EFFECTS OF WATER CONTENT ON UNCONFINED COMPRESSIVE STRENGTH OF CLAY

Md. Mostofa Al Hossain

Nahidul Islam

Department of Civil Engineering

Daffodil International University

March, 2020

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A thesis submitted to the Department of Civil Engineering of Daffodil International University (DIU) in partial fulfillment of the requirements for the degree of

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The thesis titled "***Effect of Water Content on Unconfined Compressive Strength of Clay***" submitted by Md. Mostofa Al Hossain, Student ID: 162-47-175 and Nahidul Islam, Student ID: 162-47-181, Season: Summer 2016, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Bachelor of Science in Civil Engineering on March 18, 2020.

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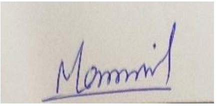

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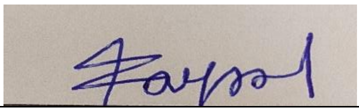

Rayhan Md. Faysal — **Member**

Lecturer

Department of Civil Engineering

Daffodil International University

AUTHOR DECLARATION

This is hereby declared that this research work has been performed under the supervision and guidance of Mohammad Mominul Hoque, Assistant Professor in the Department of Civil Engineering at Daffodil International University, Dhaka Bangladesh. Any part of this work has not been submitted elsewhere for the award of any degree or diploma.

Mostofa

Md. Mostofa Al Hossain
Student ID: 162-47-175

Nahidul

Nahidul Islam
Student ID: 162-47-181

Department of Civil Engineering
Daffodil International University
March, 2020

DEDICATION

Dedicated

To

Our Parents

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ABSTRACT

The most significant index property of clay in the natural state is the consistency. The water content has extreme influence on the consistency. At low water content clay behaves more like a solid, but at high water content clay and water may flow like a viscous fluid. Depending on water content, the consistency can qualitatively be expressed as solid, semisolid, plastic, and liquid. Quantitatively the consistency can be expressed by the unconfined compressive strength (q_u). In this research, the effects of water content on unconfined confined compressive strength of two different clays are investigated. The samples, clay-1 is collected from Jashore, Bangladesh and clay-2 is collected from Ashulia, Bangladesh. The clay-1 and clay-2 have liquid limit and plastic limit of 33.0, 44.0 and 22.5, 26.0 respectively. The laboratory compaction tests revealed that maximum dry unit weight of clay-1 is 17.20 kN/m^3 and clay-2 is 16.16 kN/m^3. In the unconfined compressive strength tests, cylindrical specimens having diameter of 38 mm and height of 76 mm are prepared at 90% of maximum dry unit weight with varying water content in the range of plastic limit. The experimental results revealed that, water content has extreme effects in the reduction of unconfined compressive strength and this reduction is predominant while water content reaches near liquid limit. It is also observed that the unconfined compressive strength of clay has a linear relationship to the water content. It is expected that, the output of this research can be used to predict the reduction of unconfined compressive strength with the changes of water content.

Key Words: Clay, Moisture content, Consistency, Unconfined compressive strength.

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Notations

q_u	Unconfined compressive strength
ε	Axial strain
c	Cohesion
φ	Angle of internal friction
S_u	Undrained shear strength
G_s	Specific gravity
Υ_{dmax}	Maximum dry unit weight
σ_1	Stress
L_0	Initial length of specimen
ΔL	Sample deformation
P	Applied axial load
ϵ_1	Initial strain for a given axial load

Abbreviations

UCT	Unconfined compression test
UCS	Unconfined compressive strength
LL	Liquid limit
PL	Plastic limit
AR	Area ratio
ICR	Inside clearance ratio
OCA	Outside cutting edge angle

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Consistency is the resistance of soils to deformation and rupture. The unconfined compression strength is often used as an indication of consistency. In the practice a term used to denote the degree of firmness of the soil which may be termed as soft, medium, stiff, very stiff, and hard are applied to rate consistency of soil. This soil index property describes both cohesive and non-cohesive soils. Consistency at non-cohesive soil depends primarily on particle shape and size distribution, while at cohesive soils consistency property primarily depends on water content.

Plasticity of a clay is referred to as its property due to which the clay possesses the ability to undergo the change of shape without deformation or rupture of the clay particles. If clay soil mixed with water to form a plastic paste which can be molded into any form and the addition of water reduces the cohesion making the clay still easier to mold. Further addition of water reduces the cohesion until the clay paste no longer retains its shape and water may flow like a viscous fluid. If further more water is added, the clay particles get dispersed in a suspension. If now the water is evaporated from such a clay suspension, the clay water mixture undergoes changes from liquid state to a plastic state and finally into a solid state. The different states through which the clay passes with the decrease in the water content. The water contents corresponding to the transition from one state to another state are termed as consistency limits, which were initially proposed by Atterberg in 1911 (Casagrande, 1932) for agriculture purpose and were later adopted by Terzaghi and Peck (1967) for the classification and identification of fine grained soils for engineering purpose. The water content corresponding to the transition from liquid state to plastic state is termed as liquid limit from plastic state to semi solid state is termed as plastic limit and from semi solid state to solid state is termed as shrinkage limit. There will be a corresponding decrease in the volume of clay as the water content decreases. This decrease in the volume takes place up to shrinkage limit and there will be no further decrease in the volume beyond this limit with the decrease in the water content.

1.2 THESIS BACKGROUND

Clayey soils are usually categorized as expansive soils. Other names of these soils are soft soils or fine-grained soils. These types of soils are known lead to critical damage to structures resting on them. Normally in construction industries, the structures that constructed on clay soils are tend to trigger the soil when exposed to additional load as well as external impact. This deformation could potentially cause significant failure to foundation and structures. Besides, the construction of roadway on the soft soils also encountered the same problem. This is because clay soil has low strength and stiffness. In this study we are trying to find out effect of moisture content on unconfined compressive strength of clay. Clay soils strength varies with variation of water content. The angle of internal friction for clayey sand is found generally to decrease with increasing water content

1.3 OBJECTIVE OF THE STUDY

The specific objective of this study is to determine effect of water content on unconfined compressive strength of two different clays.

1.4 SCOPE OF THE STUDY

This research work was undertaken in three steps in order to accomplish the specific objectives. In the first step, the review of literature related to clay properties were carried out in order to accumulate the state of current knowledge on clay properties. In addition to that, detail theoretical aspects of comprehensive methods effects of moisture content on unconfined compressive strength of clay properties and major influencing factors related to the clay soil properties were reviewed.

During the second portion of the study, clay soils were collected from two different locations where one sample (clay-1) from Jashore, Bangladesh and other sample (clay-2) from Ashulia, Bangladesh. In the third step, a comprehensive laboratory studies have been undertaken for effects of water content on unconfined compressive strength of clay in the Geotechnical Engineering Laboratory at Daffodil Civil Engineering lab. During first portion of the laboratory study, specific gravity was performed on both clay samples. Based on the results of specific gravity, a representative sample was prepared for moisture content tests and a plasticity testing was performed on representative sample. These experiments were studied with various water percentages. Based on data found from these result hydrometer tests were performed & plotted in a log paper. After these results were found Proctor compaction tests were performed with various moisture combination. Based on these result unconfined compression tests were performed for both clay with various combination of water & plotted in a log graph.

1.5 ORGANISATION OF THE THESIS

This dissertation is comprised of five chapters, including this chapter which provides an introduction to the topic of effects of water content on unconfined compressive strength of clay, as well as the objectives, thesis Background, and the scope of this study. To assist the reader, a brief outline of the material covered in each chapter is summarized below.

Chapter Two presents extensive review of literature related to Unconfined Compressive Strength of clay, specially addressing the major influencing factors related to Unconfined Compressive Strength, and critical task associated with Application of Unconfined Compressive Strength and their characterization. In addition to that, scope of the comprehensive methods for Unconfined Compressive Strength of clay are discussed with their respective advantages and limitations with a great emphasize.

Chapter Three summarized the laboratory investigations. In the first portion, laboratory tests for index properties are performed to evaluate specific gravity, particle size, liquid limit and plastic limit and maximum dry density of the representative sample. Later portion, the basic theoretical aspects of Unconfined Compressive strength test also testing machine apparatus and equations for data calculations and Calibration equation to convert load dial to evaluate unconfined compressive strength of representative samples. Besides, the limitations of unconfined compression test to evaluate unconfined compressive strength are presented sample preparation and procedure to perform unconfined compression test also calculation and stress vs strain presented to determine effect unconfined compressive strength with variation of water content of representative samples.

Chapter Four summarized the laboratory investigations. The laboratory investigations that have been performed to determine effects of water content on unconfined compressive strength are discussed. Laboratory investigations comprised of tests for index properties and series of unconfined compressive strength tests and the procedures and equations used for calculations, and interpretations of water content on unconfined compressive strength tests and the obtained results are presented.

Chapter Five presents the conclusions drawn from this study. This chapter also presents significance of research and the research has made to expand the current knowledge of moisture behavior of this two clay soils. Finally, recommendations are made for further research relating to the scope of this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 GENERAL

The review of literature regarding previous research on strength properties of clay have been presented in this chapter. The published results of geotechnical investigations on strength of clay properties have been reviewed and presented in order to clarify the state of current knowledge and standard practice. In addition to that, detail theoretical aspects of unconfined compressive strength of clay and their applications also major influencing factor of unconfined compressive strength are addresses in this chapter.

2.2 UNCONFINED COMPRESSIVE STRENGTH

The unconfined compressive strength of clay may be broadly defined as ability of the clay to resist imposed forces. If is often measured as the maximum stress clay can sustain under specified loading and boundary conditions. Since an understanding of the behavior in the strength of clay is a great importance, the strength of clay is normally measured and used to compare one clay with another or other soil. In the case of soil, attention has been directed more towards the measurement and use of the shear strength or shearing resistance than towards any other strength parameter (Bishop, 1966). The unconfined compressive strength of representative sample is defined as the maximum applied load to fail the specimen by the cross-sectional area or the load per unit area at 15% axial strain. Whichever is secured first during the performance of unconfined compressive strength test.

The unconfined compressive strength (q_u) = $\frac{q}{A}$

Where,

P= applied axial load at failure

A = corrected area = $\frac{A_O}{1-\varepsilon}$

Where,

A_O= initial area of the specimen

ε= axial strain with change in length

The undrained shear strength (s_u) of clay is equal to the one half of the unconfined compressive strength (q_u) when the clay is under the φ = 0, where (φ = is the angle of internal friction)

$s_u = c = \frac{q_u}{2}$

Here,

c = is the cohesion, which is basically equal to the undrained shear strength.

2.3 APPLICATION OF UNCONFINED COMPRESSIVE STRENGTH

The unconfined compressive strength has of great importance in the study of material strength. In the case of soil mechanics, it has massive role to obtain strength of soil, soil behavior under imposed force, also behavior of clay with variation of water content. In addition to that, it has significant amount of application to the following:

- Foundation design.
- Underground construction.
- Earth excavation.
- Finding bearing capacity.
- Improvement of loose soil.
- Stability of foundation.
- Roads and air-base design.
- Stability of earth slope and cut.
- Finding earth pressure problems.
- Blasting in construction, mining and many more.

2.4 INFLUENCING FACTORS OF UNCONFINED COMPRESSIVE STRENGTH

From the earlier, many researchers observed that unconfined compressive strength of cohesive soil primarily influenced by moisture content or degree of saturation, specimen size, remolded or reconstruction of sample, the method of specimen reconstitution, void ratio, the grain size distribution, compaction, loading frequency, loading cycles, dry density and many more. A brief discussion of the fundamental factors that affect unconfined compressive strength of clay under axial loading are presented in the following sections.

2.4.1 SPECIMEN SIZE

The effect of the specimen size on unconfined compressive strength of cohesive soil under imposed loading condition have been investigated by many researchers in unconfined compressive tests. The outcome of this studies primarily agreed that the strength properties influenced by the specimen size. Yoshinaka (1976) and LO, (1970) mentioned that the strength properties influenced by the specimen size for fissured clay and rock materials respectively. Kamei and Todika (1991) performed the UCT with specimen size of 10 mm, 20 mm, 35 mm, and 50 mm, in diameter and 10 to 100 mm in length for remolded clays having plasticity index from 19 to 36. From this research, they obtained that there is no effect of specimen size on deformation characteristics and strength if the ratio of specimen length to diameter is 2, for the diameter larger than 20 mm.

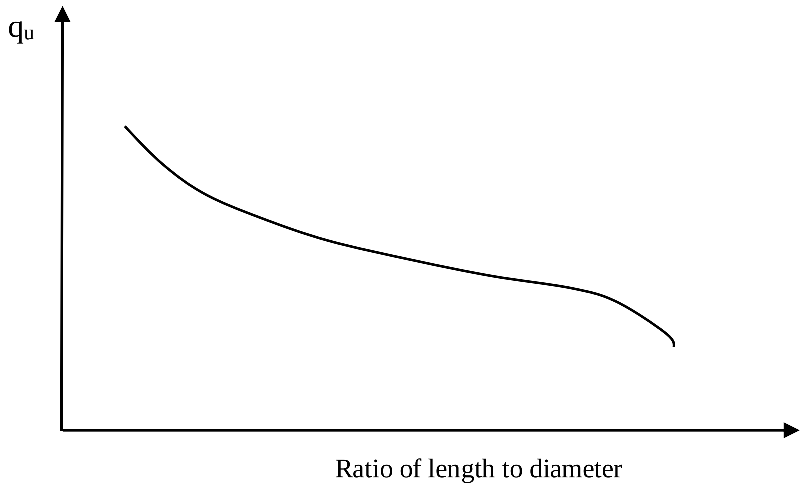


Figure 2-1: Effect of length to diameter ratio on UCS (Drnevich).

2.4.2 SAMPLE RECONSTITUTION

From the compare between the undisturbed and reconstitution samples strength for same as field condition, many researchers recognized that the unconfined compressive strength is greatly reduced when the clay tasted after remolding without any change in water content, as shown in Figure 2.2.

The loss of strength of clayey soil from remolding is caused primarily by the destruction of the clay particle structure that was developing during the original process of sedimentation. However, if after remolding a clay specimen is kept in an undisturbed condition (without change in in the water content), it will continue to gain strength with time.

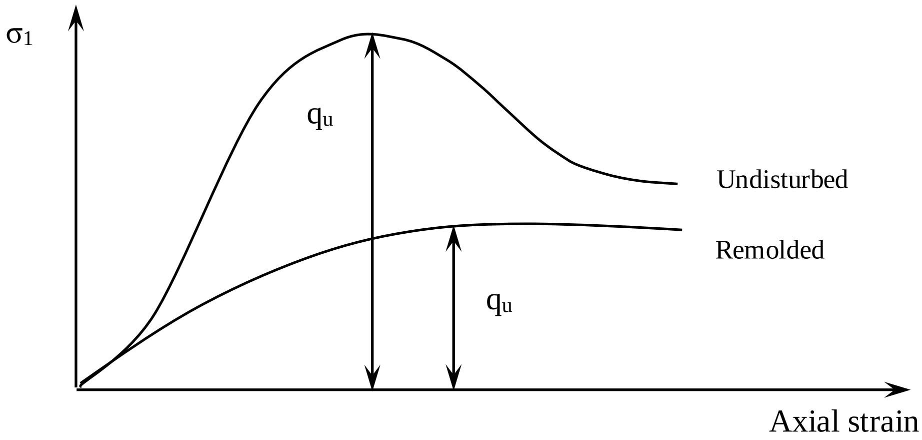


Figure 2-2: Effect on UCS for undisturbed and remolded clay (Braja M. Das)

2.4.3 SAMPLE DISTURBANCE

Many researchers obtain that during samples collection and transportation from the field to laboratory, the sample can be subjected to vibration or shock loads. Hvorslev (1949) mentioned that samples should be preferably transported privately rather than commercially. Kallstenius (1971) found that a simulated vibration of a train could cause reduction of strength or in some cases an increase in shear strength for a soft clay, also concluded that there was a variable influence due to travelling vibration. Hvorslev (1949) stated that sample disturbance would decrease with increasing sample diameter. (Berre, 1969) concluded from oedometer tests on a soft marine clay that a 95mm piston sampler (area ratio, AR = 14%, inside clearance ratio, ICR= 1.4%, outside cutting edge angle, OCA= 10 degrees) caused less sample disturbance than a 54mm piston sampler (AR= 12%, ICR= 1.3%, OCA= 12 degrees). This difference was based on measurements of pre-consolidation pressure and compressibility, where higher disturbance was associated with lower values for pre-consolidation pressure and higher values for compressibility, and was attributed to the difference in sample size. From the overview effect of disturbance which are associated with the drilling of the borehole, stress relief, transportation and storage, sample preparation, and testing influenced strength of clay.

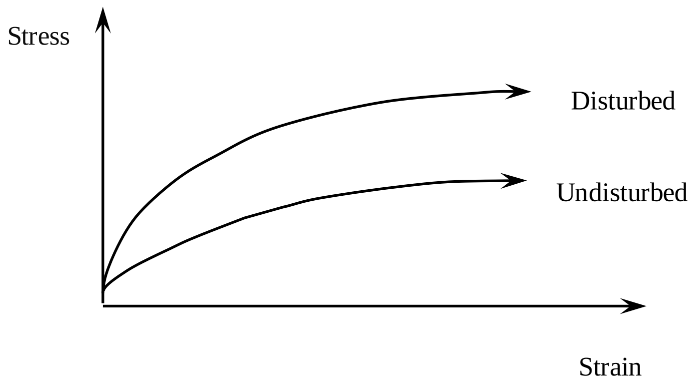


Figure 2-3: Effect of disturbance on stress vs strain behavior (Drnevich)

2.5 PREVIOUS RESEARCH

Clay soils are important in the construction of buildings, dams, roads, airports, pavements and highways. Soil problems encountered in geotechnical engineering need to be solved. Because of its double layer, clay can absorb water 10–500 times its own weight. In addition, it is considered to be a problematic soil that can show settlement under loading, with swelling or compression when it receives water. A limited research has been conducted on moisture content of clay to find out the effect on water content in clay. Dafalla (2013) investigated the cohesion and angle of internal friction for granular soils using the direct shear test for different clay contents and different moisture contents. Consequently, researchers observed a steep drop in both cohesion and angle of internal friction in a moist, clay-sand mixture when the clay content was high. Some studies indicated that Atterberg's limits and grain-size distribution are indicators of the soil mineralogy and for the determination of many fine-grained soil properties. Simultaneously, Atterberg's limits affect grain-size distribution and mineral composition. For example, an increase in the surface area is observed with increased liquid limits. (v.v Kramarenko, 2016) investigated water content in clay and organic soil using microwave oven. The findings of their research have proved that household microwave ovens are an effective means to rapidly determine water content in clay. (F. Armangil, 2004) investigated the influence of compaction water content on the shear strength of the clay. (Murayama, sakuro; 1955) investigated the effect of moisture content on the strength of an alluvial clay using triaxial consolidation test.

Finally, previous researches related to effect of water content on clay are presented and it appears that very limited number of research has been conducted to find out effect of water content in clay. Indeed, reviews of the literature have provided useful insights and valuable guidelines to perform a comprehensive research which is presented in the subsequent chapters.

CHAPTER THREE

LABORATORY INVESTIGATIONS

3.1 GENERAL

This chapter comprises of laboratory test of the representative samples. In the early portion, specific gravity, hydrometer tests are performed to evaluate the particle size and clay property of representative samples. In the mean portion, liquid limit and plastic limit and compaction tests are performed to determine strength characteristic of clays. In the last portion, sample preparation and testing procedure are performed to operating unconfined compression tests. Finally, calculations and stress vs strain characteristic are presented in last part in this chapter.

3.2 LABORATORY TEST FOR INDEX PROPERTIES

3.2.1 SPECIFIC GRAVITY

The specific gravity (G_S) of soil is used in calculating the particle size analysis of soil, density, degree of saturation, void ratio and other parameter of soil. In this study, the specific gravity of the test specimens is an essential parameter for calculating hydrometer analysis of the clay samples. The specific gravity of the representative sample is determined according to ASTM D854, (standard test methods for specific gravity of clay soils by water Pycnometer). The representative samples have a specific gravity of clay-1, G_S =2.71 and clay-2, G_S =2.68.

3.2.2 HYDROMETER ANALYSIS

In this study, particle size distribution of clay is not possible by using mechanical sieve analysis. This because clay particle size finer than 0.074mm to 0.0002mm. whereas mechanical sieve analysis limitation has 0.074mm. Therefore, hydrometer analysis is the most widely used method for obtaining particle size distribution from 0.074mm to 0.0002mm. Hydrometer analysis is performed according to ASTM D422. Around 50 gm of oven dry clay sample finer than 0.007 mm is collected from representative sample that passed through No. 200 sieve for hydrometer analysis. Sample is soaked for 12 hours in 125 cc Sodium hexa metaphosphate ($NaPO_3$) solution and mixed thoroughly before taking hydrometer readings. The test is done very carefully to avoid any source of uncertainty. Particle size distribution curve for the representative sample obtained from hydrometer analysis is presented in Figure 3-1 and Figure 3-2.

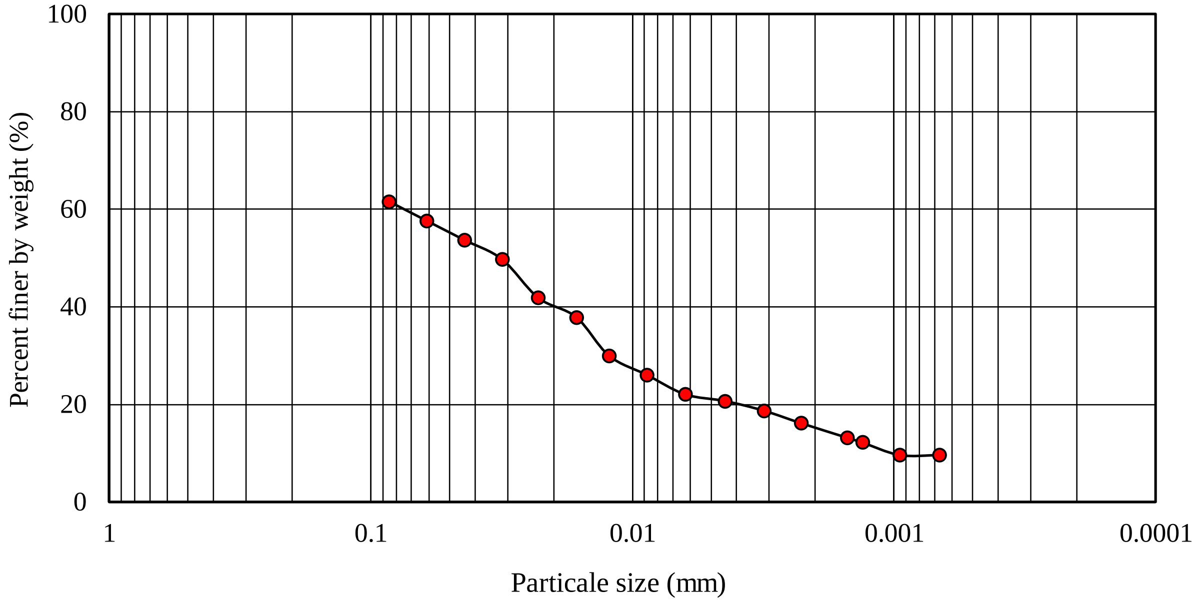


Figure 3-1: Particle size distribution curve from hydrometer analysis of clay-1.

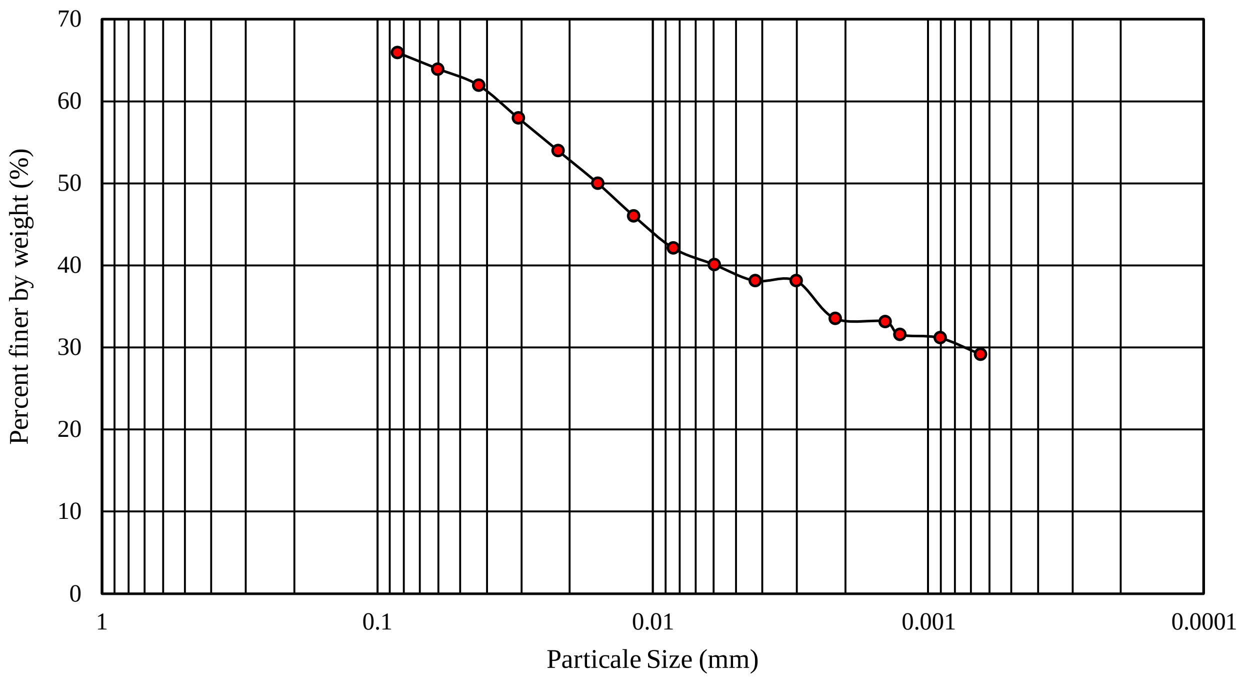


Figure 3-2: Particle size distribution curve from hydrometer analysis of clay-2.

3.2.3 ATTERBERG LIMIT TEST

3.2.3.1 LIQUID LIMIT

In this study, the liquid limit of the representative sample is mainly used to finding approximate range of water content for remolding of clay sample for unconfined compression strength test, here liquid of clay played a vital role. Moreover, the water content at which the behavior of clay changes from plastic limit to liquid limit also founded by this experiment. However, the tendency of transition from plastic to liquid limit is gradual over a range of water contents, and the shear strength of clay is not actually zero at liquid limit. Here, the liquid limit of the representative sample is determined according to ASTM D4318 standard. The representative sample have a liquid limit, clay-1 (LL = 33.0%) and clay-2 (LL = 44.0%).

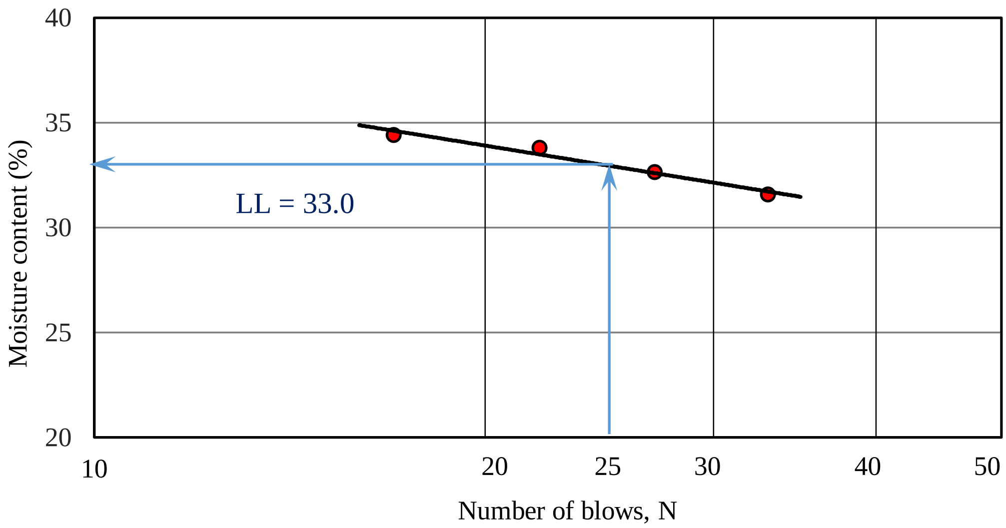


Figure 3-3: Water content vs number of blows of clay-1.

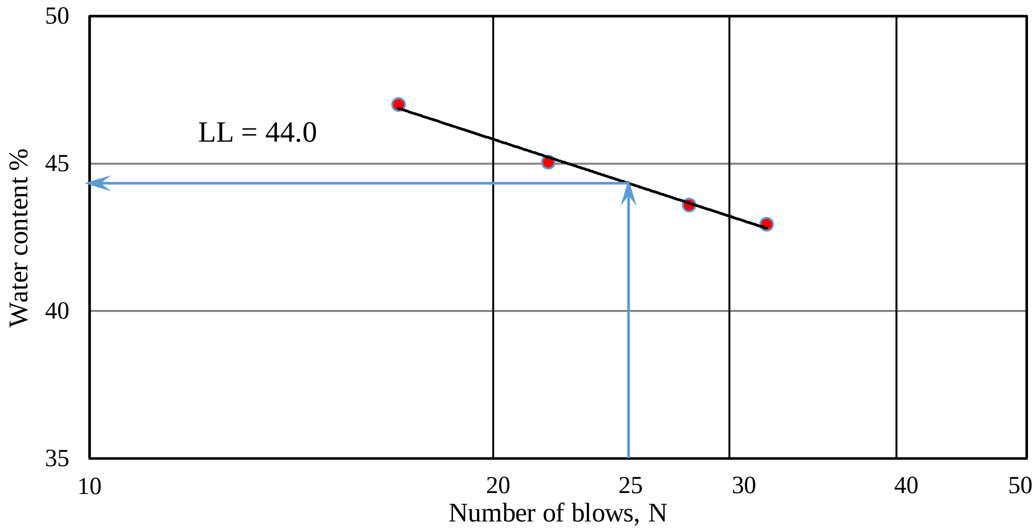


Figure 3-4: Water content vs number of blows of clay-2.

3.2.3.2 PLASTIC LIMIT

Plastic limit of representative clay is mainly used to finding water content at which clay sample change from plastic state to semi-solid state. Plastic limit of the specimen is an essential parameter for unconfined compressive strength test According to the phenomenon that, cohesive soils become plastic as their water content is increased also it leading to loss in shear strength and stability. Therefore, in this study plastic limits test will perform significant amount on unconfined compressive strength test. The plastic limit of the representative sample is determined according to ASTM D4318 standard. The plastic limit of representative sample is, clay-1 (PL = 22.5 %) and clay-2 (PL = 26.0 %).

3.2.4 COMPACTION TEST

The purpose of compaction test is to establish the maximum dry density and to understand characteristics of representative clays sample with change in moisture content. Compaction tests of the specimens are an essential parameter for unconfined compression strength test, where maximum dry density of the representative sample is used to obtain clay mass for preparing remold. In this study, the compaction test is done by standard proctor test according to ASTM D698 standard. The maximum dry unit weightclay-1 is $\gamma_{d(max)}$= 17.20 kN/m^3 and clay-2 is $\gamma_{d(max)}$= 16.16 kN/m^3.

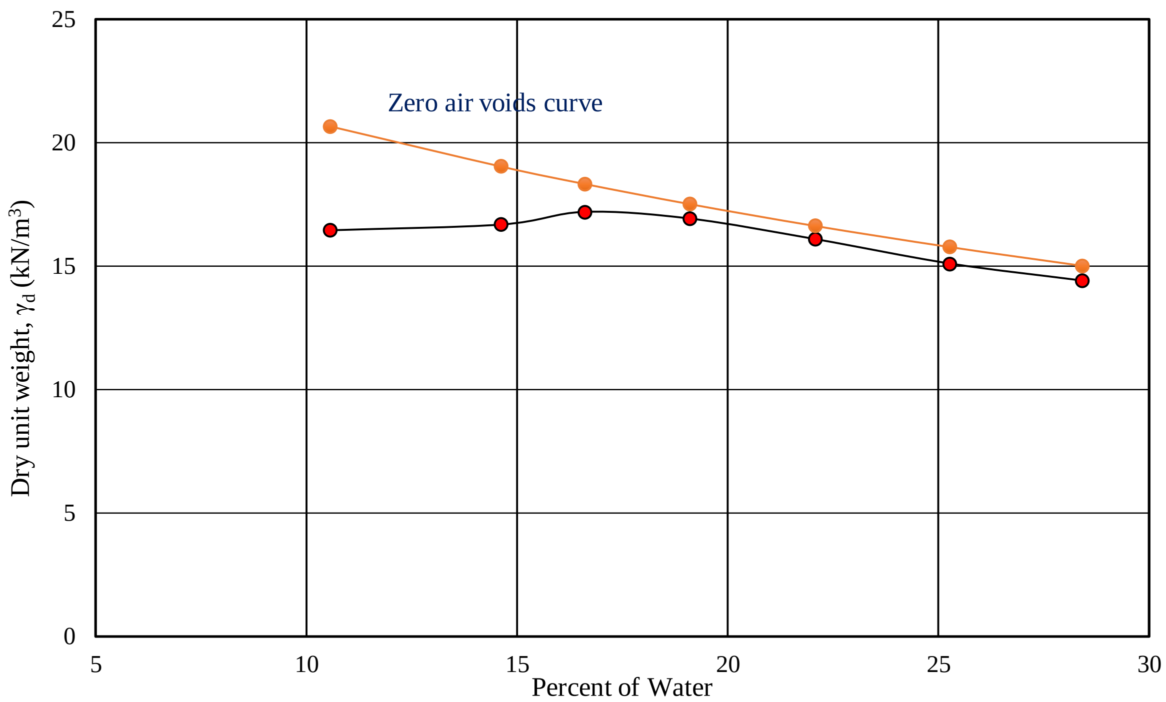


Figure 3-5: Dry unit weight vs moisture content graph for clay-1.

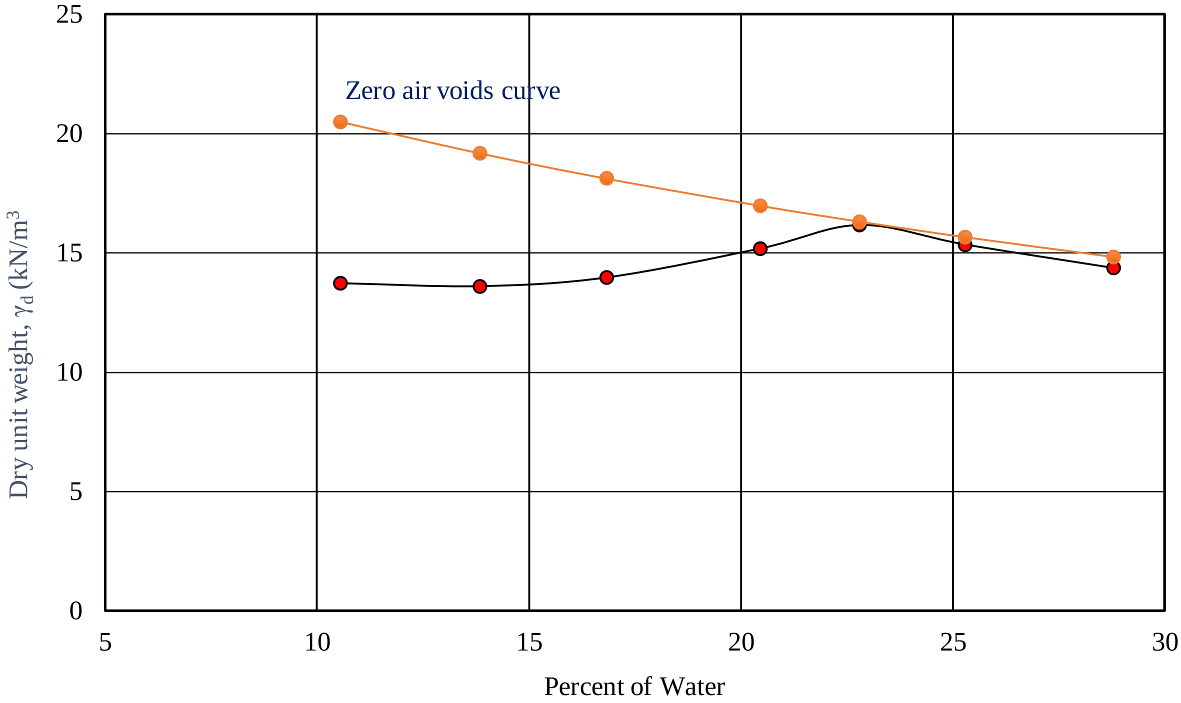


Figure 3-6: Dry unit weight vs moisture content graph for clay-2.

3.3 UNCONFINED COMPRESSIVE STRENGTH TEST

The unconfined compressive strength test so far is the most popular and easy way to testing strength of cohesive soil because it is fastest and cheapest methods of measuring unconfined compressive strength. This method is primarily used for saturated, cohesive soils recovered from thin-walled sampling tubes. This test is inappropriate for crumbly clays and dry sands because the materials would fall apart without some axial land.

The unconfined compression tests for this research are performed according to the ASTM D 2166 standard. The basic theory according to unconfined compression test and details specifications of the test equipment are presented in chapter three. For this study nine series of unconfined compression tests are conducted on remolded clay specimens made out of a representative clay sample and at three different water content for clay-1 and seven different water content for clay-2 in order to cover moisture variety of clay in different conditions in the field. Details of the test procedures including sample preparation, test procedure, calculations used for data interpretation are described in the following sections.

3.3.1 APPARATUS

To perform laboratory unconfined compressive test a number of apparatus is used according to the testing machine and sample remolded such as, unconfined mold, wooden peg about 2 inch in diameter, compression device, dial gauge, deformation indicator, dial comparator, balance, timer, oven, spatula and many more. A brief discussion of the fundamental apparatus is presented in the following sections.

Figure 3-7: Unconfined Compression Test Machine.

Compression Device

In this study, a hydraulic loading device is used as a compressive strength. Where, for cohesive soil with an unconfined compressive strength of less than 1.0tsf, the compression device has the ability to measure the compressive stress to within 0.01tsf and unconfined compressive strength of soil 1.0tsf or greater, the compression device also has the ability to measure the compressive stress to the nearest 0.05tsf.

Dial Gauge

For measuring the physical dimensions of the specimen to within 0.1 % of the measured dimension.

Deformation Indicator

The deformation indicator will be a dial indicator graduated to 0.03 mm or better and having a travel range of at least 20 % of the length of the test specimen. In this study, travel range maximum 15% of the length is enough for getting accurate results.

Dial Comparator

Dial comparator will be capable for measuring the physical dimensions of the specimen to within 0.1 % of the measured dimension.

Balance

The balance used to weigh specimens shall determine the weight of the specimen to within 0.1 % of its total weight.

Unconfined Compression Mold

For disturbed sample remolding ideal mold influence the specimen, in this specimen for avoiding any specimen size effect the ratio of diameter and height is 2.0 is used, here the mold size is 38 mm in diameter and 76 mm in height.

3.3.2 EQUATIONS FOR CALCULATIONS

▪ To calculate the axial strain (ϵ_1), for a given applied load, as follows:

$$\epsilon_1 = \frac{\Delta L}{L_O} \text{ X } 100$$

where,

L_0 = initial length of the test sample in (mm or inch).

ΔL = change of length of the sample as read from the deformation indicator in (mm or inch).

▪ For a given applied load the average cross-sectional area (A) calculate, as follows:

$$A = \frac{A_O}{\left(1 - \frac{\epsilon_1}{100}\right)}$$

Where,

A_O = average initial cross-section area of the sample in (mm^2 or inch^2).

ϵ_1 = initial strain for a given axial load.

▪ Calibration equation to convert load dial is, y = 0.010x+0.027 (kN).

Where, x= load dial.

▪ To calculate unconfined compressive strength, at nearest (1kPa or 0.01tsf)

$$q_u = \frac{P}{A}$$

where,

P = applied axial load

A = similar average cross-sectional area in (mm^2 or $inch^2$)

▪ To calculate unconsolidated undrained shear strength (s_u), as follows:

$$s_u = \frac{q_u}{2}$$

The unconsolidated undrained shear strength of a cohesive is equal one half of the unconfined compressive strength.

3.3.3 LIMITATIONS OF UNCONFINED COMPRESSIVE STRENGTH

▪ Sample disturbance (in case of samples obtained from thin wall tube) or changed from its original slat.

▪ Effective stress conditions in the field are not properly simulated.

▪ The cohesive soil conditions at initial state and during the test the water content and the pore pressure development under stress deformation cannot be controlled and measured.

▪ Limitations of sample size to represent the in situ conditions of soil with sand seams gravel and crack or fissures.

▪ A saturated sample will thus remain saturated during the test with no change in the sample volume, water content, or void ratio.

3.4 SAMPLE PREPARATION

Clay specimens of size 76 mm in height and 38 mm in diameter are used and prepared using moist tamping technique. First the desired density for the test specimens and the quantity of oven dry samples required to prepare the specimens at desired density are estimated. Secondly test specimens are prepared on different water content for clay-1, such as moisture contents are (20%, 22.5% and 25%). And for clay-2 the moisture contents are (20%, 22.5%, 25%, 27.5%, 30%, 32.5% and 35%). However, the selected desired density is 90% of maximum dry density of both samples for laboratory tests in order to cover diversity of standing clay conditions in the field. After taking required amount of oven dried clay samples in a container a desired amount of water added to the clay to bring the clay at required amount of moisture content. After that, the sample and water mixed thoroughly and then the container sealed to prevent change in moisture content and the mixed clay is kept for two hours to assure uniform moisture content distribution throughout the clay. The specimens are prepared using split mold size of 38 mm in diameter and 76 mm in height. Then place lubricated inside the mold to making friction less. After that the moist clay is placed into the mold in three separate layers of equal mass and thickness. Each layer is compacted manually by using wooden peg diameter of 2 mm. Each layer is compacted approximately same number of blow is applied to achieve targeted density and specimen height. After finished the final layer compaction, the collar is removed carefully without disturbing the compacted clay inside the mold and specimen size.

(a)

(b)

Figure 3-8: (a) Split mold before, (b) After assemble

3.5 TEST PROCEDURE

To perform unconfined compression test, extrude clay specimen is placed in a loading frame on a metal plate (sandwiched between the end plate) by turning a crank, then raised the level of the bottom plate. After that the top of the specimen is restrained by the top plate, which is attached to the calibrated proving ring. As the bottom plate is raised, then an axial load is applied to the specimen. Then the load is gradually increased to the specimen and the readings are taken periodically of the force applied to the specimen and the resulting deformation. The load is continued until the clay specimen develops the deformation become excessive. Then all the measured data are used to determine the stress vs strain characteristics of the clay specimens. Finally taking the specimens wet weight and then kept specimen in oven for 24 hours. After completed oven dried, measured oven dried clay samples for cross check the moisture content.

3.6 DATA CALCULATIONS

From unconfined compression test, all measured data are used to determine the stress vs strain characteristics of representative samples. In this study, total ten times unconfined compression test have done and their calculation procedure and calibration equation to convert load dial details have described earlier in chapter three at section.

Table 3-1: Calculations for unconfined compressive strength of clay-1 at water content 20%.

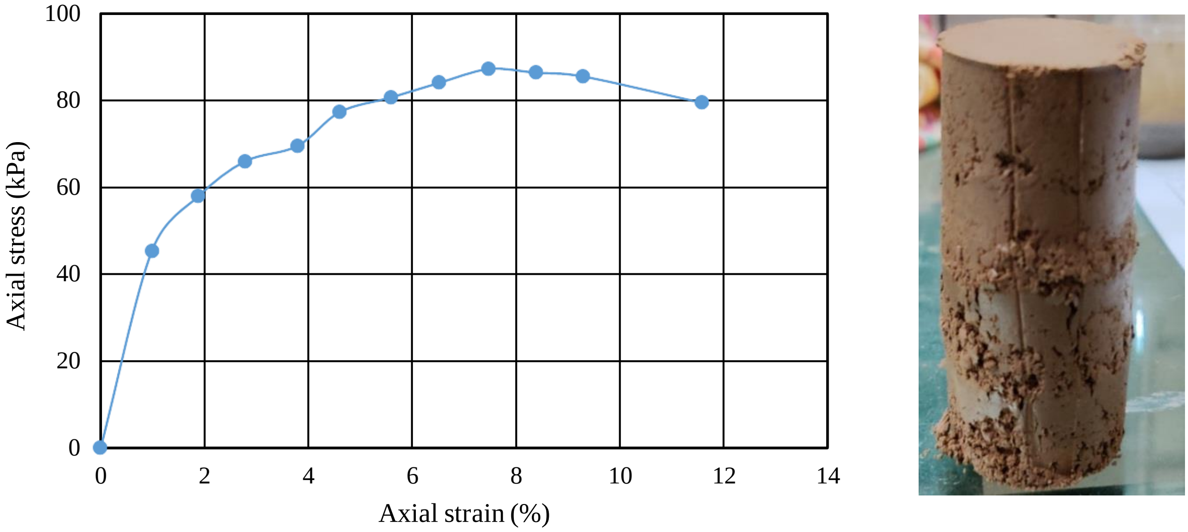
Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load dial P' (proving ring)	Load, P (kN)	Axial strain	Axial strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	75	0.75	2.5	0.052	0.010	0.987	0.0011	45.403
1	143	1.43	4	0.067	0.019	1.882	0.0012	57.971
1.5	211	2.11	5	0.077	0.028	2.776	0.0012	66.016
2	288	2.88	5.5	0.082	0.038	3.789	0.0012	69.570
2.5	350	3.5	6.5	0.092	0.046	4.605	0.0012	77.393
3	425	4.25	7	0.097	0.056	5.592	0.0012	80.755
3.5	495	4.95	7.5	0.102	0.065	6.513	0.0012	84.089
4	568	5.68	8	0.107	0.075	7.474	0.0012	87.304
4.5	637	6.37	8	0.107	0.084	8.382	0.0012	86.448
5	706	7.06	8	0.107	0.093	9.289	0.0013	85.591
5.5	880	8.8	7.5	0.102	0.116	11.579	0.0013	79.532

Table 3-2: Calculations for unconfined compressive strength of clay-1 at water content 22.5%.

Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load dial P' (proving ring)	Load, P (kN)	Axial strain	Axial strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	66	0.66	0.5	0.032	0.009	0.868	0.0011	27.974
1	137	1.37	1	0.037	0.018	1.803	0.0012	32.040
1.5	208	2.08	1	0.037	0.027	2.737	0.0012	31.735
2	276	2.76	1.5	0.042	0.036	3.632	0.0012	35.692
2.5	352	3.52	2	0.047	0.046	4.632	0.0012	39.527
3	435	4.35	2	0.047	0.057	5.724	0.0012	39.074
3.5	495	4.95	2.5	0.052	0.065	6.513	0.0012	42.869
4	565	5.65	2.5	0.052	0.074	7.434	0.0012	42.446
4.5	638	6.38	3	0.057	0.084	8.395	0.0012	46.045
5	709	7.09	3.5	0.062	0.093	9.329	0.0013	49.573
5.5	779	7.79	3.5	0.062	0.103	10.250	0.0013	49.070
6	851	8.51	4	0.067	0.112	11.197	0.0013	52.467
6.5	925	9.25	4.5	0.072	0.122	12.171	0.0013	55.764
7	995	9.95	4.5	0.072	0.131	13.092	0.0013	55.180
7.5	1068	10.68	5	0.077	0.141	14.053	0.0013	58.359

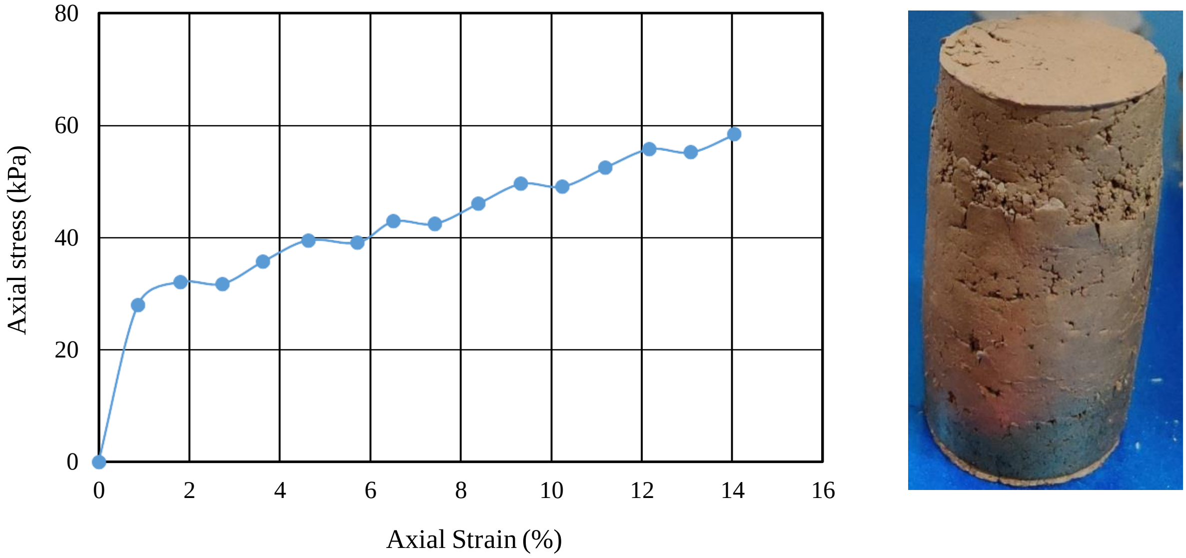
Table 3-3: Calculations for unconfined compressive strength of clay-1 at water content 25%.

Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load dial P' (proving ring)	Load, P (kN)	Axial strain	Axial strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	70	0.7	0.5	0.032	0.009	0.921	0.0011	27.959
1	138	1.38	0.5	0.032	0.018	1.816	0.0012	27.706
1.5	212	2.12	0.5	0.032	0.028	2.789	0.0012	27.432
2	283	2.83	1	0.037	0.037	3.724	0.0012	31.413
2.5	355	3.55	1	0.037	0.047	4.671	0.0012	31.104
3	454	4.54	1	0.037	0.060	5.974	0.0012	30.679
3.5	495	4.95	1.5	0.042	0.065	6.513	0.0012	34.625
4	568	5.68	1.5	0.042	0.075	7.474	0.0012	34.269
4.5	638	6.38	2	0.047	0.084	8.395	0.0012	37.967
5	710	7.1	2	0.047	0.093	9.342	0.0013	37.574
5.5	785	7.85	2	0.047	0.103	10.329	0.0013	37.165
6	854	8.54	2.5	0.052	0.112	11.237	0.0013	40.703
6.5	926	9.26	2.5	0.052	0.122	12.184	0.0013	40.268
7	998	9.98	2.5	0.052	0.131	13.132	0.0013	39.834
7.5	1065	10.65	3	0.057	0.140	14.013	0.0013	43.221



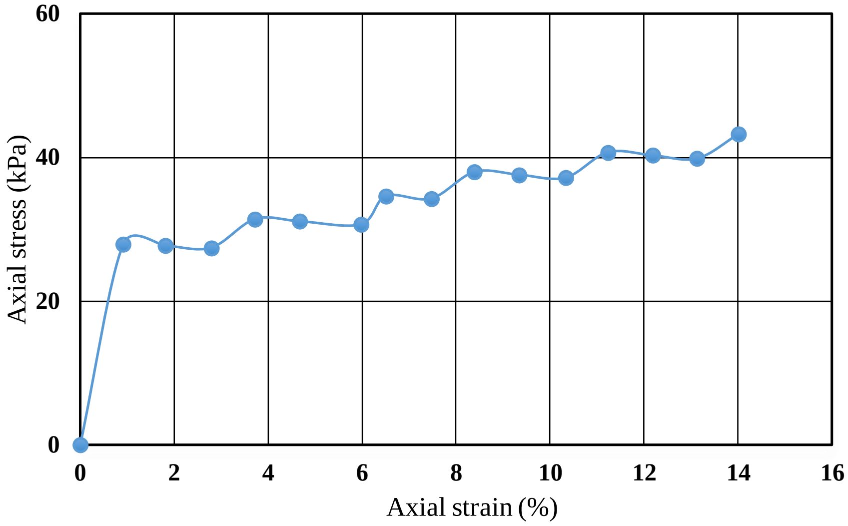
(a) **(b)**

Figure 3-9: (a) Axial stress vs axial strain (b) failure mode of clay-1 at water content 20%.



(a) **(b)**

Figure 3-10: (a) Axial stress vs axial strain (b) failure mode of clay-1 at water content 22.5%.



(a) **(b)**

Figure 3-11: (a) Axial stress vs axial strain (b) failure mode of clay-1 at water content 25%.

Table 3-4: Calculations for unconfined compressive strength of clay-2 at water content 20%.

Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load dial P' (Provig ring)	Load, P (kN)	Axial strain	Axial Strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	68	0.68	2.5	0.052	0.009	0.895	0.0011	45.445
1	127	1.27	8	0.107	0.017	1.671	0.0012	92.780
1.5	190	1.9	14	0.167	0.025	2.500	0.0012	143.585
2	262	2.62	14	0.167	0.034	3.447	0.0012	142.190
2.5	339	3.39	10.5	0.132	0.045	4.461	0.0012	111.210

Table 3-5: Calculations for unconfined compressive strength of clay-2 at water content 22.5%.

Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load dial P' (provig ring)	Load, P (kN)	Axial strain	Axial strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	70	0.7	3	0.057	0.009	0.921	0.0011	49.802
1	136	1.36	6	0.087	0.018	1.789	0.0012	75.347
1.5	205	2.05	8	0.107	0.027	2.697	0.0012	91.811
2	273	2.73	9	0.117	0.036	3.592	0.0012	99.468
2.5	346	3.46	9.5	0.122	0.046	4.553	0.0012	102.686
3	420	4.2	10	0.127	0.055	5.526	0.0012	105.804
3.5	496	4.96	9.5	0.122	0.065	6.526	0.0012	100.563

Table 3-6: Calculations for unconfined compressive strength of clay-2 at water content 25%.

Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load sial P' (proving ring)	Load, P (kN)	Axial strain	Axial strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	62	0.62	1	0.037	0.008	0.816	0.0011	32.362
1	114	1.14	2	0.047	0.015	1.500	0.0012	40.825
1.5	180	1.8	3	0.057	0.024	2.368	0.0012	49.074
2	252	2.52	4	0.067	0.033	3.316	0.0012	57.124
2.5	322	3.22	4.5	0.072	0.042	4.237	0.0012	60.802
3	394	3.94	5	0.077	0.052	5.184	0.0012	64.381
3.5	465	4.65	5.5	0.082	0.061	6.118	0.0012	67.886
4	538	5.38	6	0.087	0.071	7.079	0.0012	71.289
4.5	610	6.1	6	0.087	0.080	8.026	0.0012	70.562
5	785	7.85	6.5	0.092	0.103	10.329	0.0013	72.749
5.5	852	8.52	7	0.097	0.112	11.211	0.0013	75.949
6	923	9.23	7	0.097	0.121	12.145	0.0013	75.150
6.5	990	9.9	7	0.097	0.130	13.026	0.0013	74.395
7	1068	10.68	7	0.097	0.141	14.053	0.0013	73.518

Table 3-7: Calculations for unconfined compressive strength of clay-2 at water content 27.5%.

Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load dial P' (proving ring)	Load, P (kN)	Axial strain	Axial strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	70	0.7	0.5	0.032	0.009	0.921	0.0011	27.959
1	142	1.42	1	0.037	0.019	1.868	0.0012	32.018
1.5	210	2.1	1.5	0.042	0.028	2.763	0.0012	36.014
2	285	2.85	2	0.047	0.038	3.750	0.0012	39.892
2.5	357	3.57	2.5	0.052	0.047	4.697	0.0012	43.701
3	428	4.28	2.5	0.052	0.056	5.632	0.0012	43.273
3.5	502	5.02	3	0.057	0.066	6.605	0.0012	46.944
4	570	5.7	3.5	0.062	0.075	7.500	0.0012	50.573
4.5	645	6.45	4	0.067	0.085	8.487	0.0012	54.069
5	712	7.12	4.5	0.072	0.094	9.368	0.0013	57.544
5.5	780	7.8	4.5	0.072	0.103	10.263	0.0013	56.976
6	855	8.55	5	0.077	0.113	11.250	0.0013	60.262
6.5	925	9.25	5	0.077	0.122	12.171	0.0013	59.637
7	998	9.98	5.5	0.082	0.131	13.132	0.0013	62.815
7.5	1068	10.68	6	0.087	0.141	14.053	0.0013	65.938

Table 3-8: Calculations for unconfined compressive strength of clay-2 at water content 30%.

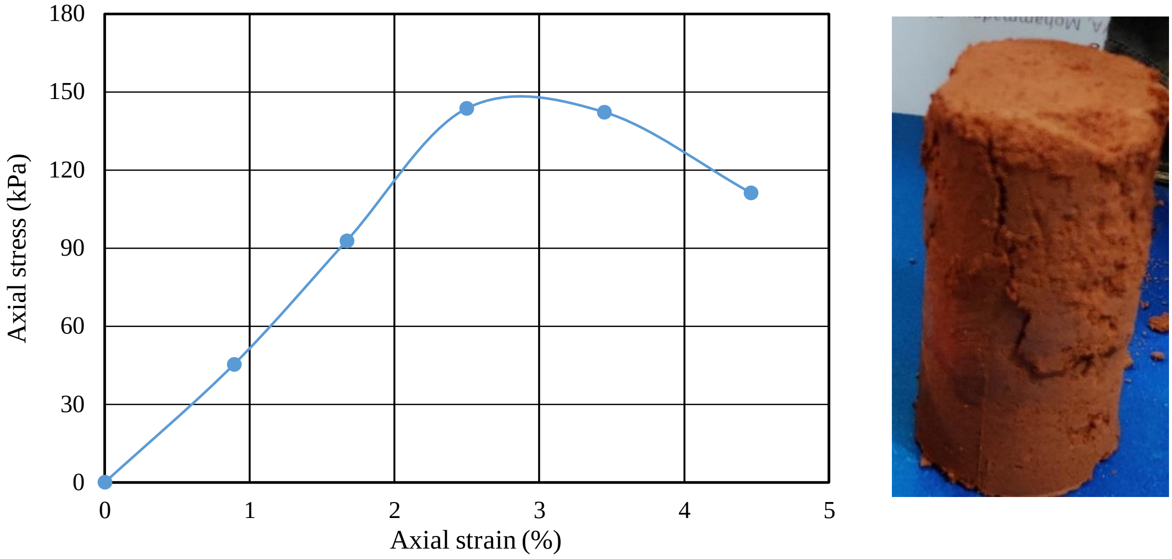
Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load dial P' (proving ring)	Load, P (kN)	Axial strain	Axial strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	69	0.69	0.5	0.032	0.009	0.908	0.0011	27.962
1	140	1.4	1	0.037	0.018	1.842	0.0012	32.027
1.5	211	2.11	1	0.037	0.028	2.776	0.0012	31.722
2	282	2.82	1.5	0.042	0.037	3.711	0.0012	35.663
2.5	355	3.55	2	0.047	0.047	4.671	0.0012	39.510
3	427	4.27	2	0.047	0.056	5.618	0.0012	39.118
3.5	495	4.95	2	0.047	0.065	6.513	0.0012	38.747
4	570	5.7	2.5	0.052	0.075	7.500	0.0012	42.416
4.5	642	6.42	3	0.057	0.084	8.447	0.0012	46.019
5	712	7.12	3	0.057	0.094	9.368	0.0013	45.556
5.5	789	7.89	3	0.057	0.104	10.382	0.0013	45.046
6	856	8.56	3	0.057	0.113	11.263	0.0013	44.603
6.5	930	9.3	3.5	0.062	0.122	12.237	0.0013	47.983
7	997	9.97	4	0.067	0.131	13.118	0.0013	51.332

Table 3-9: Calculations for unconfined compressive strength of clay-2 at water content 32.5%.

Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load dial P' (proving ring)	Load, P (kN)	Axial strain	Axial strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	65	0.65	0.5	0.032	0.009	0.855	0.0011	27.977
1	138	1.38	0.5	0.032	0.018	1.816	0.0012	27.706
1.5	208	2.08	0.5	0.032	0.027	2.737	0.0012	27.446
2	278	2.78	0.5	0.032	0.037	3.658	0.0012	27.186
2.5	353	3.53	1	0.037	0.046	4.645	0.0012	31.112
3	422	4.22	1	0.037	0.056	5.553	0.0012	30.816
3.5	495	4.95	1	0.037	0.065	6.513	0.0012	30.503
4	568	5.68	1	0.037	0.075	7.474	0.0012	30.189
4.5	638	6.38	1	0.037	0.084	8.395	0.0012	29.889
5	715	7.15	1	0.037	0.094	9.408	0.0013	29.558
5.5	788	7.88	1.5	0.042	0.104	10.368	0.0013	33.197
6	857	8.57	1.5	0.042	0.113	11.276	0.0013	32.861
6.5	930	9.3	1.5	0.042	0.122	12.237	0.0013	32.505
7	1000	10	2	0.047	0.132	13.158	0.0013	35.993

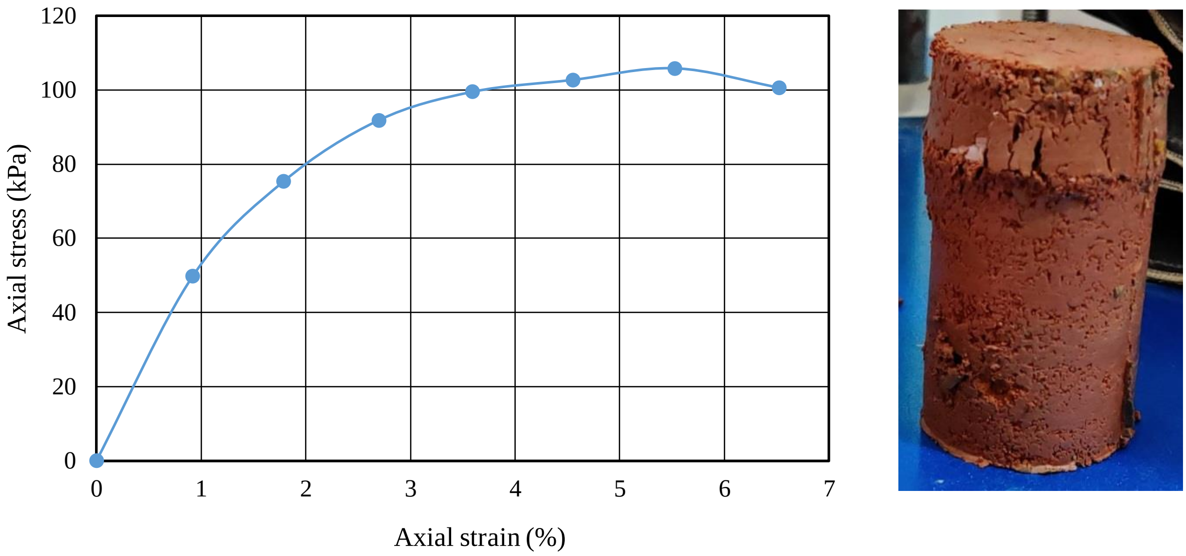
Table 3-10: Calculations for unconfined compressive strength of clay-2 at water content 35%.

Elapsed time (minutes)	Dial reading	Sample deformation ΔL(mm)	Load Dial P' (proving ring)	Load, P (kN)	Axial strain	Axial strain (ϵ) %	Corrected area (m^2)	Stress (kPa)
0	0	0	0	0	0	0	0.0011	0
0.5	70	0.7	0.5	0.032	0.009	0.921	0.0011	27.959
1	138	1.38	0.5	0.032	0.018	1.816	0.0012	27.706
1.5	212	2.12	0.5	0.032	0.028	2.789	0.0012	27.432
2	283	2.83	1	0.037	0.037	3.724	0.0012	31.413
2.5	356	3.56	1	0.037	0.047	4.684	0.0012	31.100
3	428	4.28	1	0.037	0.056	5.632	0.0012	30.790
3.5	500	5	1	0.037	0.066	6.579	0.0012	30.481
4	573	5.73	1	0.037	0.075	7.539	0.0012	30.168
4.5	645	6.45	1	0.037	0.085	8.487	0.0012	29.859
5	715	7.15	1	0.037	0.094	9.408	0.0013	29.558
5.5	788	7.88	1	0.037	0.104	10.368	0.0013	29.245
6	860	8.6	1	0.037	0.113	11.316	0.0013	28.936
6.5	933	9.33	1.5	0.042	0.123	12.276	0.0013	32.490
7	1005	10.05	1.5	0.042	0.132	13.224	0.0013	32.139



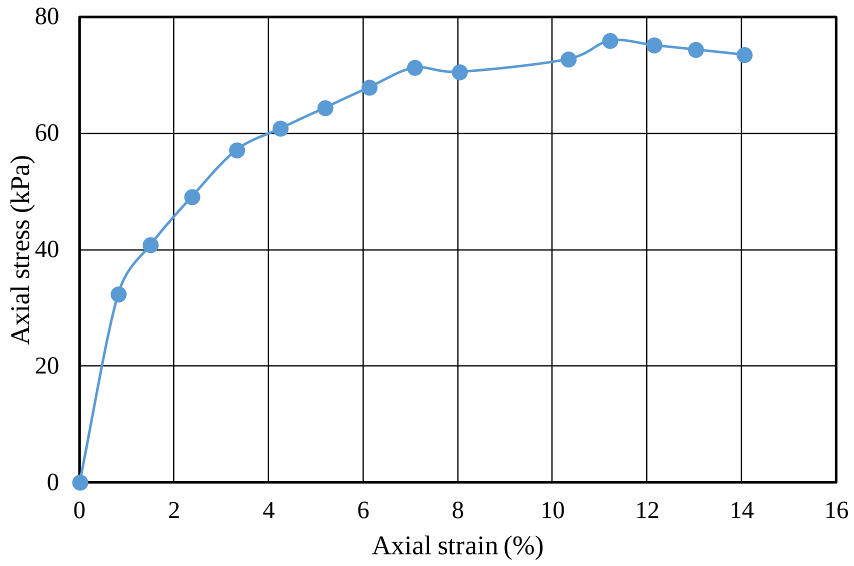
(a) **(b)**

Figure 3-12: (a) Axial stress vs axial strain (b) failure mode of clay-2 at water content 20%.



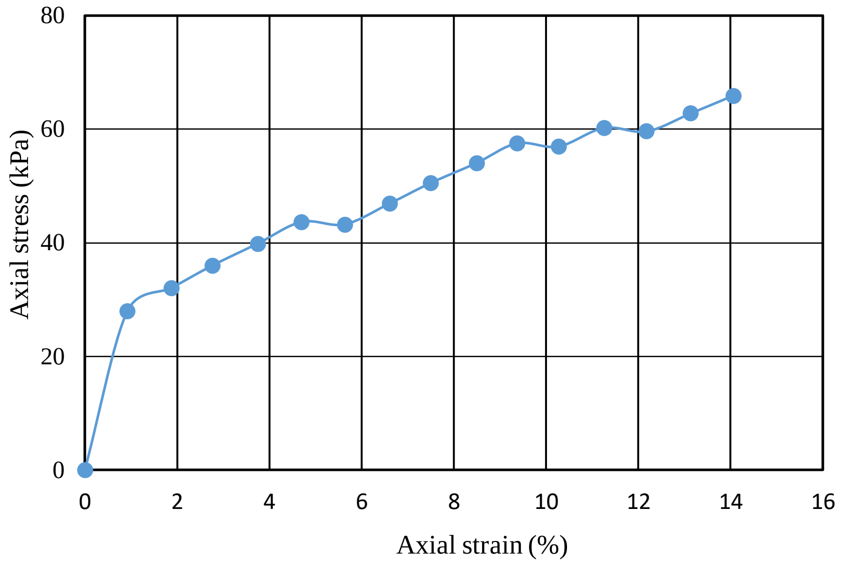
(a) **(b)**

Figure 3-13: (a) Axial stress vs axial strain (b) failure mode of clay-2 at water content 22.5%.



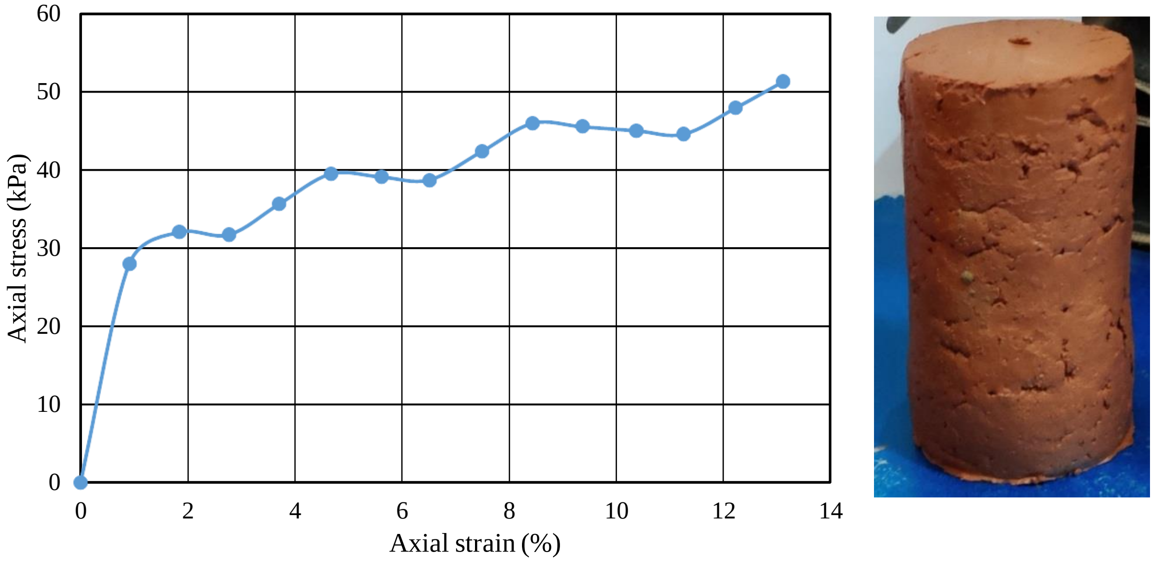
(a) **(b)**

Figure 3-14: (a) Axial stress vs axial strain (b) failure mode of clay-2 at water content 25%.



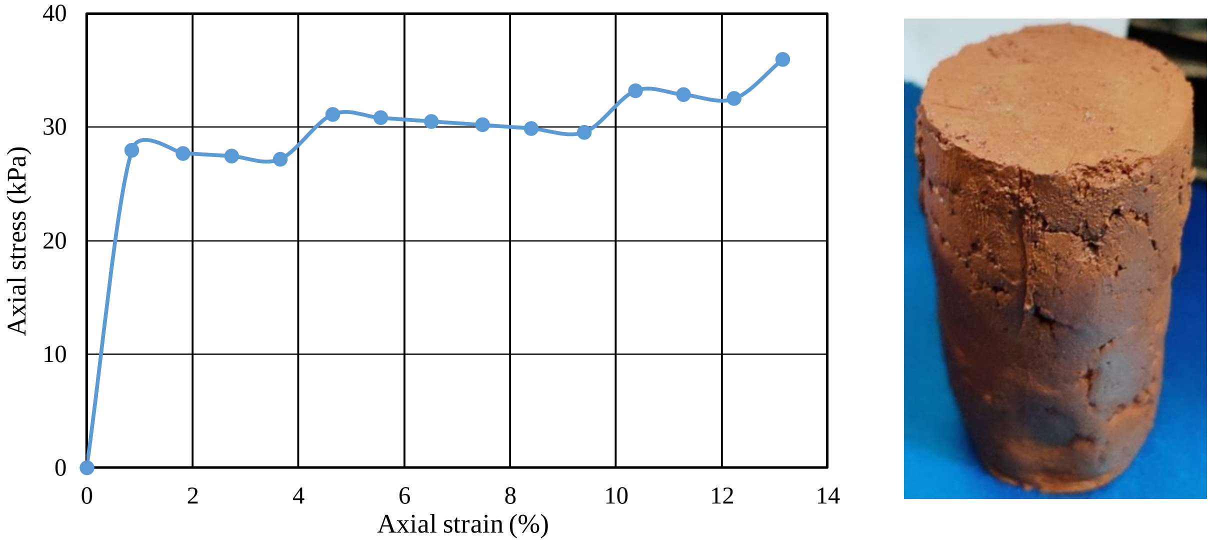
(a) **(b)**

Figure 3-15: (a) Axial stress vs axial strain (b) failure mode of clay-2 at water content 27.5%.



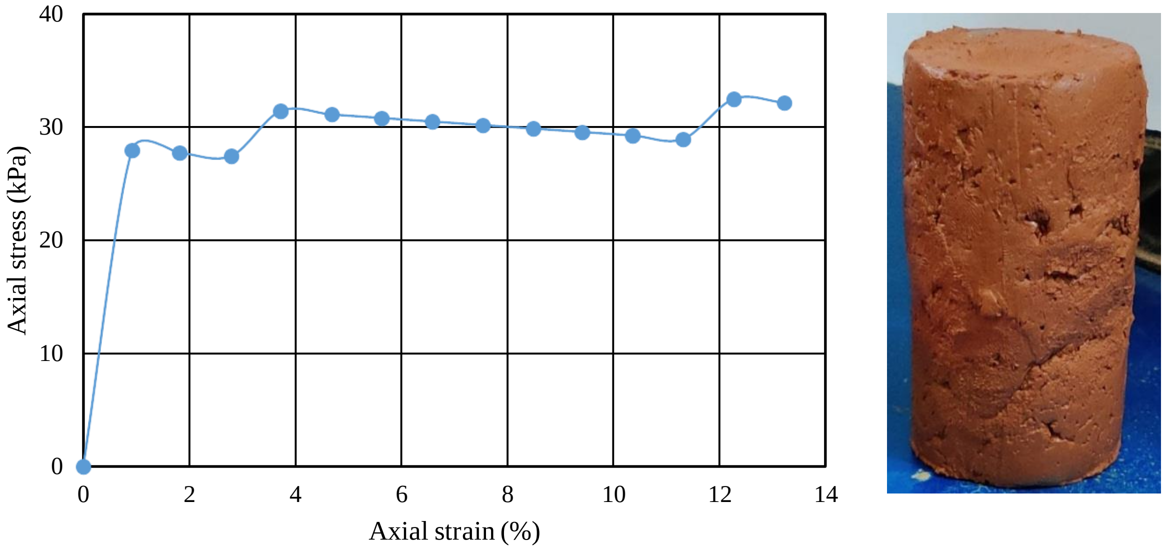
(a) **(b)**

Figure 3-16: (a) Axial stress vs axial strain (b) failure mode of clay-2 at water content 30%.



(a) **(b)**

Figure 3-17: (a) Axial stress vs axial strain (b) failure mode of clay-2 at water content 32.5%.



(a) **(b)**

Figure 3-18: (a) Axial stress vs axial strain (b) failure mode of clay-2 at water content 35%.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 GENERAL

In this research a total of ten unconfined compression test are conducted on remolded clay specimens with water contents at clay-1(water content 20%, 22.5% and 25%) and clay-2 moisture content 20%, 22.5%, 25%, 27.5%, 30%, 32.5%and 30% under axial load. This chapter discussed about the unconfined compressive strength result of representative samples, which is evaluated from laboratory investigation.

4.2 RESULTS AND DISCUSSION

The unconfined compression test was conducted for two different types of clay with various water content and the result are presented in Figure 4-1 and Figure 4-2.

It was found that the unconfined compressive strength of clays goes on decreasing with increasing in water content, in the case of both clay-1 and clay-2 samples.

It is also observed that the unconfined compressive strength of clay has a linear relationship to the water content in Fig 4-3 and Fig 4-4.

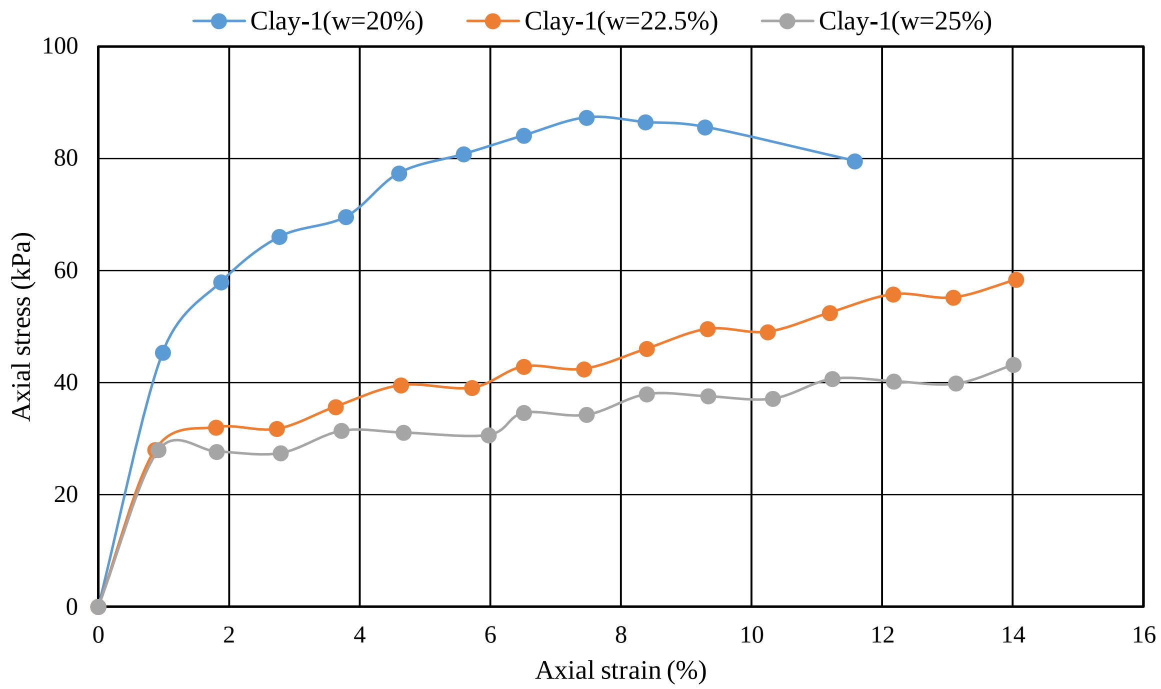


Figure 4-1: Axial stress vs axial strain of clay-1.

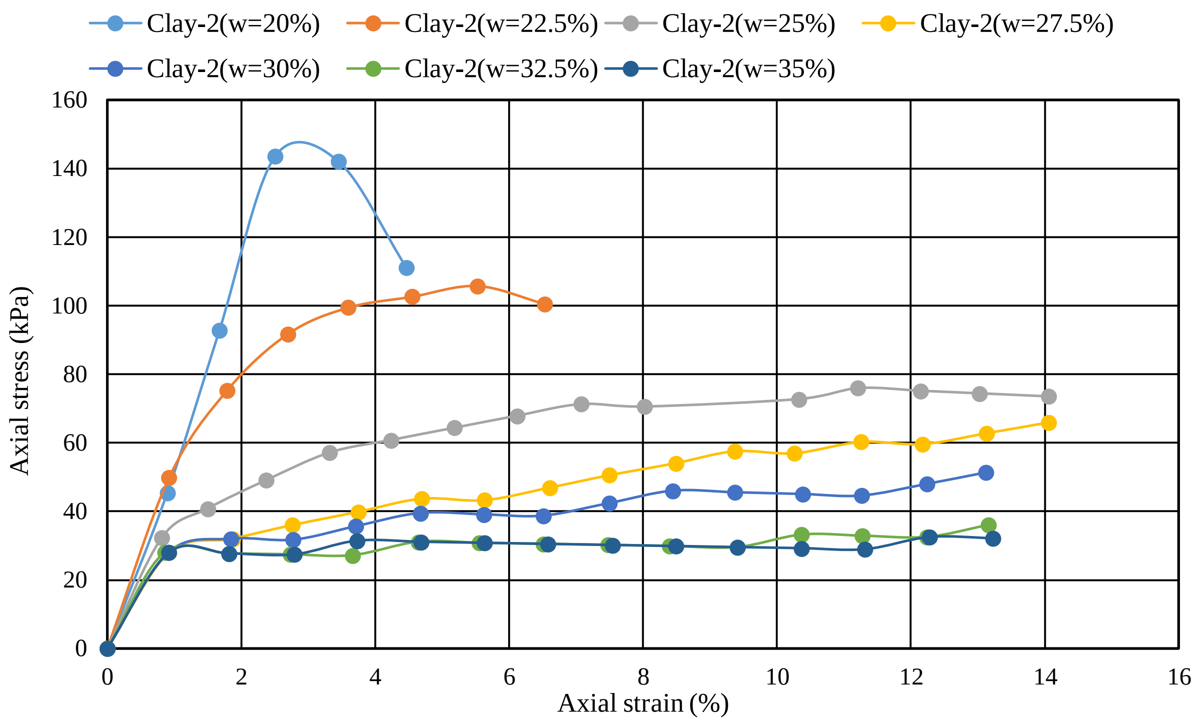


Figure 4-2: Axial stress vs axial strain of clay-2.

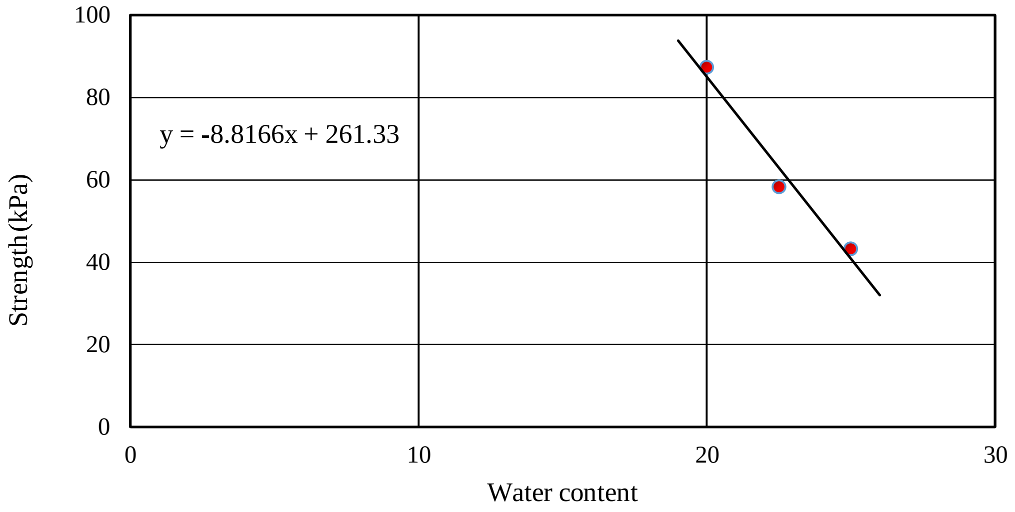


Figure 4-3: Strength vs water content of clay-1.

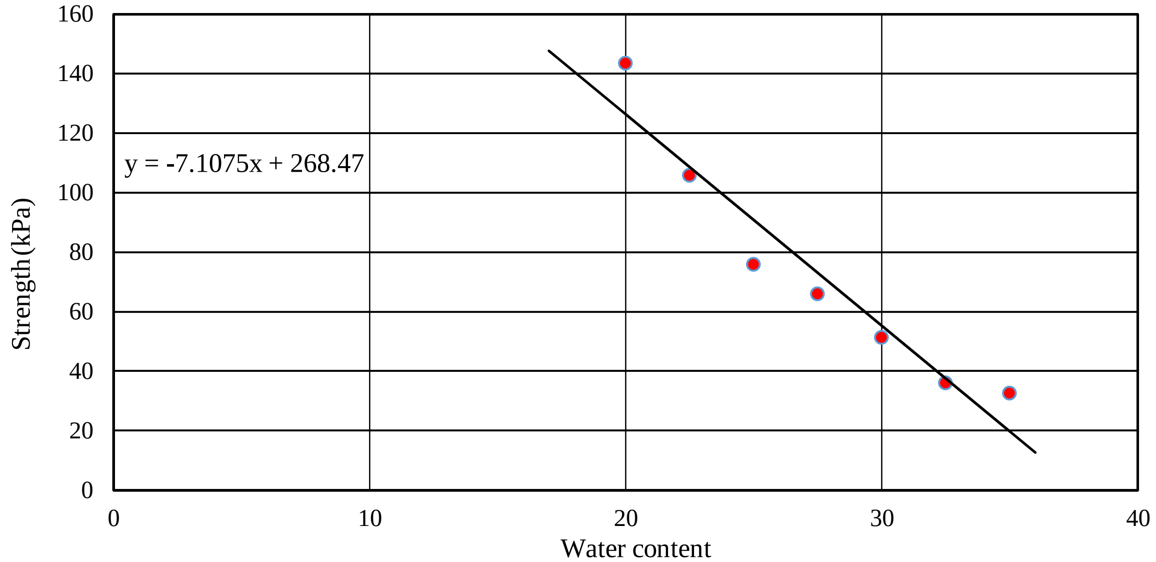


Figure 4-4: Strength vs water content of clay-2.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The conclusions drawn from this research may be summarized as follows –

▪ Water content has extreme effects in the reduction of unconfined compressive strength and this reduction is predominant while water content reaches near liquid limit.

▪ It also observed that the unconfined compressive strength of clay has a linear relationship to the water content.

▪ The output of this research can be used to predict the reduction of unconfined compressive strength with changes of water content.

5.2 SIGNIFICANCE OF RESEARCH

There is no one specific reason for a decrease or increase in strength of the representative sample tested. The effects of water content on clays strength have been presented to bring out the fact that moisture, which is always present in field with variation of water content and the variation of water effects of clay must be considered in future soils mechanics design. It may also become economical to dewater a zone which shows pronounced weakening with the presence of water or, on the other hand, saturate an area where caving is desired. The effect of water and strength on open pit mining and tunneling operations and slope stability designs must also be considered. At the present time determining the allowable design strength of clay is a difficult task, but the effects of water contents must be considered.

5.3 RECOMMENDATIONS

Shear strength of soils is highly affected by water conditions especially if the soil contains clay materials. Usually the laboratory specimen, which are used to determine shear strength of soil are prepared at water content and dry density same as in the field conditions, without respect to the fact, that the conditions in the future might not remain the same.

Also this research suggest the following point should be study for further study-

▪ Effect of water content on shear strength parameters of stabilized soil.

▪ Measurements on the pore water pressures developed to determine their influence on the saturated strength of clay.

▪ Effect of compaction on strength of clay with variation of moisture.

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