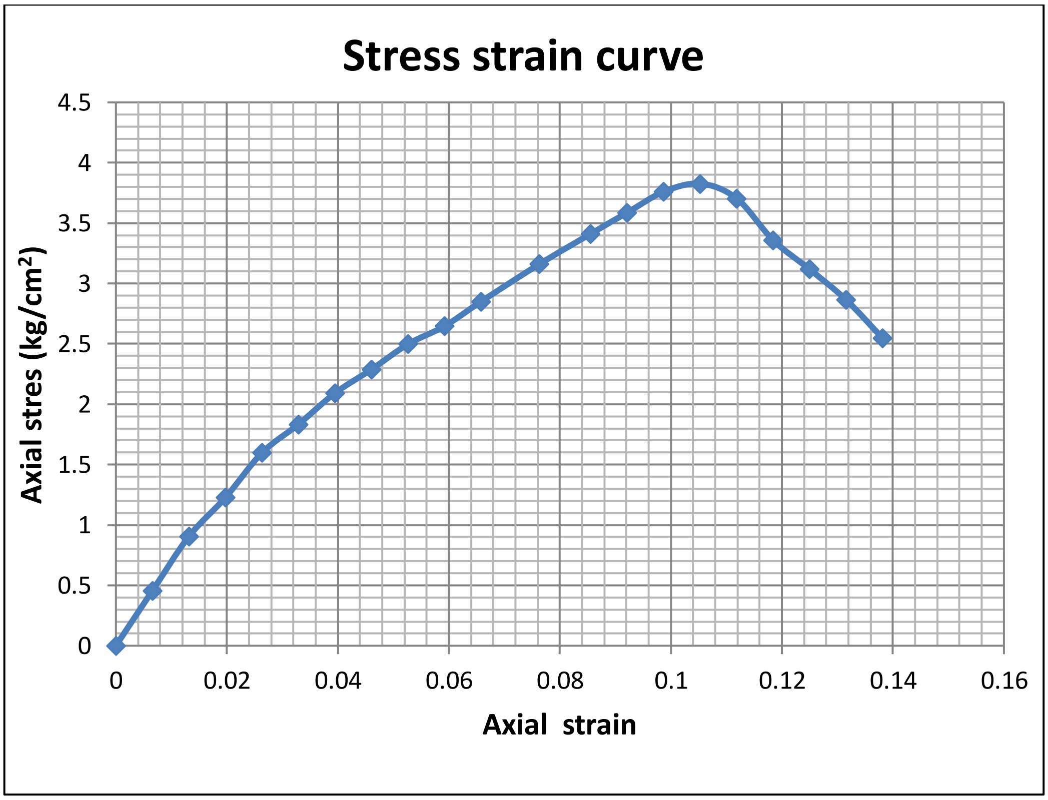
(MDD-16.2 kN/m^3, OMC-18.67% 1.25mm/min)
Fig.3.9: Stress-strain graph of UCS test for sample 1 (dynamically compacted)



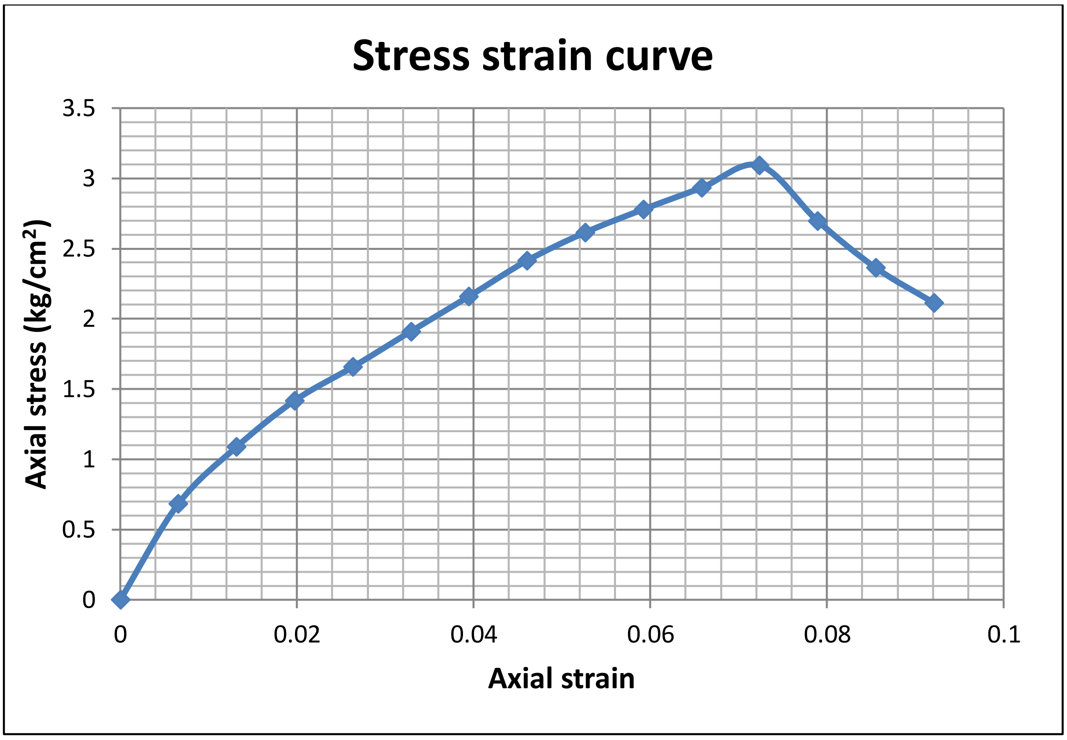
(MDD-16.2 kN/m^3, OMC-18.67% 1.25mm/min)
Fig.3.10: Stress-strain graph of UCS test for sample 1 (statically compacted)



(dry density-17.3 kN/m^3,w.c.-20%, 1.25mm/min)
Fig.3.11: Stress-strain graph of UCS test for sample 1 (dynamically compacted

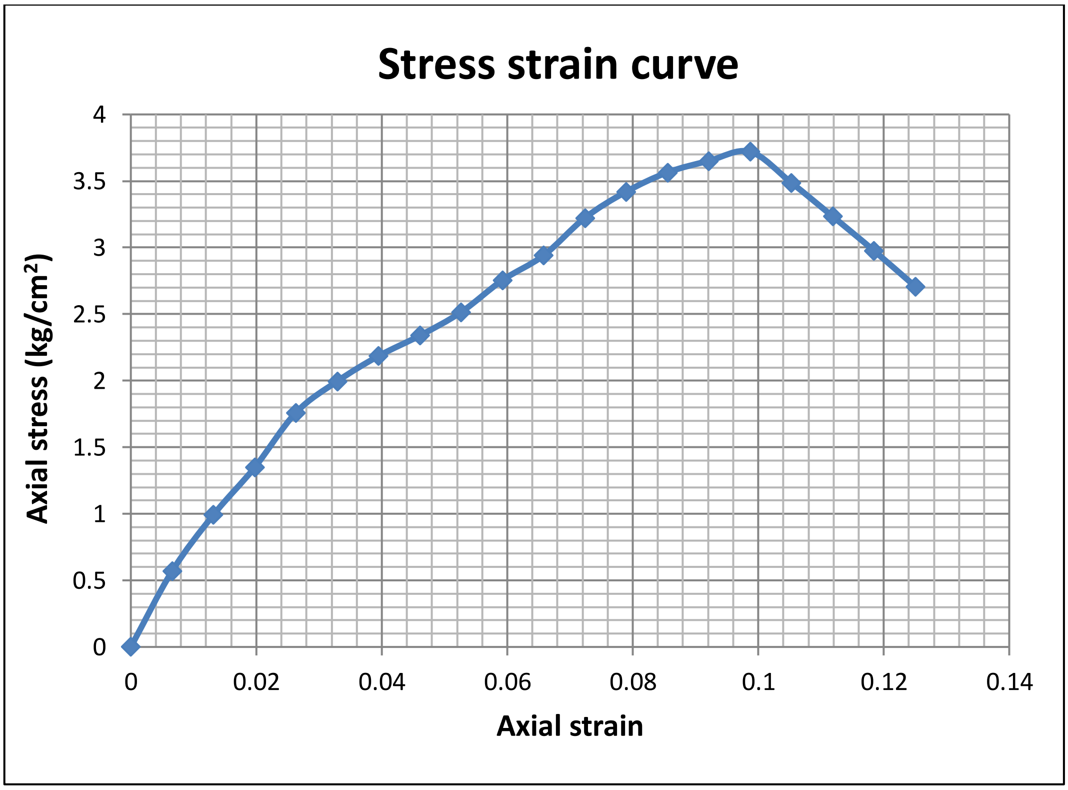


(dry density-17.3 kN/m^3,w.c.-20%, 1.25mm/min)
Fig.3.12: Stress-strain graph of UCS test for sample 1 (statically compacted)



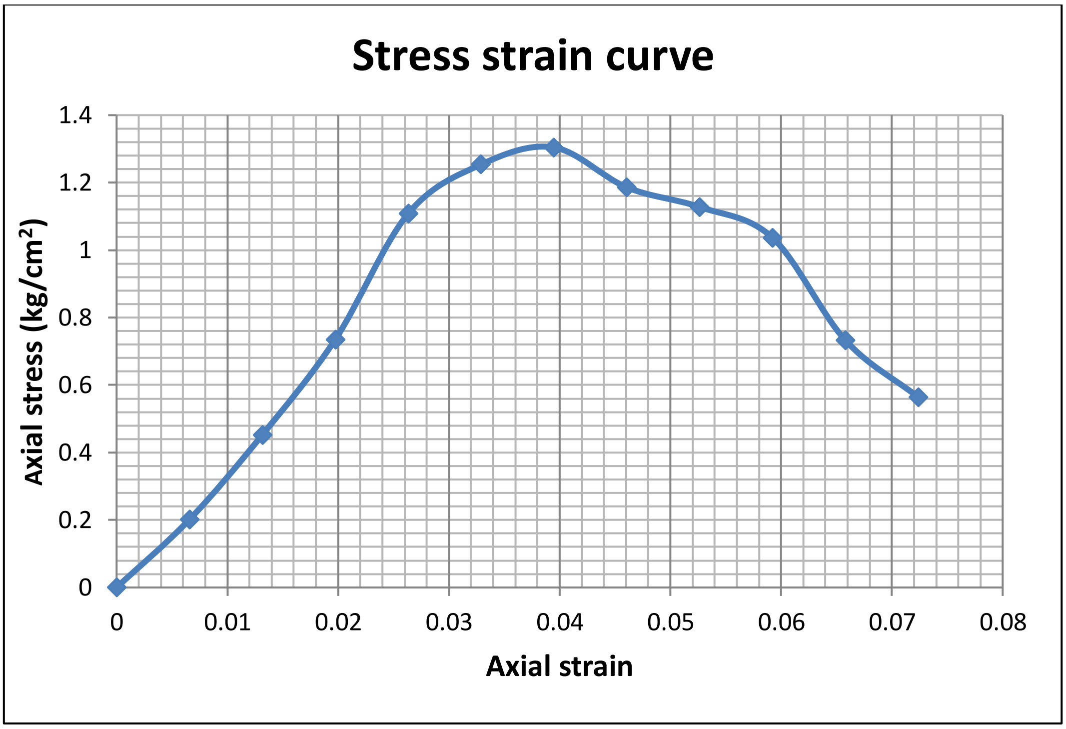
(dry density-18 kN/m^3,w.c.-17.67, 1.25mm/min)

Fig.3.13: Stress-strain graph of UCS test for sample 1 (dynamically compacted)



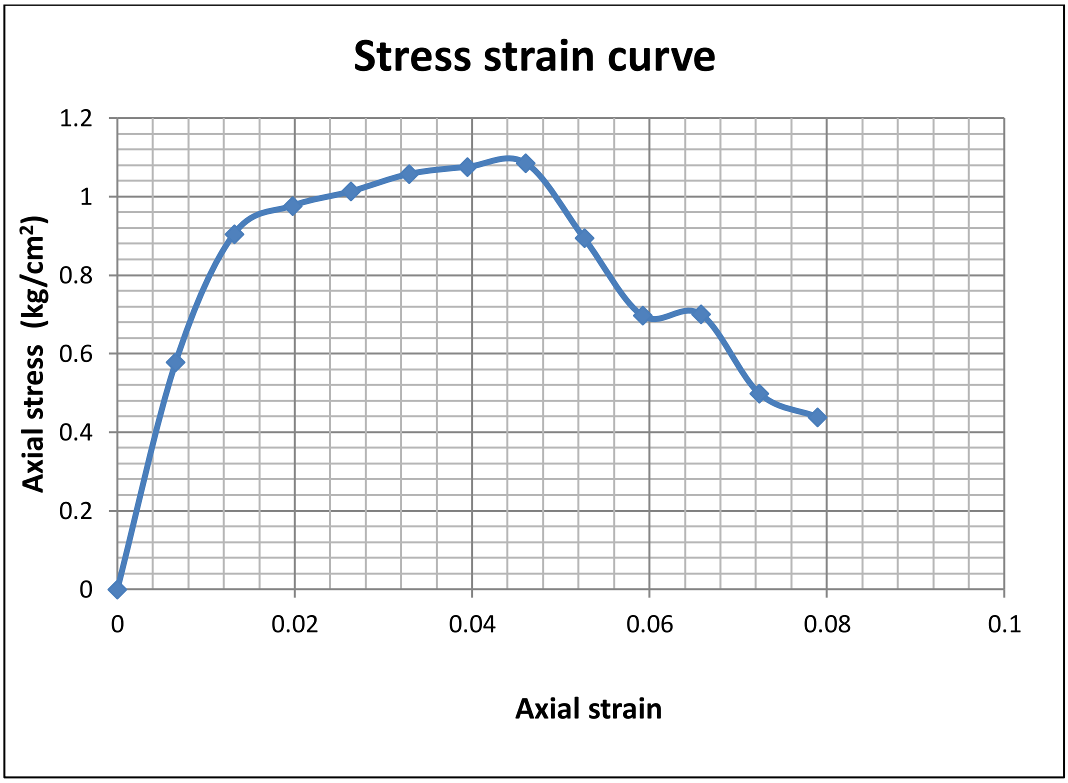
(dry density-18 kN/m^3,w.c.-17.67, @1.25mm/min)

Fig.3.14: Stress-strain graph of UCS test for sample 1 (statically compacted)



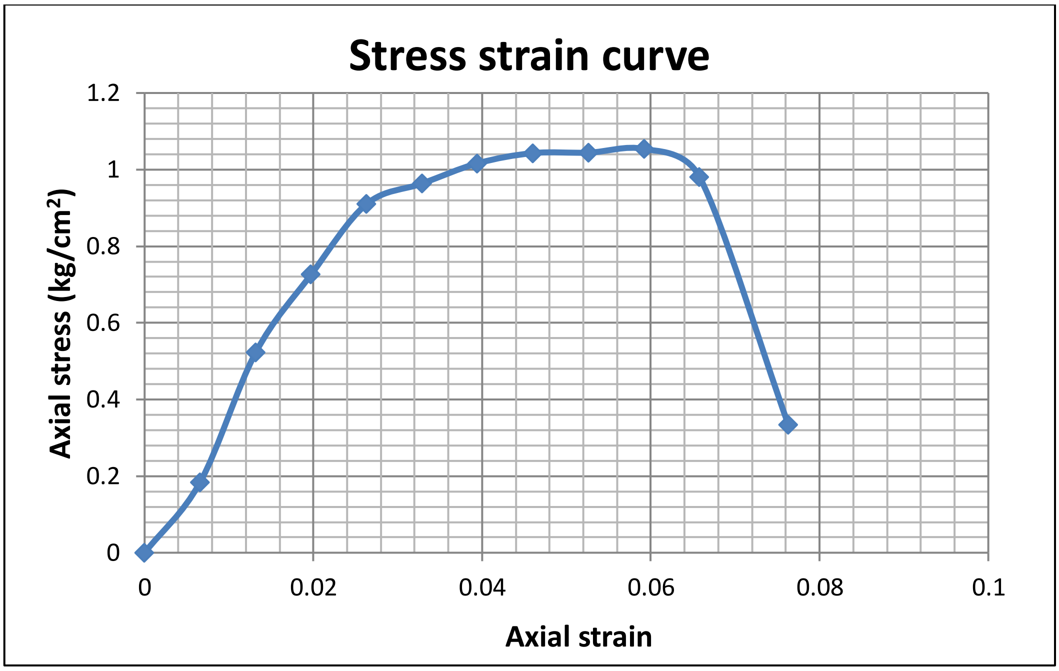
(MDD-16.94 kN/m^3,w.c.-12.48%, @1.5mm/min)

Fig.3.15: Stress-strain graph of UCS test for sample 2 (dynamically compacted)



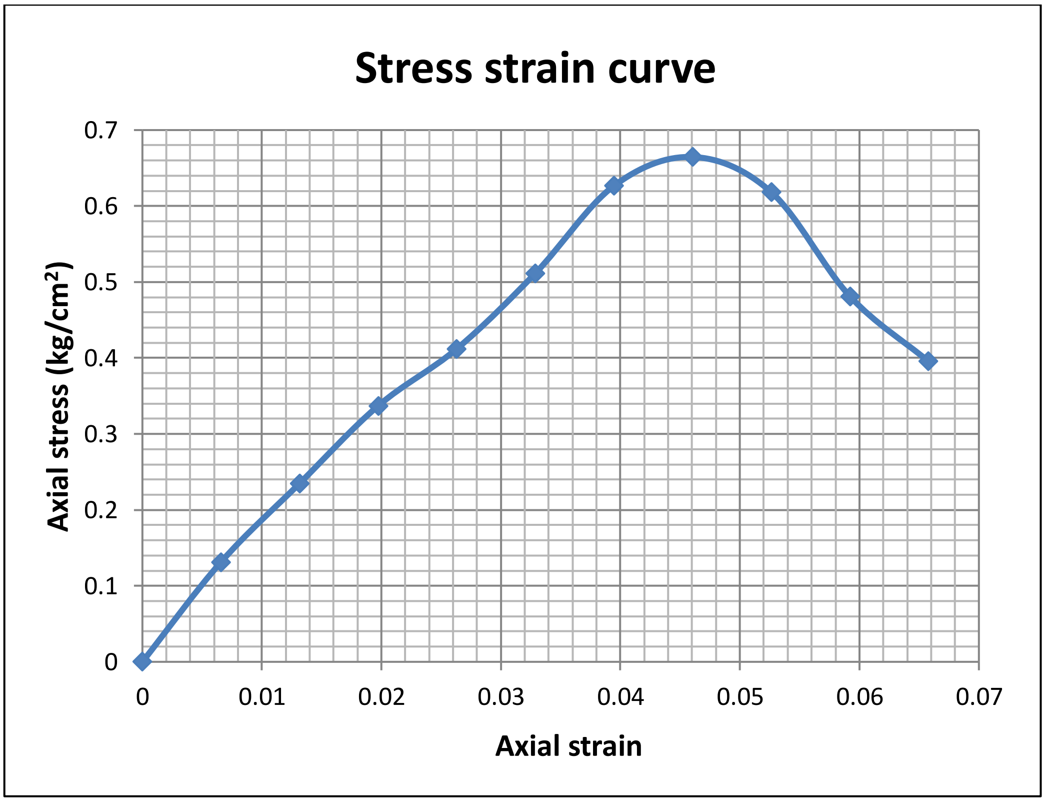
(MDD-16.94 kN/m^3,w.c.-12.48%, @1.25mm/min)

Fig.3.16: Stress-strain graph of UCS test for sample 2 (dynamically compacted)



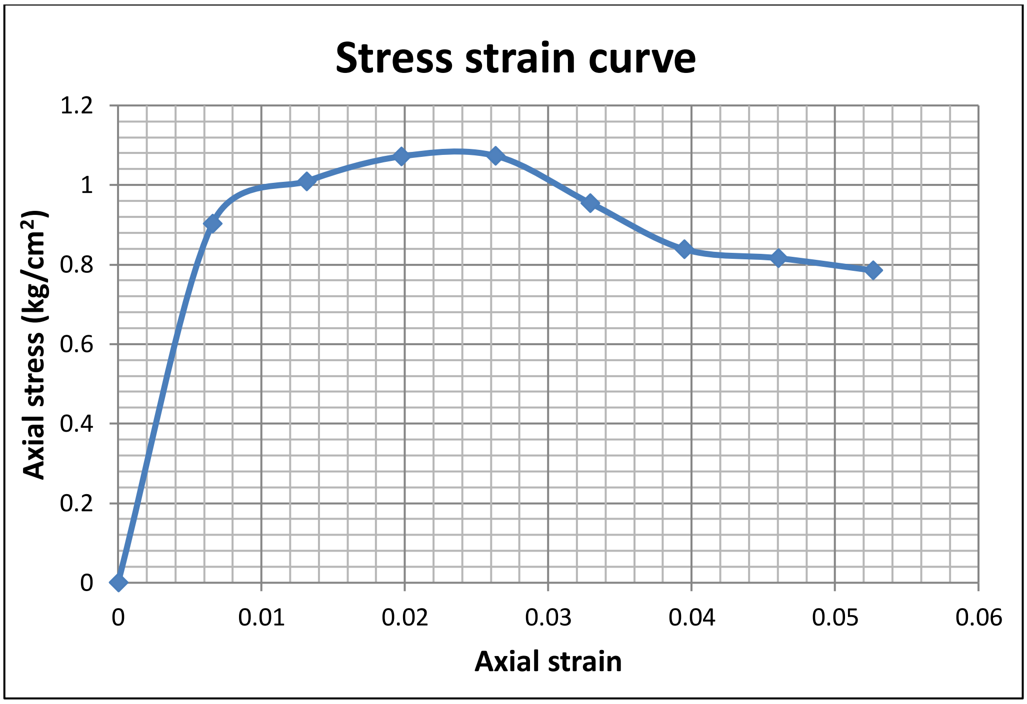
(dry density-18.59 kN/m^3,w.c.-15.29%, @1.5mm/min)

Fig.3.17: Stress-strain graph of UCS test for sample 2 (dynamically compacted)



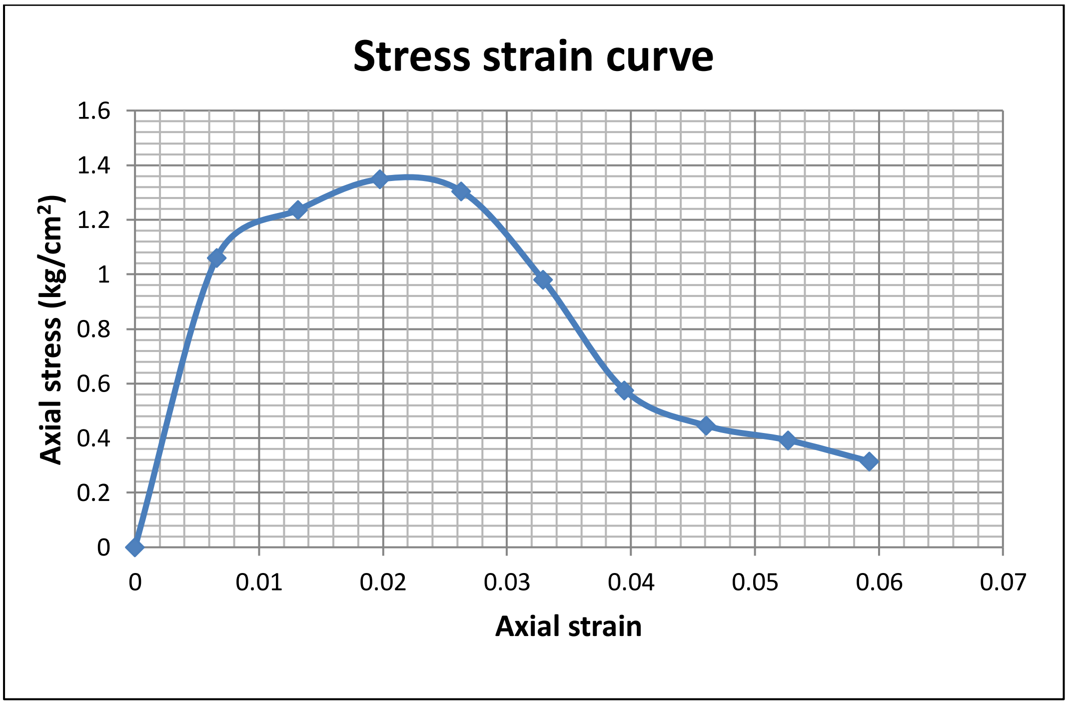
(dry density-18.59 kN/m^3,w.c.-15.29%, @1.25mm/min)

Fig.3.18: Stress-strain graph of UCS test for sample 2 (dynamically compacted)



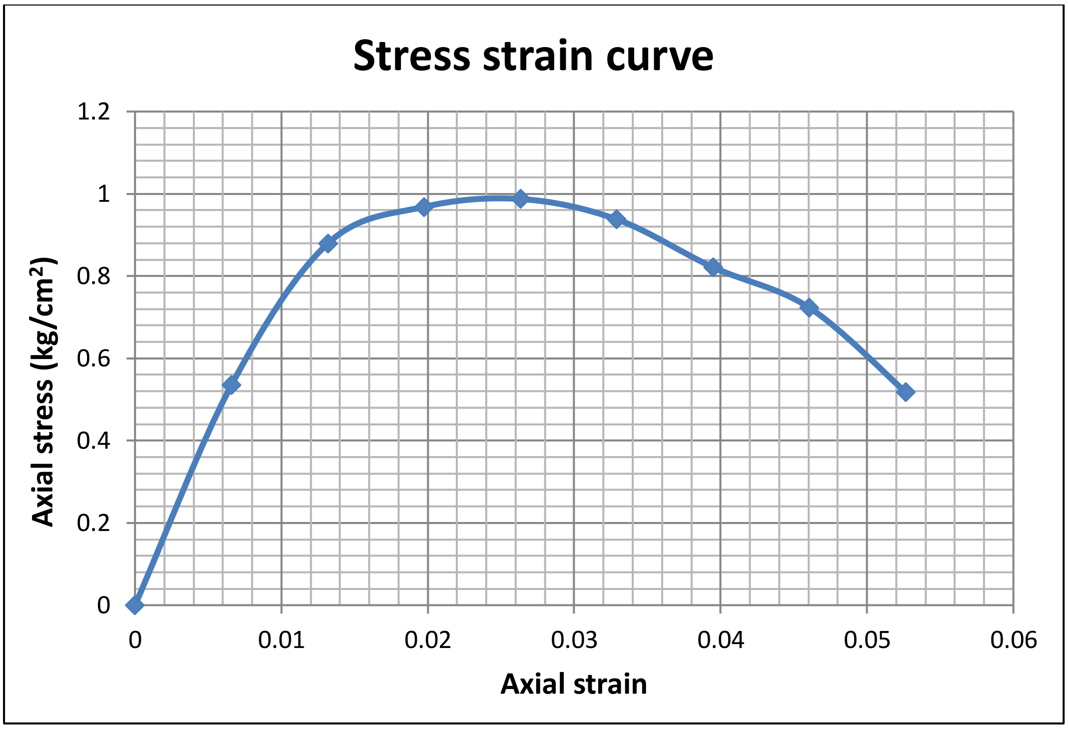
(dry density-16.62 kN/m³,w.c.9.88%, @1.5mm/min)

Fig.3.19: Stress-strain graph of UCS test for sample 2 (dynamically compacted)



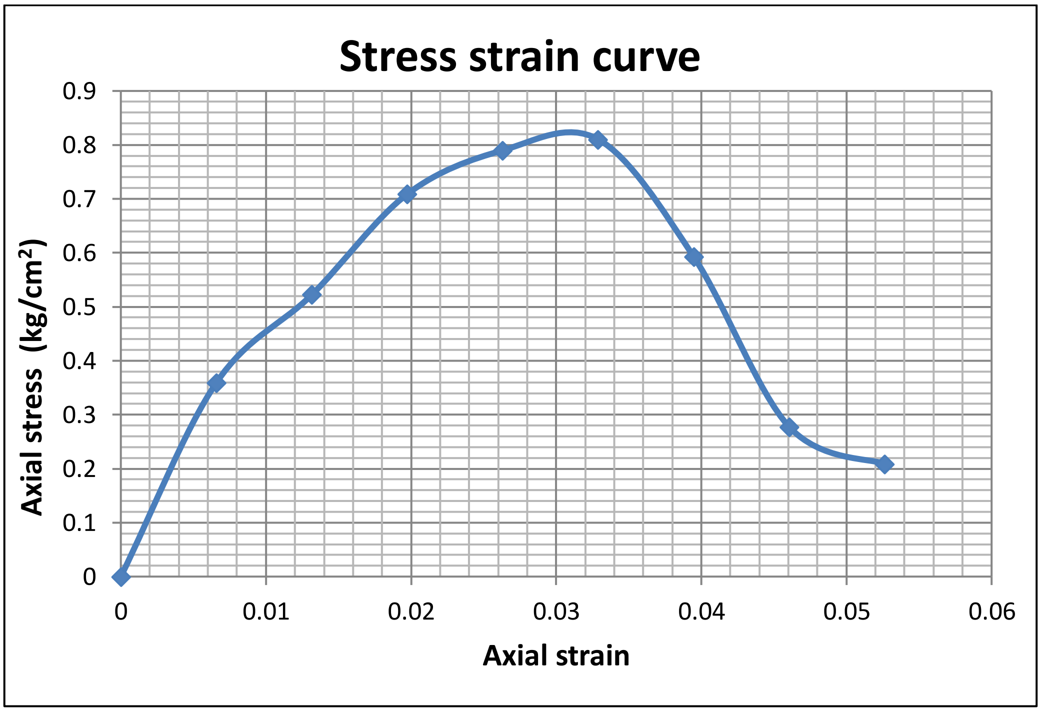
(dry density-16.62 kN/m³,w.c.9.88%, @1.25mm/min)

Fig.3.20: Stress-strain graph of UCS test for sample 2 (dynamically compacted)



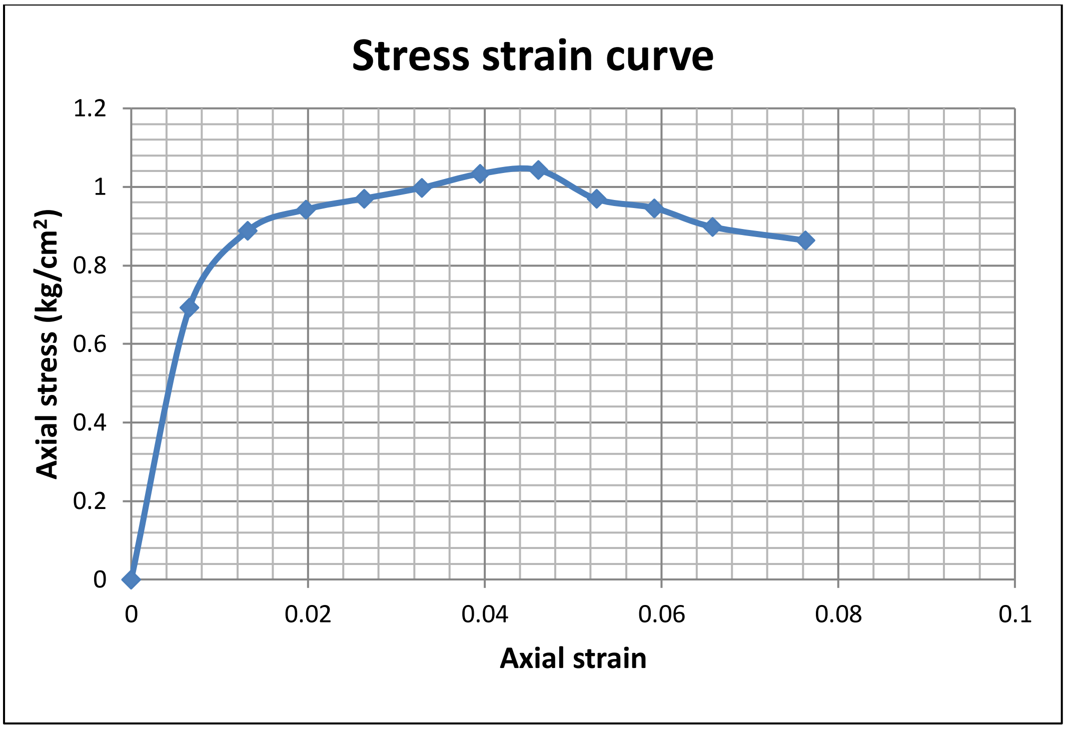
(MDD-16.94 kN/m^3,w.c.-12.48%, @1.5mm/min)

Fig.3.21: Stress-strain graph of UCS test for sample 2 (statically compacted)



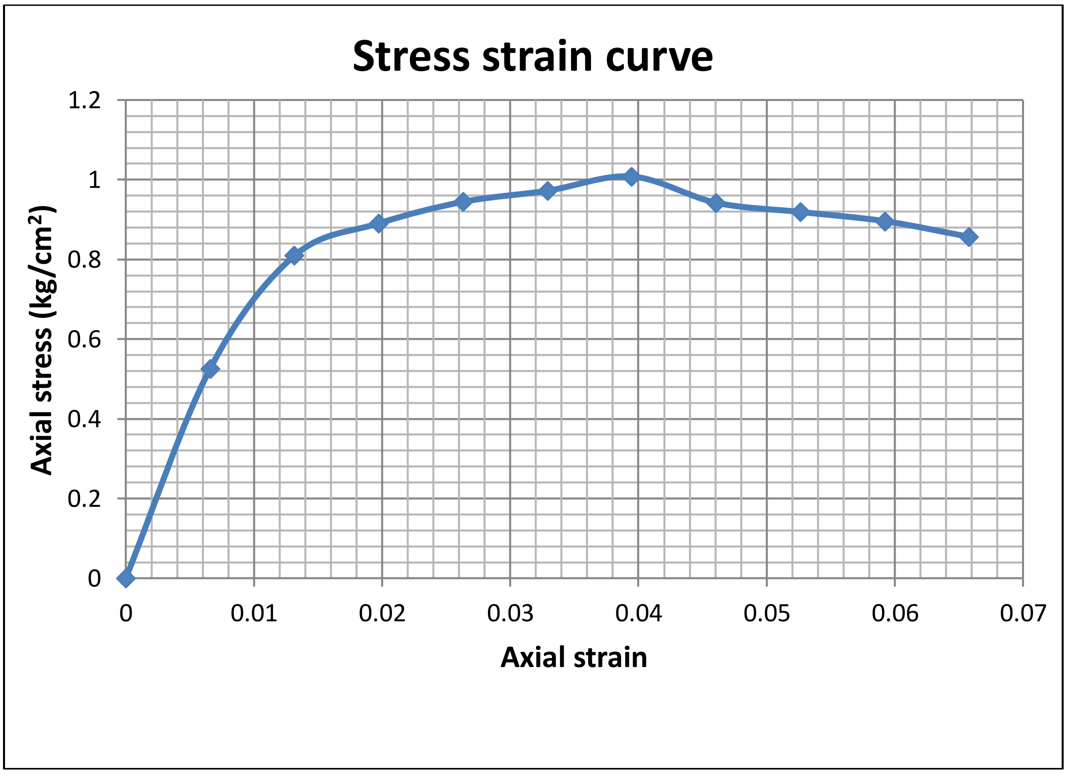
(MDD-16.94 kN/m^3,w.c.-12.48%, @1.25mm/min)

Fig.3.22: Stress-strain graph of UCS test for sample 2 (statically compacted)



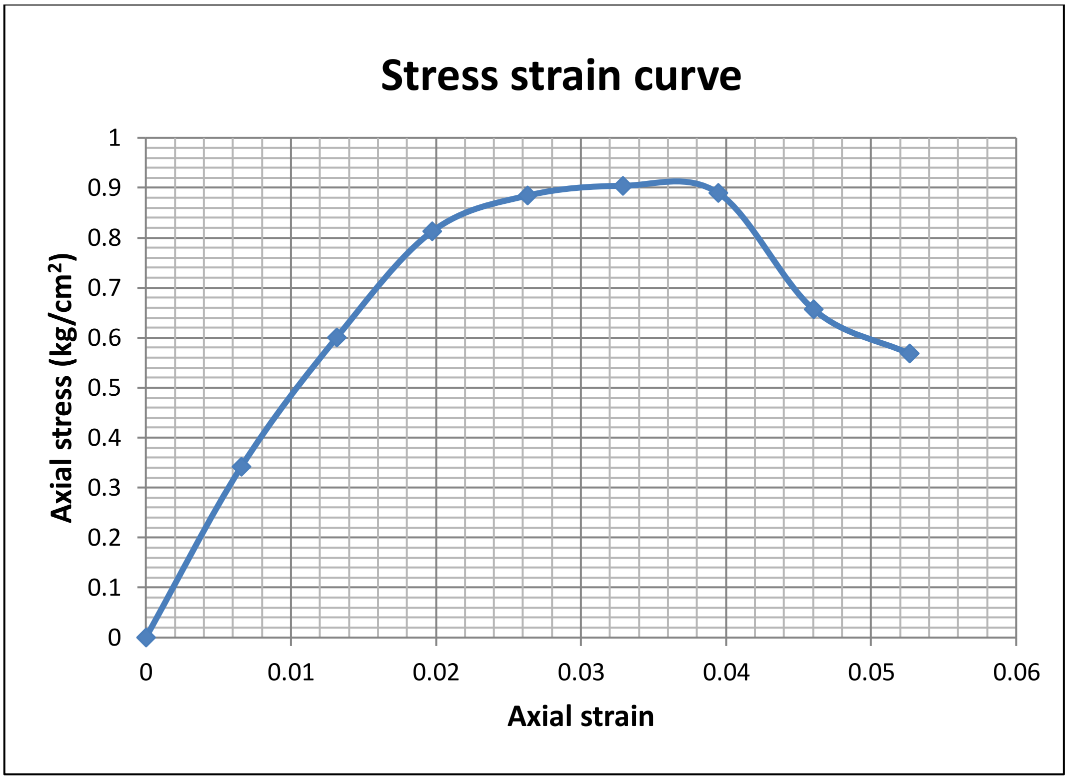
(dry density-18.59 kN/m^3,w.c.-15.29%, @1.5mm/min)

Fig.3.23: Stress-strain graph of UCS test for sample 2 (statically compacted)



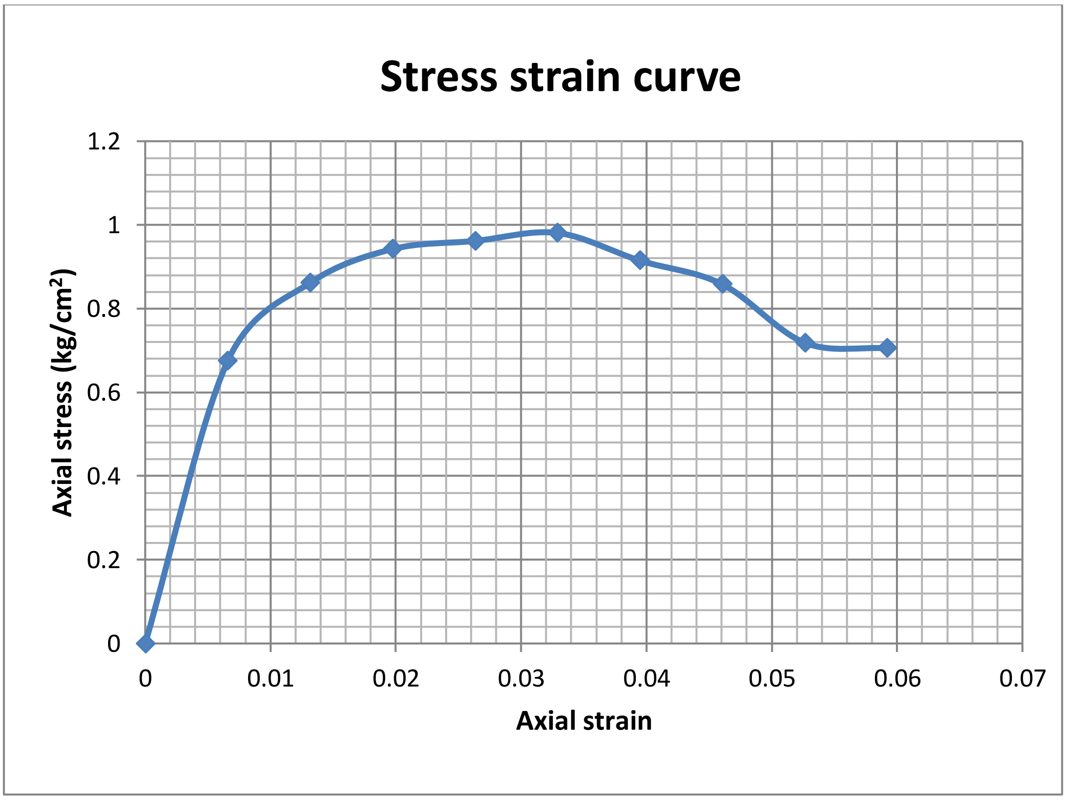
(dry density-18.59 kN/m^3,w.c.-15.29 %, @1.25mm/min)

Fig.3.24: Stress-strain graph of UCS test for sample 2 (statically compacted)



(dry density-9.88 kN/m³,w.c.-16.624 %, @1.5mm/min)

Fig.3.25: Stress-strain graph of UCS test for sample 2 (statically compacted)



(dry density-9.88 kN/m³,w.c.-16.624 %, @1.25mm/min)

Fig.3.26: Stress-strain graph of UCS test for sample 2 (statically compacted)

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

1. Soil sample 1(Deppor beel):

Table 3.5 Unconfined compressive strength of soil sample 1 under strain rate 1.25mm/min & 1.5 mm/min

Strain rate (mm/min)	**ρ_d-16.2 kN/m^3, w(%)-18.67 (OMC & MDD)**	
	UCS (kPA)	
	Static compaction	**Dynamic compaction**
1.25	364.81	257.91
1.5	276.74	515.63

Strain rate (mm/min)	**ρ_d-17.3 kN/m^3, w(%)-20 (ZAVL)**	
	UCS (kPA)	
	Static compaction	**Dynamic compaction**
1.25	375.59	378.54
1.5	414.13	378.34

Strain rate (mm/min)	**ρ_d- 18 kN/m^3, w(%)- 16.67 (ZAVL)**	
	UCS (kPA)	
	Static compaction	**Dynamic compaction**
1.25	384.81	304
1.5	329.99	550.64

2. Soil sample 2 (Barpeta):

Table 3.6 Unconfined compressive strength of soil sample 2 under strain rate 1.25mm/min & 1.5 mm/min

Strain rate (mm/min)	ρ_d- 16.937kN/m^3, w(%)- 12.48 (OMC &MDD)	
	UCS (kPA)	
	Static compaction	Dynamic compaction
1.25	81.34	106.402
1.5	96.79	127.878

Strain rate (mm/min)	ρ_d- 18.241kN/m^3, w(%)- 15.29 (wet optimum)	
	UCS (kPA)	
	Static compaction	Dynamic compaction
1.25	98.85	64.233
1.5	102.968	103.362

Strain rate (mm/min)	ρ_d- 16.624kN/m^3, w(%)- 9.88 (dry optimum)	
	UCS (kPA)	
	Static compaction	Dynamic compaction
1.25	96.2	132.291
1.5	88.65	104.931

CHAPTER 4

ANALYSIS OF TEST RESULTS

4.1 Introduction:

The shear strength of the compacted soils depends upon the soil type, the moulded water content, drainage condition, the method of compaction and strain rate. In general, at a given water content, the shear strength of the soil increases with an increases in the compactive effort till a critical degree of saturation is reached. With further increase in the compactive effort, the shear strength decreases.

In this study the unconfined compressive strength value for different dry density and moisture content by different compaction method under different strain rate was examine .The study is divided into two parts. First part referred as phase 1, in this part the unconfined compressive strength of soil sample 1 is tested under strain rate 1.25mm/min & 1.5mm/min and the soil sample was compacted by two different mode of compaction (static & dynamic), one sample is compacted at OMC and MDD and other two are at dry density corresponding to zero air void line (ZAVL). The second part of the study or phase 2, studied the effect on unconfined compressive strength of soil sample 2 compacted at OMC ,wet side of the optimum & dry side of the optimum under strain rate 1.25 mm/min & 1.5 mm/min .The soil sample was compacted statically and dynamically. A comparative study was carried out on unconfined compressive strength, compactive effort, strain rate, dry density and moisture content.

4.2 Comparative Analysis of UCS of soil sample 1:

The experimental results showing the variation of UCS value at different dry density and moisture content under static and dynamic compaction test under two different strain rate (1.5 mm/min & 1.25 mm/min). The effects of loading rate on UCS values were investigated. Soil sample was moulded at different moisture content and dry density. A relationship was established between unconfined compressive strength (UCS) and moisture content, variation of strength of CI soil was study. In similar manner the variation of dry density and unconfined strength also studied. Behavior of compactive effort on UCS was investigated by observing the results.

4.2.1: Comparative analysis: Unconfined strength and dry density under static compaction at strain rate 1.25 mm/min & 1.5 mm/min:

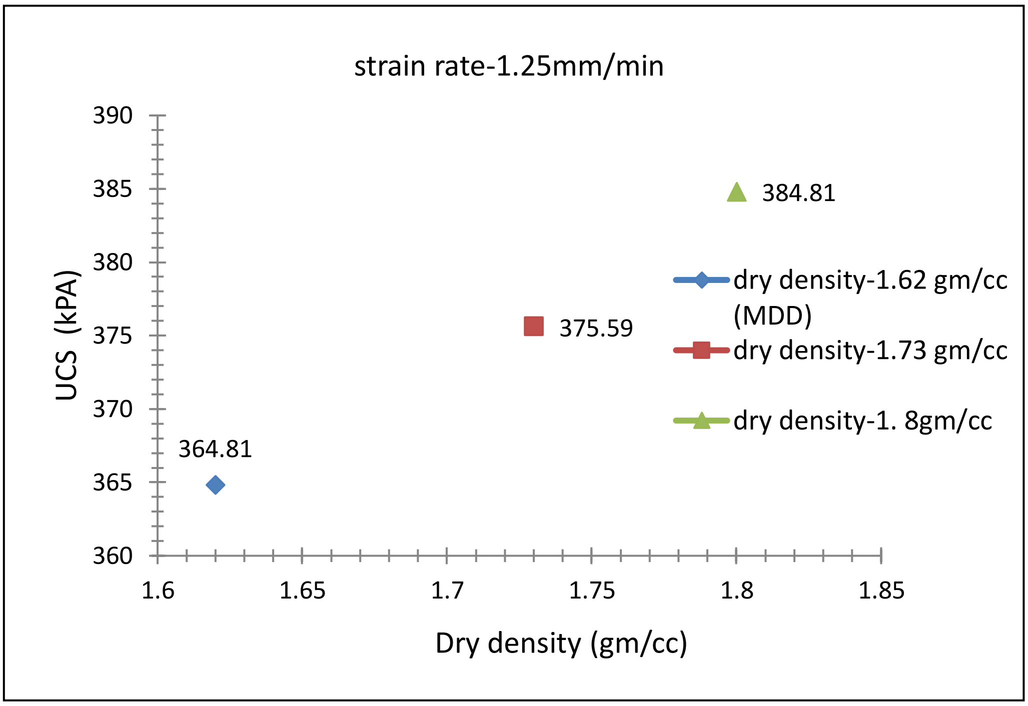


Fig 4.1: Relationship between dry density and unconfined compressive strength at strain rate 1.25 mm/min (static compaction)- soil sample 1

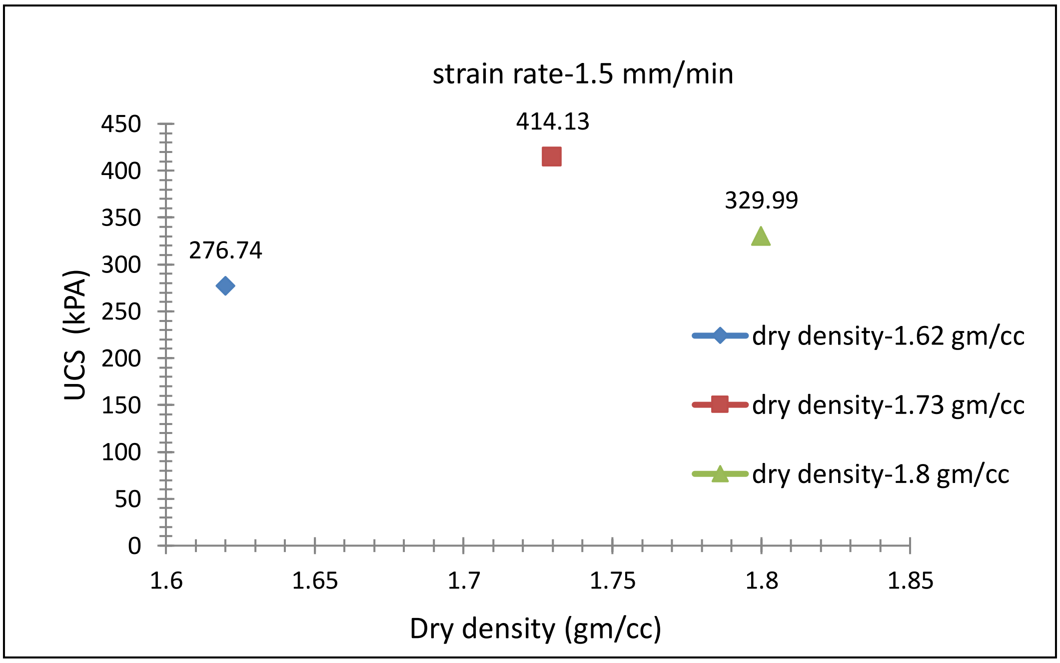


Fig 4.2: Relationship between dry density and unconfined compressive strength at strain rate 1.5 mm/min (static compaction)-soil sample 1

4.2.2: Comparative analysis: Unconfined strength and moisture content under static compaction at strain rate 1.25 mm/min & 1.5 mm/min:

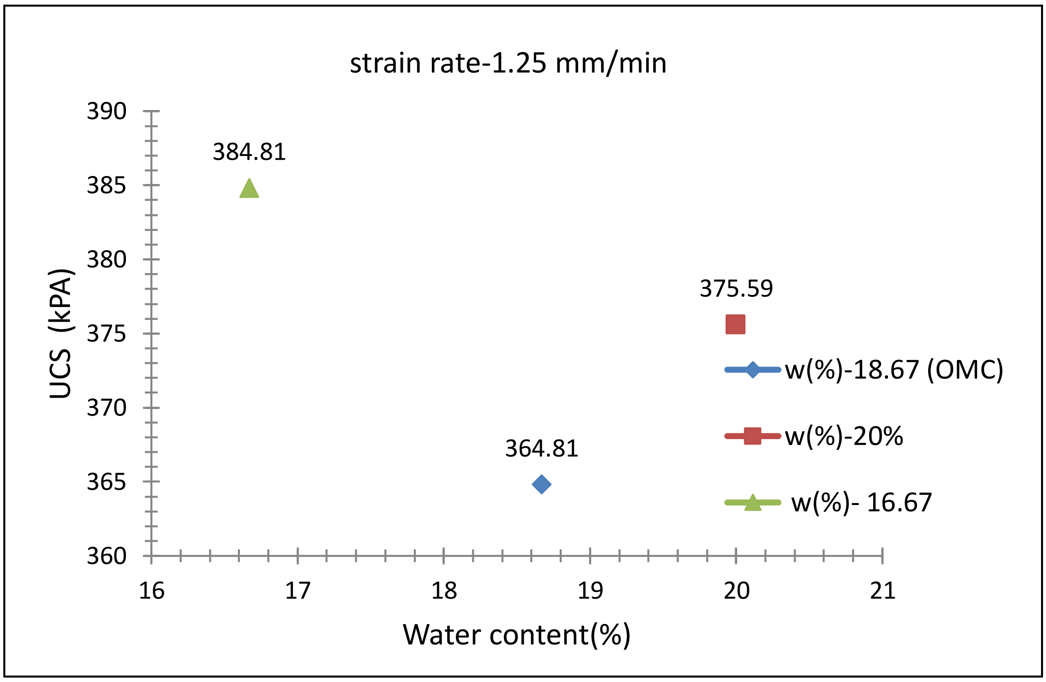


Fig 4.3: Relationship between moisture and unconfined compressive strength at strain rate 1.25 mm/min (static compaction)-soil sample 1

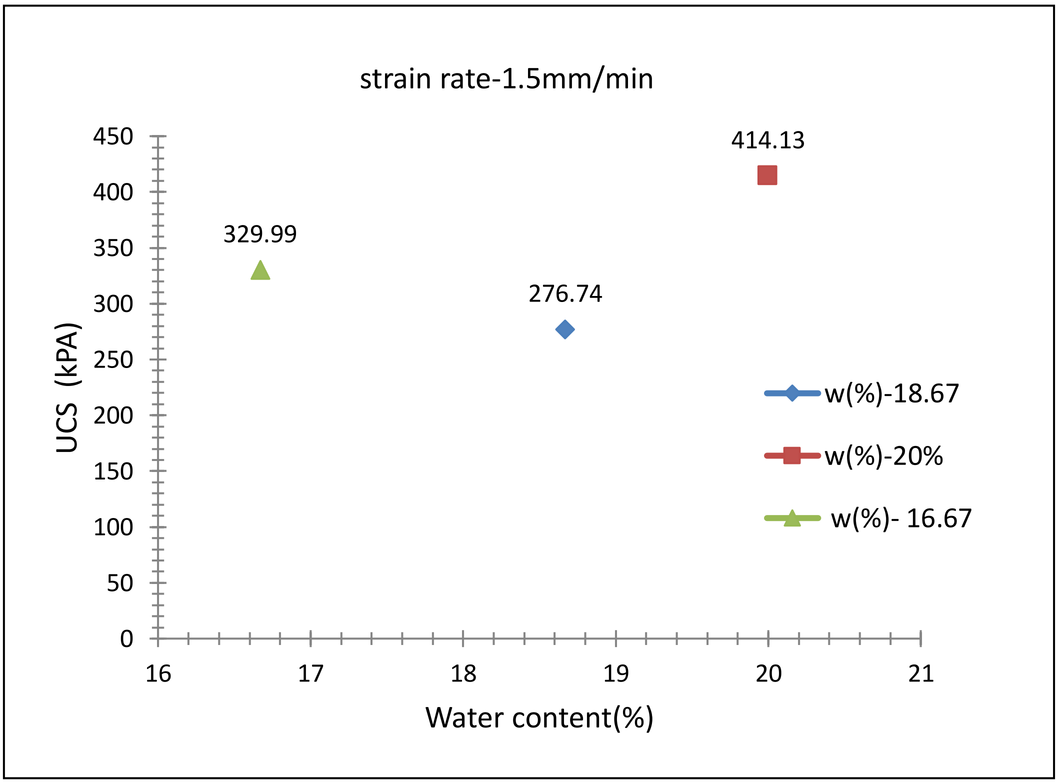


Fig 4.4: Relationship between moisture and unconfined compressive strength at strain rate 1.5 mm/min (static compaction)-soil sample 1

4.2.3: Comparative analysis: Unconfined strength and dry density under dynamic compaction at strain rate 1.25 mm/min & 1.5 mm/min:

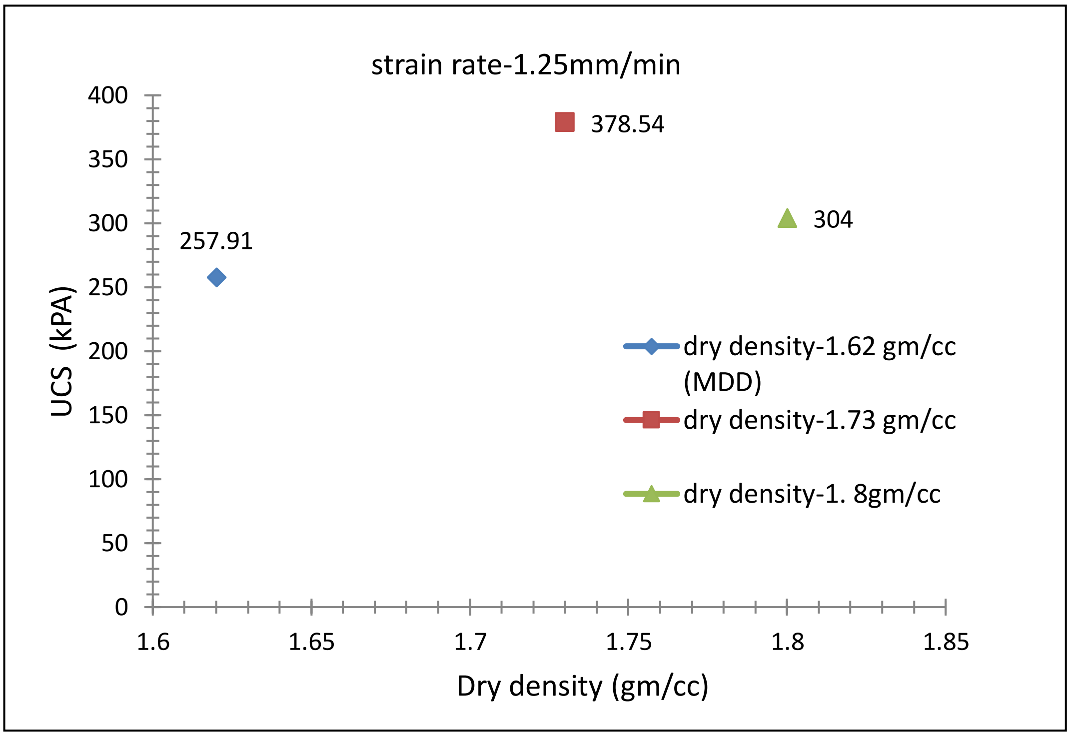


Fig 4.5: Relationship between dry density and unconfined compressive strength at strain rate 1.25 mm/min (dynamic compaction)-soil sample 1

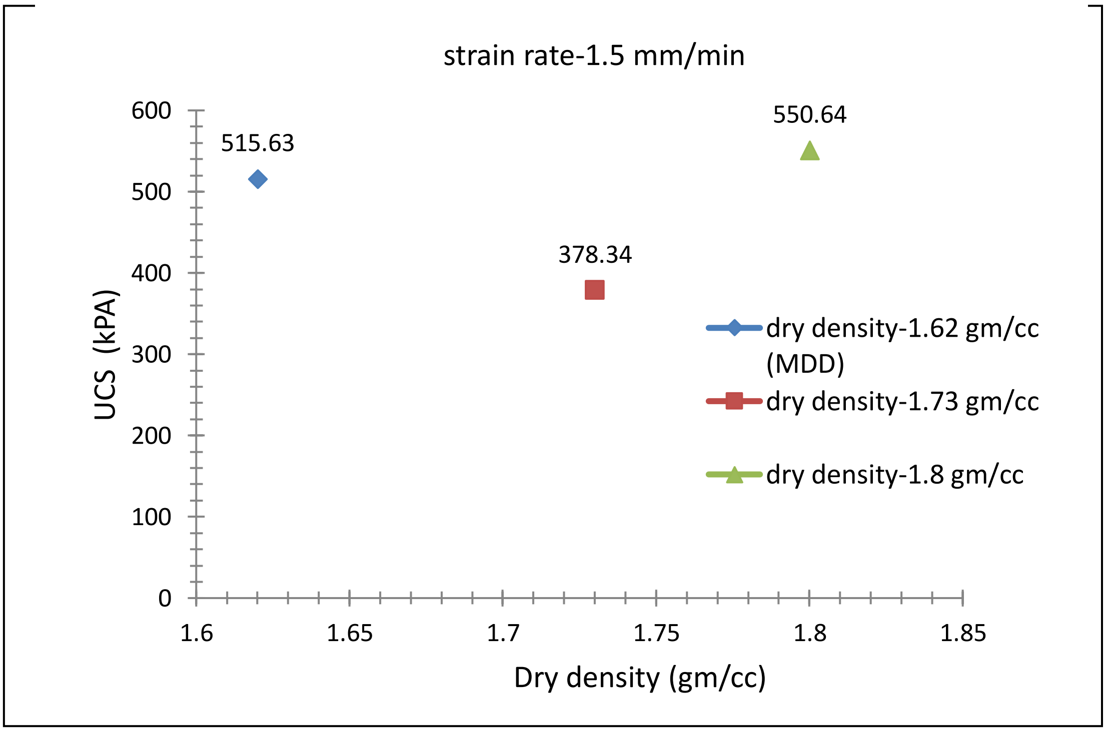


Fig 4.6: Relationship between dry density and unconfined compressive strength at strain rate 1.5 mm/min (dynamic compaction)-soil sample 1

4.2.4: Comparative analysis: Unconfined strength and moisture content under dynamic compaction at strain rate 1.25 mm/min & 1.5 mm/min:

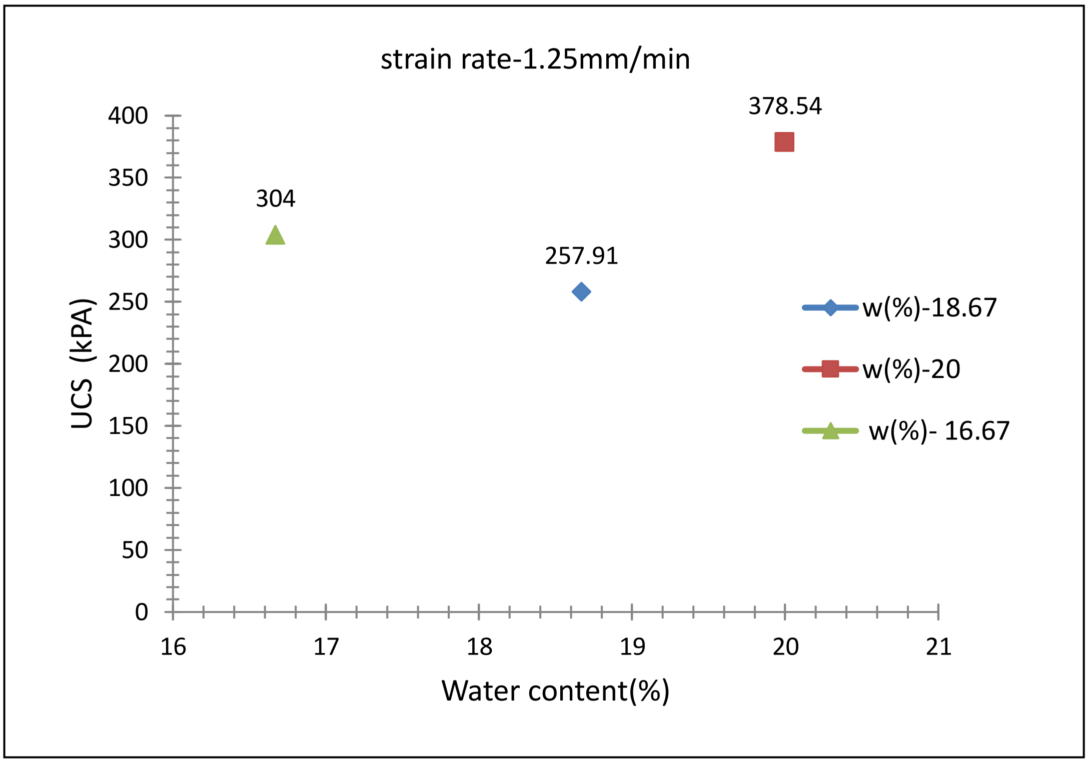


Fig 4.7: Relationship between moisture and unconfined compressive strength at strain rate 1.25 mm/min (dynamic compaction)-soil sample 1

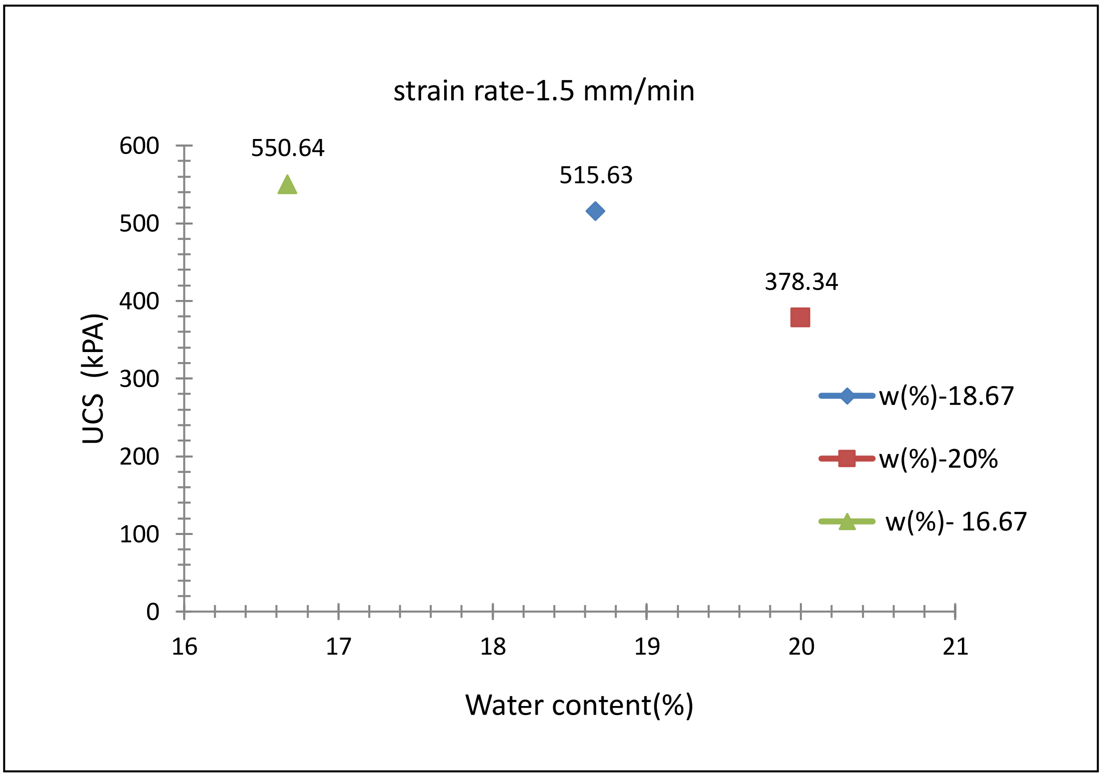


Fig 4.8: Relationship between moisture and unconfined compressive strength at strain rate 1.5 mm/min (dynamic compaction)-soil sample 1

Figure 4.1 shows the relationship between unconfined compressive strength and dry density at strain rate 1.25 mm/min under static compaction. As dry density increases the UCS value increases under slow rate of loading under static compaction. Howevere, from Fig 4.2 as the rate of loading increases the maximum UCS value obtained dry density just above the MDD. Figure 4.3 shows the relationship between moisture content and dry density, from the figure it can be seen that at lower water content which is below OMC under slow transient loading static compaction give higher UCS value. From the figure 4.1 & 4.2, increasing dry density and decreasing water content under static compaction at slow transient loading gives maximum UCS value. From Fig 4.3 it was observed that at slower loading rate the maximum strength value occurred moisture content less than the optimum. A study of the aforementioned figure, it can be seen that under static compaction increasing strain rate and moisture content increases strength of the soil. It is due to at higher water (i.e above OMC) the clay particles exhibit dispersed structure that’s why static compaction govern the shear strength of soil. On the other hand as the water content decreases Maximum dry unit weight increases, dynamic compaction gives higher UCS value than static compaction.

By observation of Figure 4.5 & 4.6 it can be seen that under dynamic compaction increasing dry density and loading rate increases significant amount of strength of CI soil. However, from Fig 4.7 & 4.8 moisture content plays a significant role in unconfined strength of soil. From the aforementioned figure, it can be seen that the strength of the test specimen under fast transient loading at lower moisture content exceed by more than 45 percent specimen tested under slow transient loading at higher moisture content under same compactive effort. Theoretically the strength should continue to rise as the moisture content decreased. However, there was a tendency for a reduction in this "peaked" condition as the rate of strain increased. There are two possible reasons for the aforementioned; (a) the condition is the result of the inherent characteristics of the test i.e. at low moisture contents the specimens fail by crumbling rather than shear, due to a lack of lateral confinement, or (b) the condition is a result of the molding process i.e. kneading type compaction imparts this characteristic to the soil.

Comparing aforementioned figure, it can be seen that for both the cases maximum strength occurred under fast transient loading under both compacted condition.

4.2.5: Comparative analysis: Unconfined strength and strain rate under dynamic and static compaction (soil sample 1):

Table 4.1: unconfined compressive strength and strain rate under dynamic compaction (soil sample 1)

Strainrate (mm/min)	UCS (kPA)		
	OMC	Wet of optimum	Dry of optimum
1.25	257.91	378.54	304
1.5	515.63	378.34	550.64

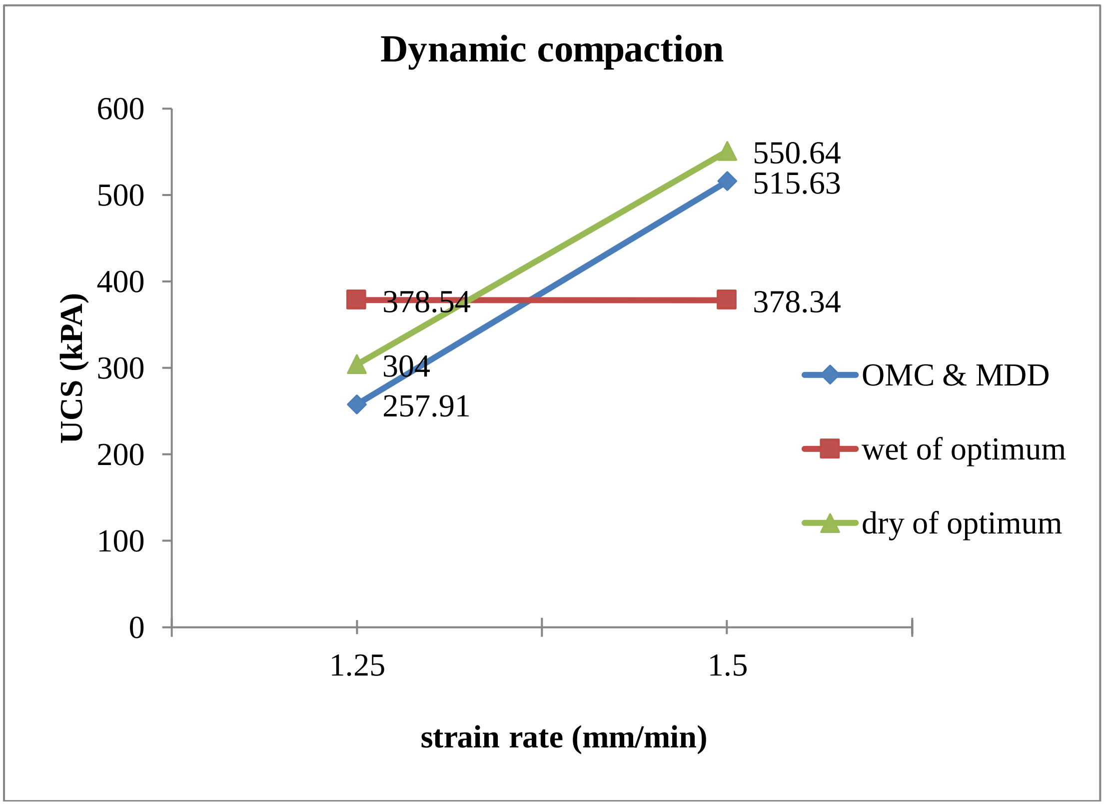


Fig 4.9: Relationship between strain rate and unconfined compressive strength (dynamic compaction)-soil sample 1

From Fig 4.8 it can be seen that at OMC and dry of optimum, increases strain rate increases the unconfined strength of CI soil but at wet of optimum no significant difference on strength when the rate of strain increases under dynamic compaction.

Table 4.2: unconfined compressive strength and strain rate under static compaction (soil sample 1)

Strainrate (mm/min)	UCS (kPA)		
	OMC	Wet of optimum	Dry of optimum
1.25	364.81	375.59	384.81
1.5	276.74	414.13	329.99

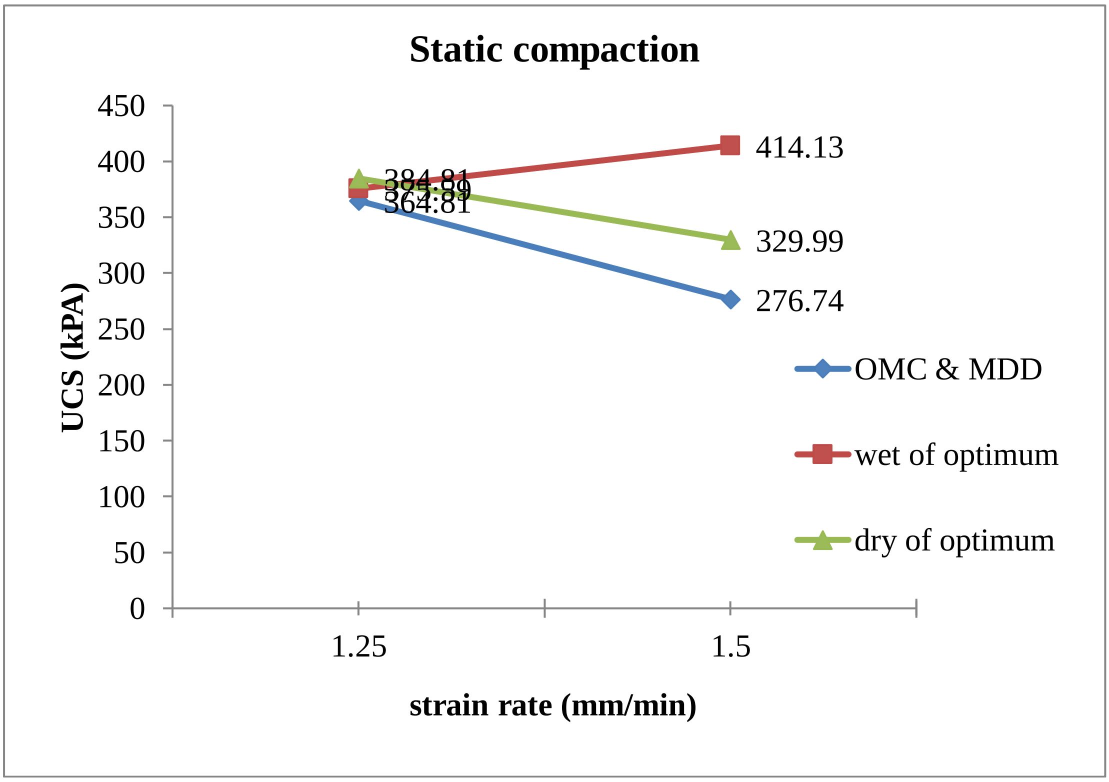


Fig 4.10: Relationship between strain rate and unconfined compressive strength (static compaction)-soil sample 1

From the fig 4.8, under static compaction for the same soil sample increasing strain rate decreases unconfined strength at OMC and dry side of the optimum. However, at wet side of optimum rate of strain increases unconfined strength increases. Comparing the result obtained from Fig 4.7 and 4.8, under dynamic compaction at OMC and dry of optimum, increases strain rate increases the unconfined strength of CI soil which was opposite in case of static compaction.

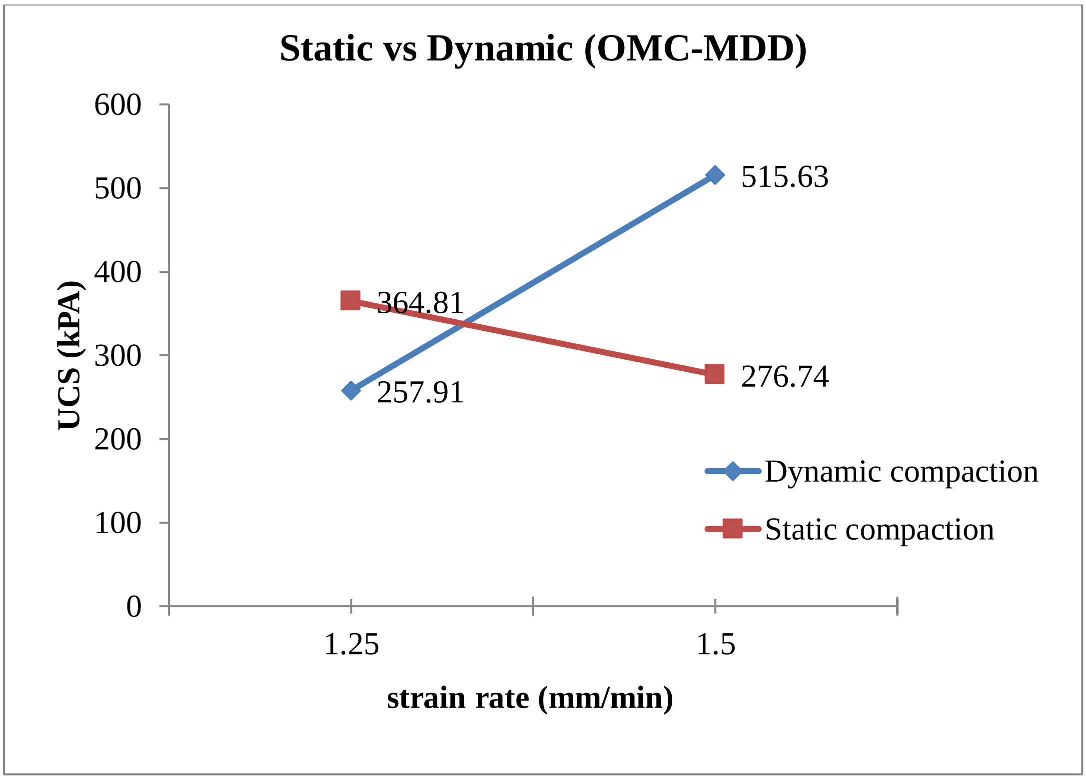


Fig 4.11: Comparison between Static vs Dynamic at OMC and MDD

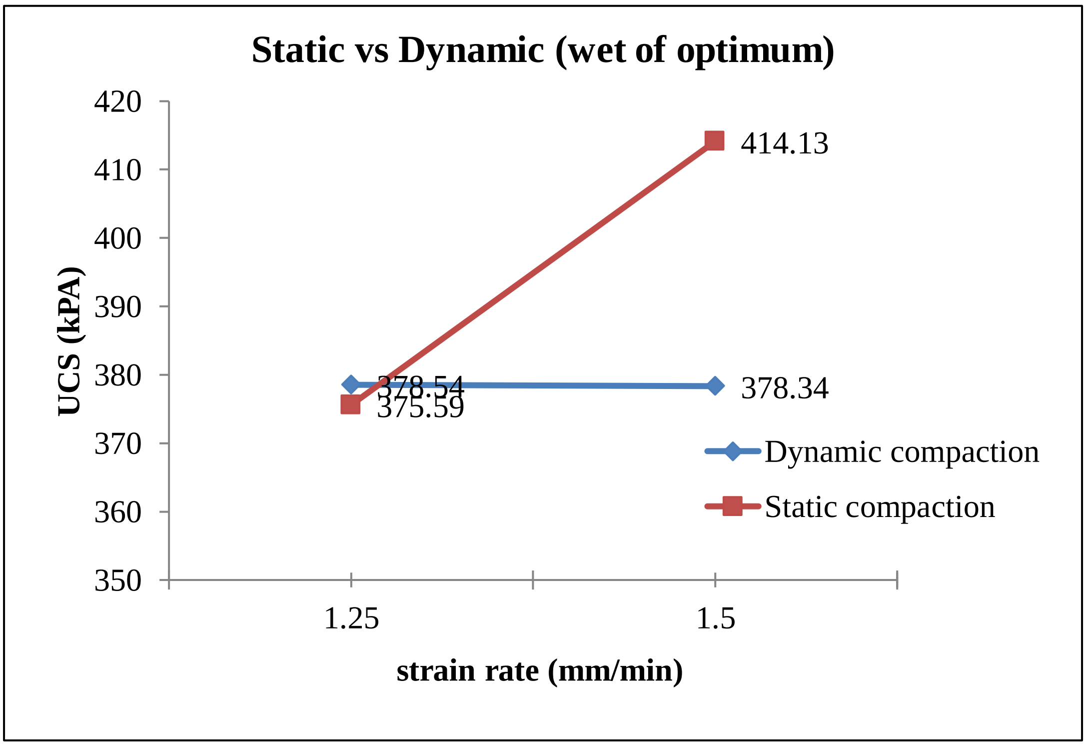


Fig 4.12: Comparison between Static vs Dynamic at wet of optimum

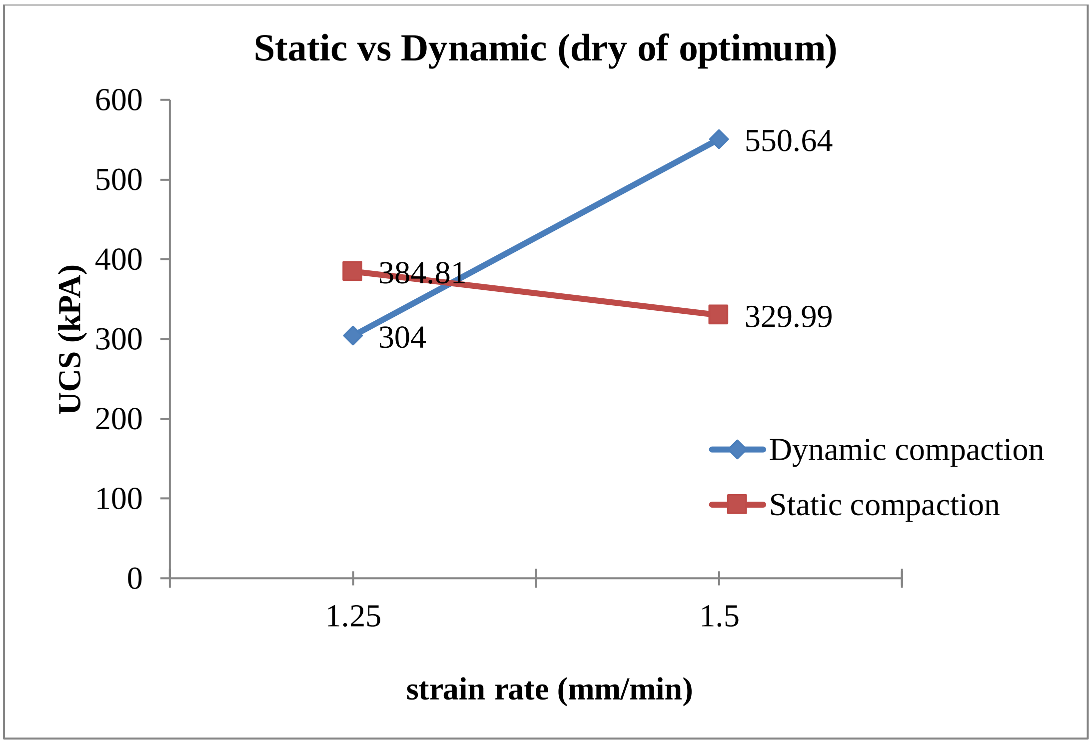


Fig 4.13: Comparison between Static vs Dynamic at dry of optimum

From Fig 4.9 unconfined strength increases with increases rate of strain at OMC and MDD under dynamic compaction and for static it was reverse, under same moisture condition and dry density. Fig 4.10 shows that at wet side of optimum under static compaction, unconfined strength increases with increasing rate of strain but at dry of optimum under static compaction unconfined strength decreases with increasing strain rate. From the aforementioned figure, maximum strength occurred at fast transient load under dynamic compaction at dry side of optimum. In Hampton et al.(1958) theoretically the strength should continue to rise as the moisture content decreased. However, there was a tendency for a reduction in this "peaked" condition as the rate of strain increased. There are two possible reasons for the aforementioned: (a) the condition is the re-sult of the inherent characteristics of the test; that is, at low moisture contents the specimens fail by crumbling rather than shear, due to a lack of lateral confinement, or (b) the condition is a result of the molding process; that is, kneading type compaction imparts this characteristic to the soil.

4.3 Comparative Analysis of UCS of soil sample 2:

The experimental results showing the variation of UCS value at different dry density and moisture content under static and dynamic compaction test under two different strain rate (1.5 mm/min & 1.25 mm/min). The effects of loading rate on UCS values were investigated. Soil sample was moulded at dry side of OMC and wet side of OMC.A relationship was established between unconfined compressive strength (UCS) and moisture content, variation of strength of CL-ML soil was study. In similar manner the variation of dry density and unconfined strength also studied. Behavior of compactive effort on UCS was investigated by observing the results.

4.3.1: Comparative analysis: Unconfined strength and dry density under static compaction at strain rate 1.25 mm/min & 1.5 mm/min

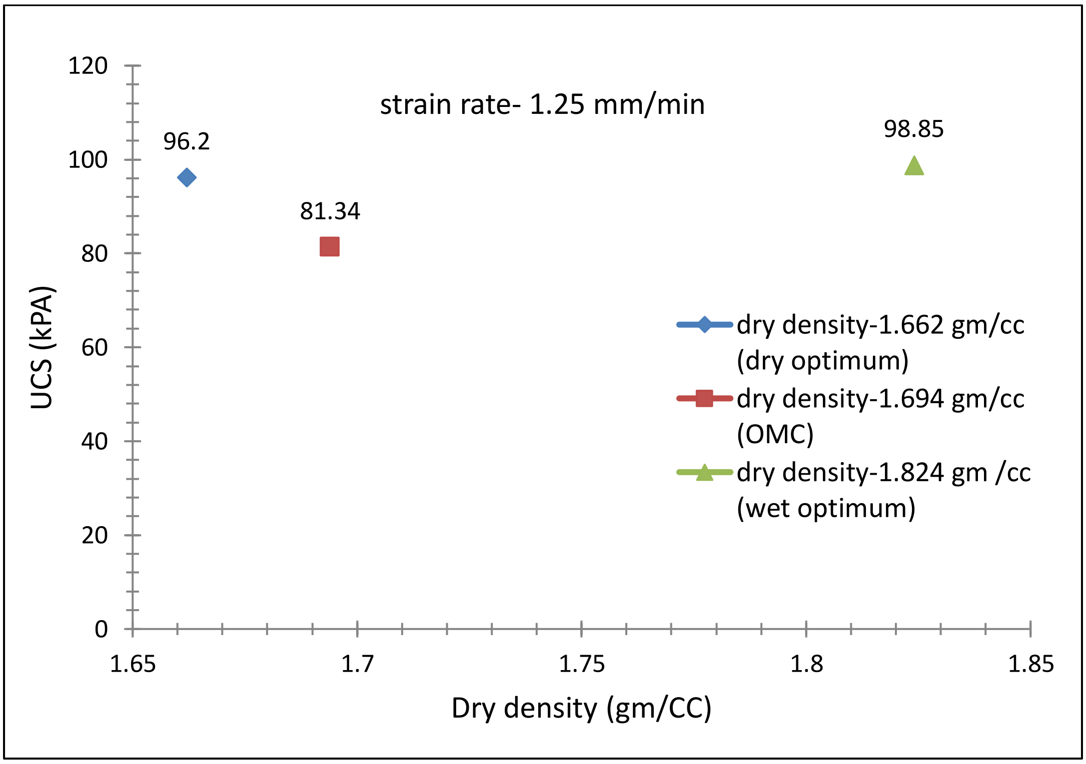


Fig 4.14: Relationship between dry density and unconfined compressive strength at strain rate 1.25 mm/min (static compaction)

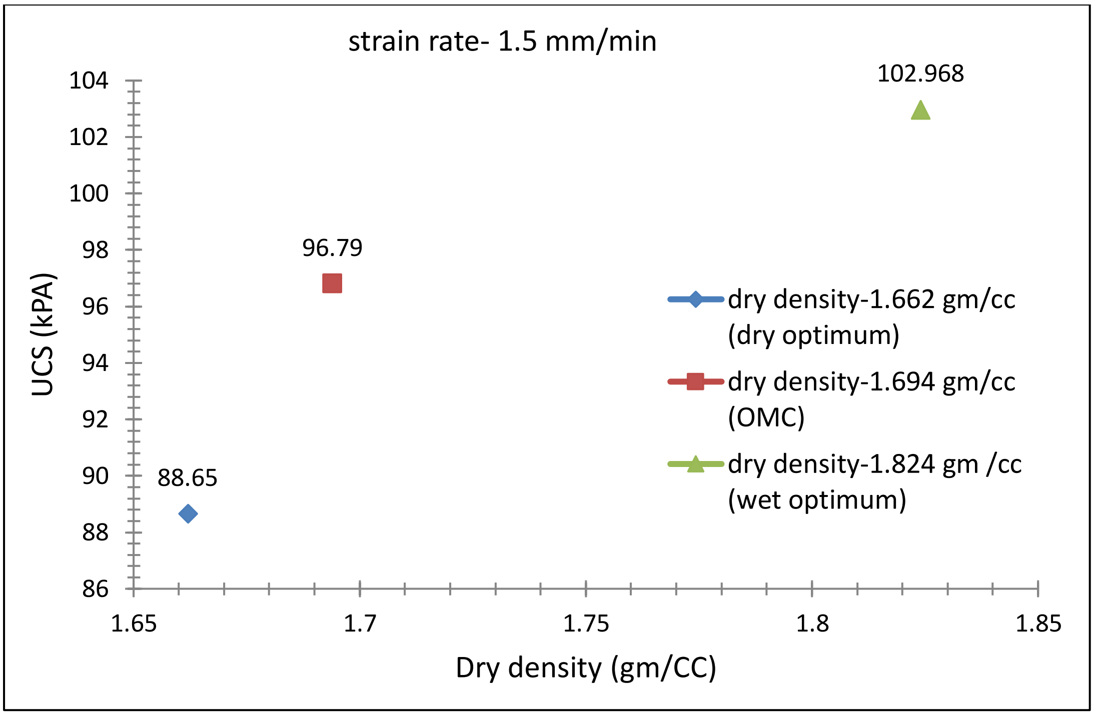


Fig 4.15: Relationship between dry density and unconfined compressive strength at strain rate 1.5 mm/min (static compaction)

4.3.2: Comparative analysis: Unconfined strength and moisture content under static compaction at strain rate 1.25 mm/min & 1.5 mm/min

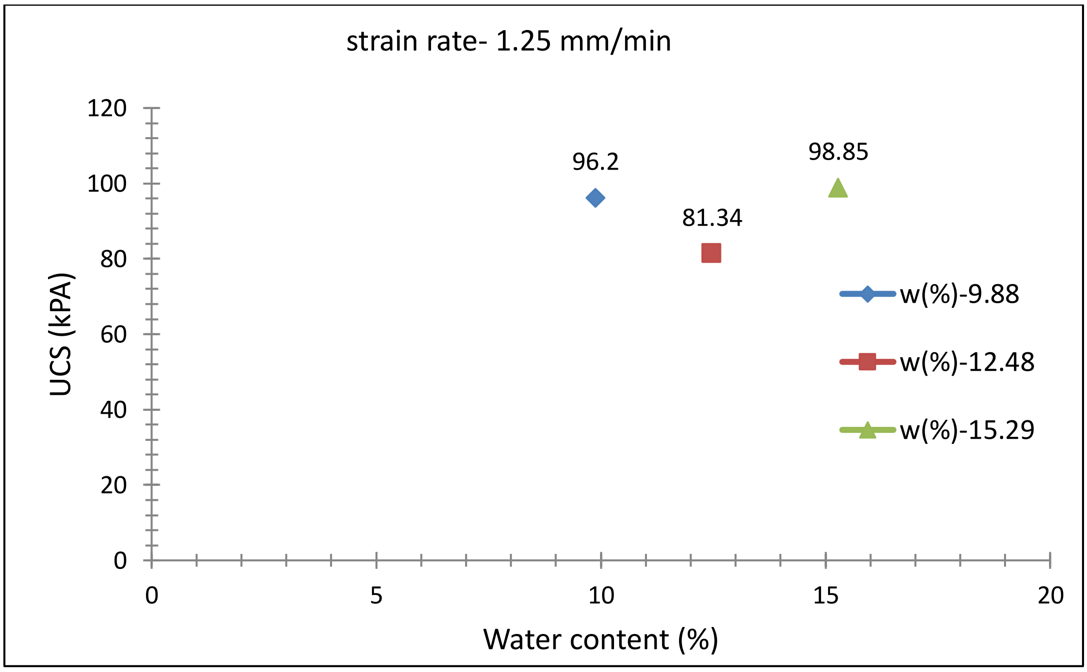


Fig 4.16: Relationship between moisture and unconfined compressive strength at strain rate 1.25 mm/min (static compaction)

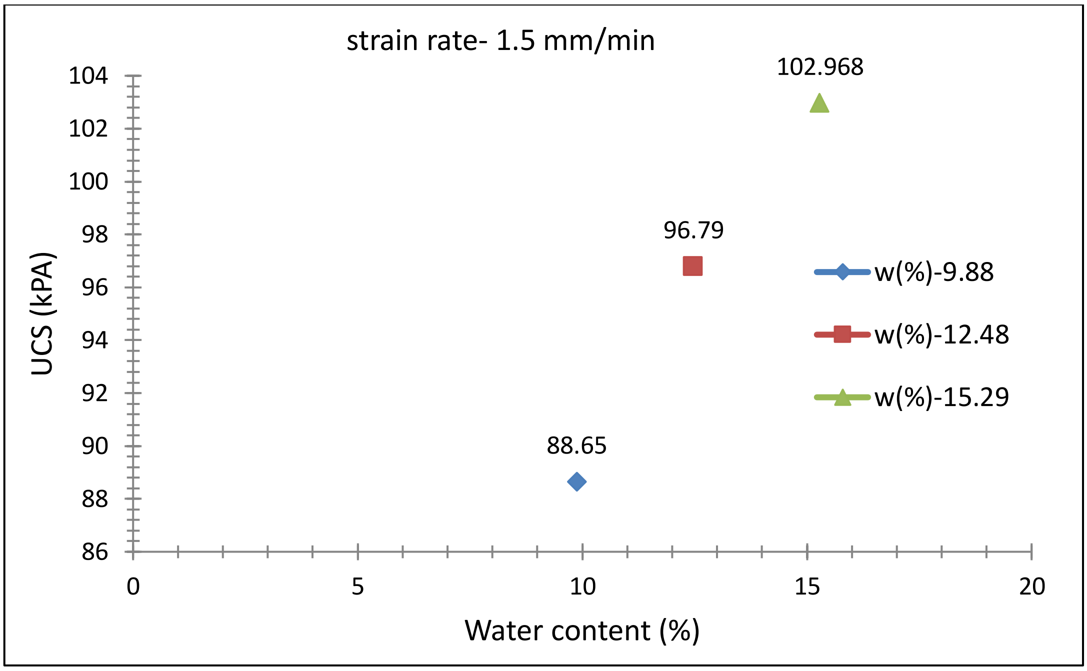


Fig 4.17: Relationship between moisture and unconfined compressive strength at strain rate 1.5 mm/min (static compaction)

4.3.3: Comparative analysis: Unconfined strength and dry density under dynamic compaction at strain rate 1.25 mm/min & 1.5 mm/min

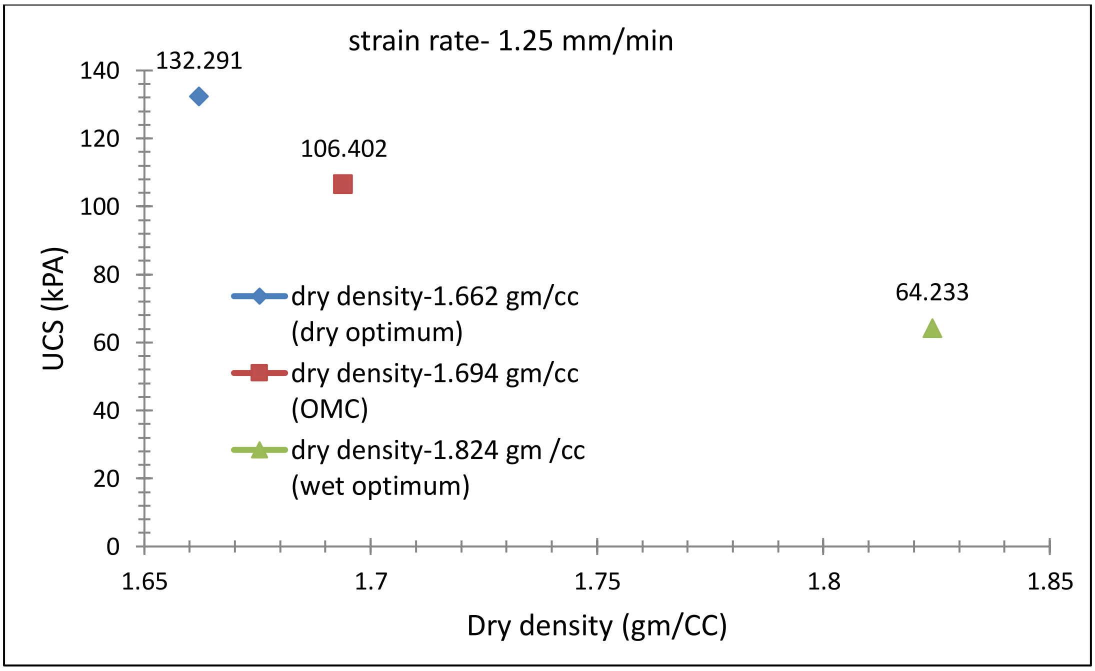


Fig 4.18: Relationship between dry density and unconfined compressive strength at strain rate 1.25 mm/min (dynamic compaction)

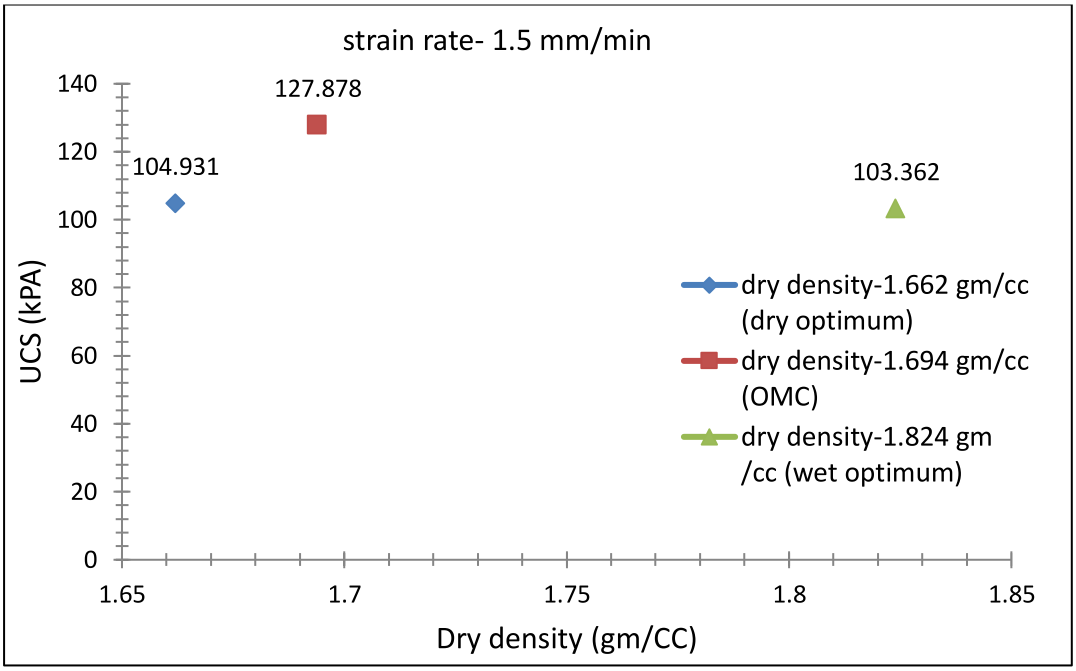


Fig 4.19: Relationship between dry density and unconfined compressive strength at strain rate 1.5 mm/min (dynamic compaction)

4.3.4: Comparative analysis: Unconfined strength and moisture content under dynamic compaction at strain rate 1.25 mm/min & 1.5 mm/min

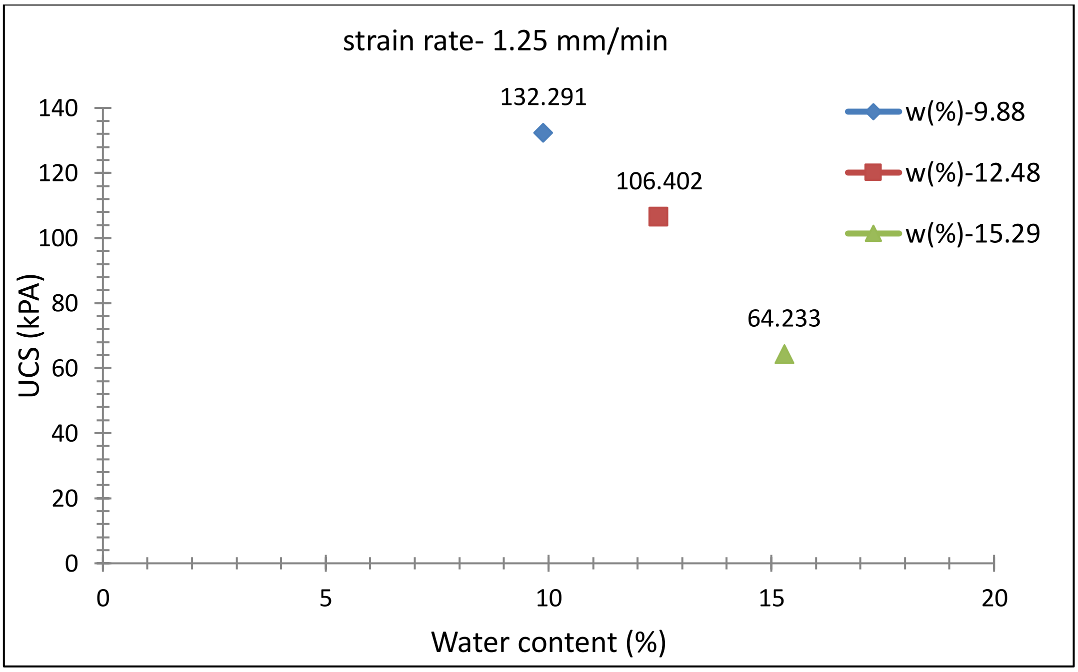


Fig 4.20: Relationship between moisture and unconfined compressive strength at strain rate 1.25 mm/min (dynamic compaction)

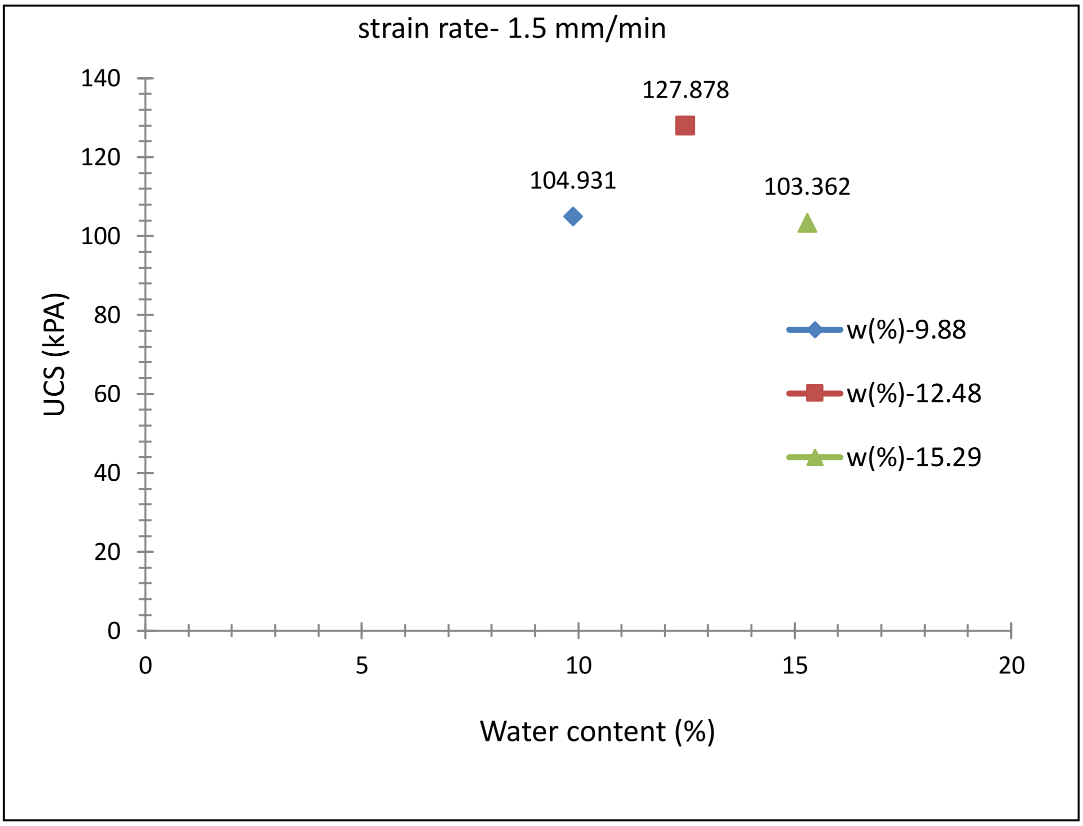


Fig 4.21: Relationship between moisture and unconfined compressive strength at strain rate 1.5 mm/min (dynamic compaction)

From the Fig 4.10, it can be seen that at higher strain rate unconfined compressive strength is linearly increases with increase in rate of loading compacted statically under same conditions of moisture content and dry density, which was shown in Fig (4.9-4.12).But in case of dynamic compaction at slower rate of loading the unconfined strength decreases as dry density and moisture content increases, which shown in Fig (4.13 & 4.15).However, from Fig 4.14 & 4.16, it can been seen that the maximum strength occurred at dry density correspond to OMC under fast transient loading. silty clay under unconfined compression, the strain rate (the rate at which the material is deformed) can influence the measured strength. Generally, higher strain rates tend to result in higher measured strengths due to the dynamic loading effect. This is often referred to as strain rate sensitivity. At higher strain rates, the loading on the material is more dynamic and rapid. This dynamic loading can induce additional inter-particle friction and changes in pore pressure within the clay matrix. These factors contribute to an apparent increase in strength observed during unconfined compressive strength testing.

For both soil the maximum strength occurred at moisture content less than optimum, regardless of the compactive effort or rate of strain. From the analysis it can be seen that for CI soil the maximum strength occurred at faster loading rate under dynamic compaction which was shown in Fig 4.9 & for the CL-ML soil the maximum strength occurred at slow loading rate under dynamic compaction.

Xu L et al. (2021) investigated the compaction characteristics of raw earth through both double faced static compaction and the traditional Proctor test (dynamic process). They tried the compaction energy for each sample and measured the matric suction using a filter per method. They found that the matric suction of specimens subject to static compaction was slightly higher than that in dynamic Proctor tests at the same moisture content, but dry density had little correlation with the variation of matric suction. It is widely accepted test earthen materials gain a component of shear strength through matric suction, which can be considered as an apparent cohesion.

Based on the results of these experiments, it is necessary to draw the conclusion that, for a given moisture content and density, significant improvements in strength or modulus of deformation require a rate of strain that is roughly similar to fast transient conditions. Additionally, at lower water content, increasing the rate of strain was the most effective way to increase strength of CI soil, and as the rate of strain grew, the strain at failure reduced as well. On the other hand for CL- ML clay at lower water content , increasing the compactive effort and decrease the rate of loading was the most effective way to increase strength of the soil. The phenomenon under investigation is caused by time lag, or the need for a specific amount of time for the shear planes to grow before failure occurred.

4.3.5: Comparative analysis: Unconfined strength and strain rate under dynamic and static compaction (soil sample 2):

Table 4.3: unconfined compressive strength and strain rate under dynamic compaction (soil sample 2)

Strain rate (mm/min)	**UCS (kPA)**		
	OMC	**Wet of optimum**	**Dry of optimum**
1.25	106.402	64.23	132.98
1.5	127.878	103.362	104.931

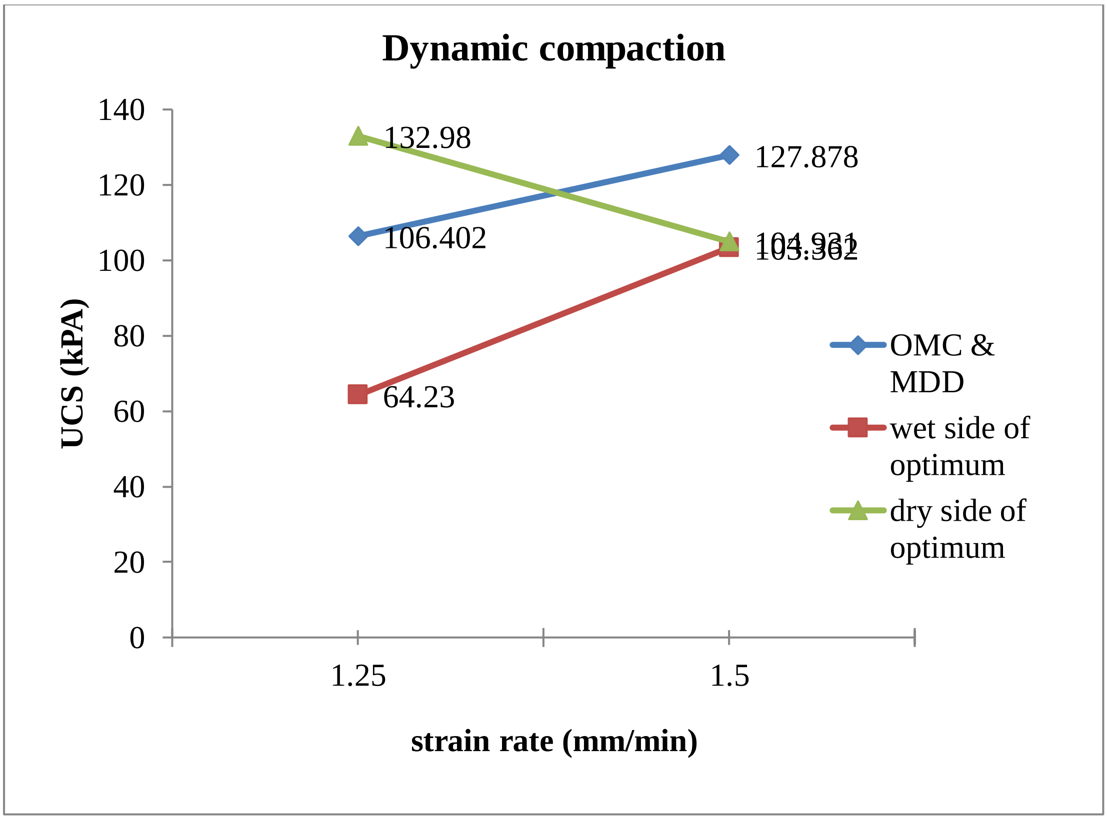


Fig 4.22: Relationship between strain rate and unconfined compressive strength (dynamic compaction)-soil sample 2

From Fig 4.3 under static compaction as the strain rate increases unconfined strength increases soil compacted at OMC and wet of optimum. But in case of dry of optimum it was opposite.

Table 4.2 unconfined compressive strength and strain rate under static compaction (soil sample 2)

Strain rate (mm/min)	UCS (kPA)		
	OMC	Wet of optimum	Dry of optimum
1.25	81.34	98.85	96.2
1.5	96.79	102.968	88.65

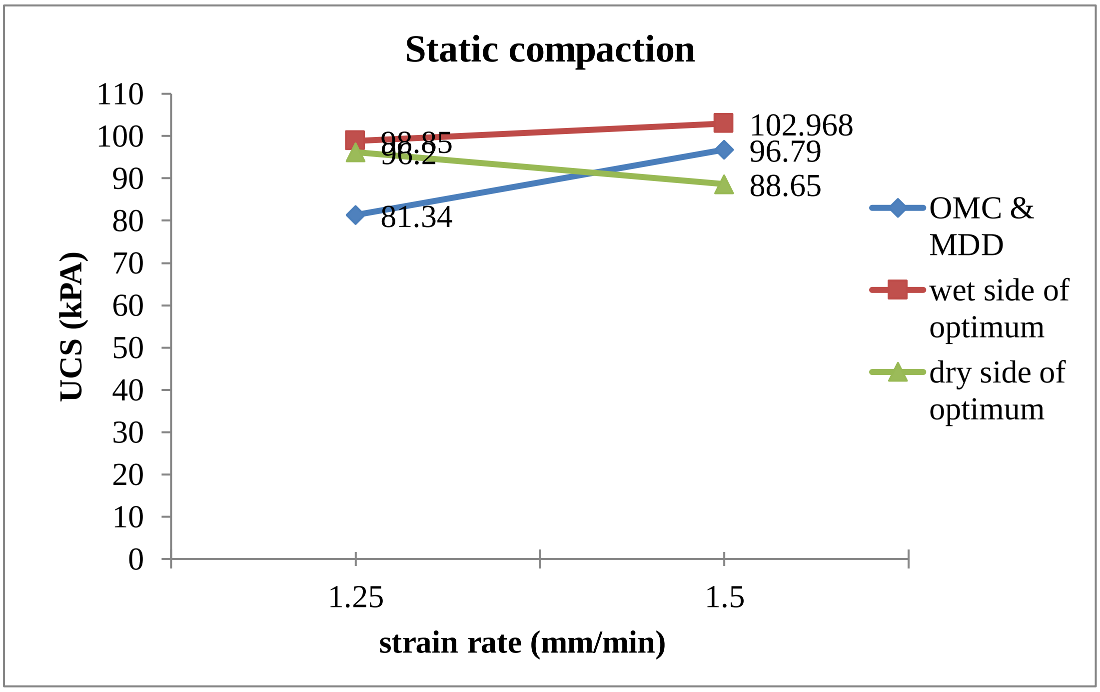
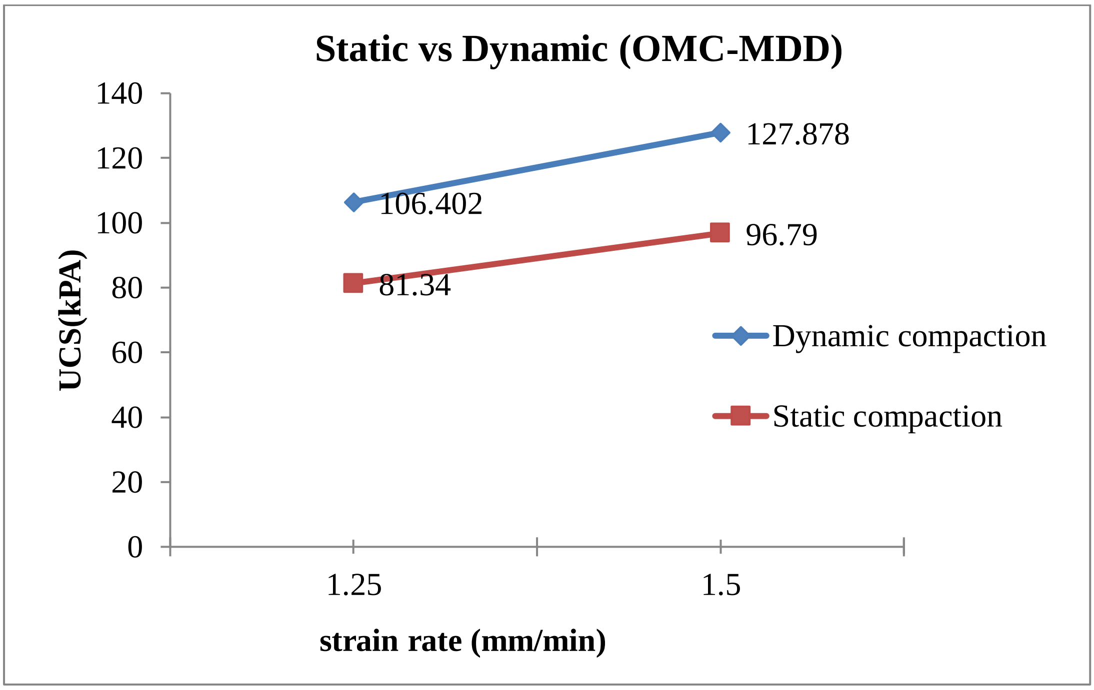
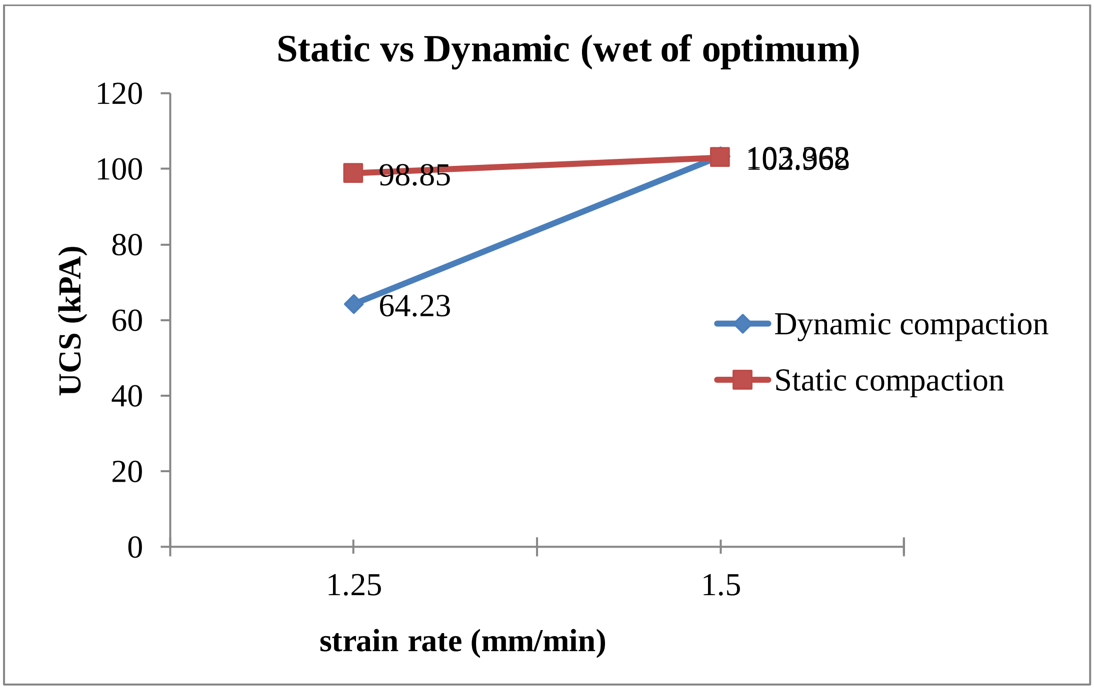


Fig 4.23: Relationship between strain rate and unconfined compressive strength (static compaction)-soil sample 2

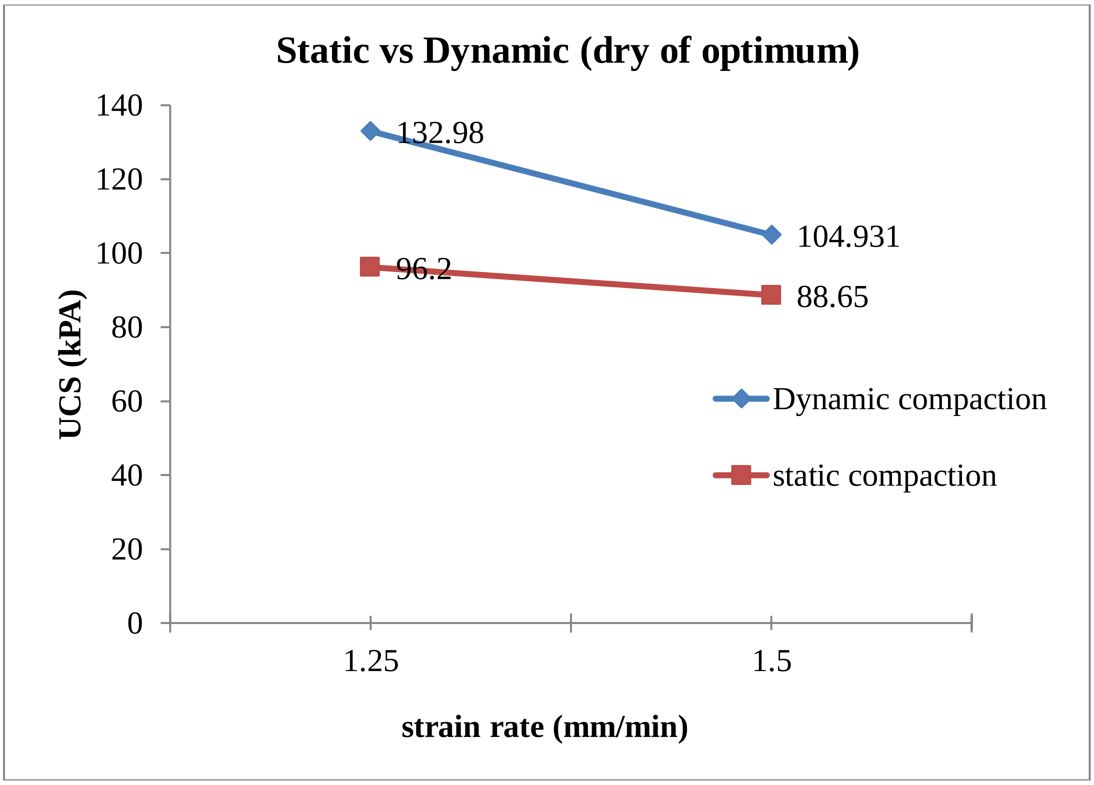
From Fig 4.21, under static compaction increases strain rate increases unconfined compressive strength of soil at OMC and wet of optimum. However, at dry of optimum it was opposite. From Fig 4.20 & 4.21 it can be seen that variation of unconfined strength for CL-ML clay was same under both compaction regardless of the strain rate under same condition of moisture content and dry density. But in case of static compaction wet of optimum gives maximum strength. The shear strength of the dynamically compacted samples was higher than those of the statically compacted samples, as was cohesion (c), and the sample preparation method had little effect on the internal friction angle (φ).Furthermore, samples that were compacted at optimum water content (w) had greater strength than those compacted on the dry or wet side of the optimum. Compared with the static compaction sample, the pore size distribution curve of the dynamic compaction sample shifted to the left with the peak pore size, distribution density, and the inter aggregate pores proportion decreased. The strength discrepancy could be traced to differences in the silt structure features, for example, pore size distribution and particle orientation between statically or dynamically compacted specimens.



4.24: Comparison between Static vs Dynamic at OMC and MDD



4.25: Comparison between Static vs Dynamic at wet of optimum



4.26: Comparison between Static vs Dynamic at wet of optimum

Comparing aforementioned figure at OMC & wet of optimum as increasing strain rate from 1.25 to 1.5 mm/min the unconfined strength increasing under same compactive effort (Fig 4.21 & 4.23). However, at dry of optimum increases strain rate decreases unconfined strength for silty clay. it can be stated that for a given rate of strain the Modulus of deformation increases with increasing moisture content. Also, modulus deformation for a given moisture content and the fast transient test conditions, increased as the compactive effort increased.

Casagrande and Shannon, found that the modulus of deformation of clays for fast transient tests was approximately twice as great (for both unconfined and consolidated quick tests) as that for slow tests. Also, the modulus of deformation of Manchester sand increased slightly with decreasing time of loading; that is, the average value for static tests is about 300 kg per sq cm and for fast transient tests about 400 kg per sq cm.

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE STUDY

5.1 Introduction

Based on the analysis of shear strength behaviour of fine-grained soil tested by Unconfined compression strength test under static and dynamic compaction method at different dry density and moisture content under different strain rate, the primary purpose of the research reported herein was to investigate the strength properties of a clay and silty clay under conditions of transient loading under different dry density and moisture content. Specifically, the aim was to attempt to ascertain the relationship between rate of strain and unconfined compressive strength at various moisture contents and densities the conclusion which are derived together with few suggestions for further study are incorporated in this chapter.

5.2 Conclusion

Following conclusion can be made on shear strength of fine grained soil from the comparative analysis of UCS value at different dry density and moisture content by different compaction method under different strain rate:

1. For soil sample 1 (CI), compacted under static compaction UCS value increases with increasing dry density at strain rate 1.25 mm/min. Maximum UCS values exhibit at strain rate 1.5mm/min compacted under same condition.
2. For CI soil at lower water content unconfined compressive strength exhibit higher value as compare to water content above OMC. However, under same compactive effort specimen tested at higher strain rate the UCS value increases by 10% specimen tested at lower strain rate under same conditions of moisture content and dry density.
3. For CI soil dynamic compaction of soil can enhance its strength by increasing both dry density and strain rate. Test specimens tested under fast transient loading with lower moisture content showed more than a 45% increase in strength compared to specimens tested under slow transient loading with higher moisture content at the same compactive effort.
4. For CI soil .in both the cases maximum unconfined strength occurred at fast transient loading under both compactive effort. Under dynamic compaction maximum strength occurred at water content below OMC and under static compaction maximum strength occurred at water content above OMC.

5. In CL clay at higher strain rate unconfined compressive strength is linearly increases with increase in rate of loading as compared to lower strain rate compacted statically under same conditions of moisture content and dry density.

6. Under dynamic compaction at slower rate of loading unconfined strength decreases with increase in moisture content for silty clay.

7. For silty clay under dynamic compaction maximum strength occurred at dry side of the optimum at lower transient loading but at higher loading rate maximum strength occurred at OMC.

8. The highest strength was observed in both soils at a moisture content below optimal levels, regardless of compaction intensity or strain rate. Analysis shows that CI soil reached peak strength at higher loading rate with dynamic compaction, while CL soil reached peak strength at lower loading rate with dynamic compaction.

On the basis of these tests, it must be concluded that to obtain significant increases in strength or modulus of deformation, at a given moisture content and density, it takes a rate of strain approximately equivalent to fast transient conditions. Furthermore, when the water content is reduced, the most effective method to enhance the strength of both CI & CL-ML soil is by increasing the rate of strain. Moreover, as the rate of strain increases, the strain at failure decreases.

5.3 Scope for future study:

Though an study have been made on the unconfined compressive strength of statically and dynamically compacted clay and silty clay at different strain rates. Thus, the main aim of this study was to examine the strength characteristics of clay and silty clay when subjected to transient loading with varying dry density and moisture content and exploring the effects of dry density, compactive effort, and strain rate on unconfined compressive strength (UCS) is crucial for understanding and improving geotechnical design and construction practices. it is only a part of an extensive investigation that has to be carried out in the concerned area to ensure strength of CI & CL soil. Further scopes of work are as follows

1. To Use advanced imaging techniques (e.g., scanning electron microscopy, X-ray computed tomography) to investigate how changes in dry density and compactive effort affect the microstructure of soil.

2. To study effect of the Suction Stress on the Unconfined Compression Strength

3. To established a Relationship between Suction and Suction Stress in Unconfined Compression Test.

REFERENCES

1. Alsameri, B. m. (2017). comparison of the effect of fine content and density towads the shear strength parameters. *Geotechnical Engineering 48(2).104-110* .

2. Bureau of Indian Standards (1980) Methods of test for soils: Determination of specific gravity , IS 2720-3, New Delhi, India.

3. Bureau of Indian Standards (1980) Methods of test for soils: Grain size analysis IS-2720-4, New Delhi, India.

4. Bureau of Indian Standards (1980) Methods of test for soils: Determination of liquid limit and plastic limit, IS 2720-5, New Delhi, India.

5. Bureau of Indian Standards (1980) Methods of test for soils:, Determination of UCS , IS 2720-10, New Delhi, India.

6. Castellanos, B. A., & Brandon, T. L. (2013, September). A comparison between the shear strength measured with direct shear and triaxial devices on undisturbed and remolded soils. In *Proceedings of the 18th international conference on soil mechanics and geotechnical engineering, Paris* (Vol. 1, pp. 317-320).

7. Chae, J., Kim, B., Park, S. W., & Kato, S. (2010). Effect of suction on unconfined compressive strength in partly saturated soils. *KSCE Journal of Civil Engineering*, *14*, 281-290.

8. Cokca, E., Erol, O., & Armangil, F. (2004). Effects of compaction moisture content on the shear strength of an unsaturated clay. *Geotechnical & Geological Engineering*, *22*, 285-297.

9. Crispim, F. A., Lima, D. C., Schaefer, C. E. G. R., Silva, C. D. C., Carvalho, C. A. B., Barbosa, P. D. A., & Brandão, E. H. (2011). The influence of laboratory compaction methods on soil structure: Mechanical and micromorphological analyses. *Soils and Rocks*, *34*(1), 91-98.

10. Das, B. M., & Sobhan, K. (1990). Principles of geotechnical engineering.

11. Das, D., Kalita, T., & Chetia, M. (2020). Influence of strain rate on unconfined compressive strength of bentonite and sand mixes. In *Geotechnical Characterization and Modeling: Proceedings of IGC 2018* (pp. 195-204). Springer Singapore.

12. Hampton, D., & Yoder, E. J. (1958). The effect of rate of strain on soil strength.

13. Kang, Q., Xia, Y., Li, X., Zhang, W., & Feng, C. (2022). Study on the effect of moisture content and dry density on shear strength of silty clay based on direct shear test. *Advances in Civil Engineering, 2022*(1), 2213363.

14. Poudel, S., Karki, R., & Acharya, I. P. (2019). Comparative Study of Sensitivity and Thixotropic Behavior of Various Clayey Soil Using Unconfined Compression and Lab Vane Shear Test. In *Proceedings of IOE Graduate Conference*.

15. Proctor, R. (1933). Fundamental principles of soil compaction. *Engineering news-record*, *111*(13).

16. Xu, L., Wong, H., Fabbri, A., Champiré, F., & Branque, D. (2021). A unified compaction curve for raw earth material based on both static and dynamic compaction tests. *Materials and structures*, *54*, 1-16.