THE EFFECT OF SAMPLE HEIGHT ON THE STRESS STRAIN BEHAVIOR OF BLACK CLAY SOILS

Birtukan Ayenew[1]* and Samuel Tadesse[2]

ABSTRACT

This study investigated the effect of the sample height on the stress and strain behavior of the black clay soil in Addis Ababa by using unconfined compression test (UCT). A cohesive soil specimen height to diameter (H/D) ratio of 2 up to 3 is recommended by accepted scientific and technical authorities. However, published reports on the effect of sample height on stress- strain behavior of black clay soil in Addis Ababa are limited. The study was conducted by four different samples with H/D ratios of 1, 1.5, 2, and 2.5 keeping constant 38mm diameter of sample. The test results showed that unconfined compressive strength decreases with increasing H/D ratio of the specimens. The pre-peak stress-strain curve increases with decreasing H/D ratio. The smaller specimen with H/D ratio of 1 showed consistent bulging, diagonal and vertical failure plane within the entire part of it. The specimens with H/D ratio of 1.5 showed diagonal shear failure within the entire height of specimen and bulging localized to some portions of specimen height. The specimens H/D ratio of 2 and 2.5 showed different and complicated failure planes; which are diagonal, with near vertical shear failure planes and bulging in some part of it.

Keywords: Stress-strain curve, height-to-diameter ratio, unconfined compression test and black clay soil.

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1. INTRODUCTION

1.1. Background information

Deep black clay soils often known as black cotton soils which cover 8 million Ha of the Ethiopian highlands (Jutzi, 1988). Generally, clay is a naturally occurring material primarily composed of fine-grained minerals, showing plasticity when mixed with appropriate amount of moisture and becomes hard when dried or fired. Clay is small particle size usually smaller than 0.002 mm (Firoozi et al., 2016).

Clay minerals are mostly found in the form of sheets; their thickness is relatively smaller than the width and length of the sheets, their surface area is larger than their volume. As a result the behavior of clay is governed by the surface forces (Terzaghi et al., 1996). Most black clay soils are expansive and contain considerable amount of montmorillonite mineral which has a potential for swelling or shrinking due to changes in its moisture content (Chen, 2012, Ramesh et al., 2014).

Black cotton soil occurs in many countries such as Australia, Canada, Ethiopia, Ghana, India, South Africa, USA, etc. In Ethiopia, black cotton soil occurs in the northern and central Ethiopian Plateaus, the Rift valley, inter-mountain depressions, alluvial plains, etc. Even in the capital city, Addis Ababa, considerable areas of Bole, Kotebe, CMC and Mekanisa, are covered by black cotton soils (Mulachew, 2005). Addis Ababa map sheet is mainly covered by three main soil types black cotton soil, brown soil, and lateritic soil (Fentaw and Alemayehu, 2011). A great number of residential and office buildings are located in the eastern and southern part of Addis Ababa, where expansive soils are predominant. The undrained shear strength of such clay soil is determined by using UCT, which is easily performed and economical than the other tests (Teferra and Yohannes, 1986).

The unconfined compressive strength which fairly describes the undrained conditions of fine grained (cohesive and semi-cohesive) foundations, is widely used in almost all geotechnical engineering applications, such as buildings, bridges, dams, and embankments (Güneyli and Rüşen, 2016).

The UCT results determine cohesion, the unconfined compressive strength and stress- strain behavior of the soils in the undisturbed, remolded or compacted condition using strain-controlled application of the axial load (Güneyli and Rüşen, 2016, DING Q and H-l, 2014). Pore pressures are not measured in an unconfined compression test; consequently, the effective stress is unknown. Hence, the undrained shear strength measured in an unconfined test is expressed in terms of the total stress (Technology). There are a number of factors that affect the compressive strength, cohesion and stress-strain behavior of the clay soil while conducting the UCT. Some of the factors are sample disturbance, sample size, confinement. The sampling disturbance and confinement usually have the effect of lowering the strength of the soil or reducing the slope of stress strain behavior of clay soil (Güneyli and Rüşen, 2016, Terzaghi et al., 1996).

One of the critical problems in geotechnical engineering analysis for determining undrained shear strength is the effect of sample height on stress-strain behavior of clay soil.

Effect of length to diameter ratio on the unconfined compressive strength of cohesive soil specimens conducted by Guneyli and Rüşen (2016) indicated that the unconfined compression strength value

decreases significantly with increasing length-to-diameter ratio of clay soil which are Handere clay, Almanpınari clay, Sam-Tekin clay, and Kaolinite. The effect of specimen shape on the UCS values of those four clay soils were determined by testing 11 compacted cylindrical specimens with L/D ratios ranging from 0.5 to 3. The test results showed that the decrease in UCS value becomes particularly steep when the length-to-diameter ratio exceeds 1, but then becomes less steep when the length-to-diameter ratio is between 1.25 and 2.5. In addition, the failure pattern generally changes from ductile to brittle and the failure mechanism develops in quite complex and obscure ways when the length-to-diameter ratio is greater than 2.75. Brittle failure appears to be particularly dominant in the range $1.25 \leq L/D \leq 2.5$. Brittle and ductile failure mechanisms develop together in complex ways when $L/D \geq 2.75$ (Güneyli and Rüşen, 2016) .

Merga (2016) determined the appropriate sample size of red clay soil in Addis Ababa by using the UCT. Cylindrical soil samples were used with 4 different H/D ratios from 1:1 to 2.5:1, prepared from red clay soils in Bethel area of Addis Ababa. The stress-strain curves showed that peak strengths of all specimens tend to increase with decreasing height to diameter ratio. The peak strength is large for H/D =1 and decreases as the specimen's height increases. Based on the uniformity of the stress-strain curve, the failure patterns developed within the entire specimens height and axial strain ranges at which sample attain its peak strength for the investigated ranges of H/D ratio, it is possible to use samples with H/D = 1 to H/D = 2 to determine undrained shear strength of red clay soil in Addis Ababa (Terzaghi et al., 1996).

There are published data on engineering property of black clay soil in Addis Ababa (Ababu, 2019, Abeje, 2017, Ephrem, 2020, Gashaw et al., 2021, Kiros, 2016, Mindaye et al., 2021, Moges and Meten, 2019, Tsion, 2021, Winta, 2016); however published data on the effect of sample height on the stress and strain behavior of black clay soil are limited. Hence, the main objective of this study is to investigate the effect of sample height on the stress and strain behavior of black clay soil by using unconfined compression test in Addis Ababa specifically at Bole Ayat sub city.

2. METHODOLOGY

To achieve the objectives of this study, preliminary information about establishment of black clay soils in Addis Ababa was gathered and research papers related to this study reviewed. Disturbed soil samples were collected from Bole Ayat condominium project at a depth of 1.5m. Some of the index properties of soil were determined which are used for soil classifications and remolding purposes for unconfined compression test. Unconfined compressive strength and cohesion of black clay soil determined by using the constant sample diameter 38 mm and different sample height of 38 mm, 57 mm, 76 mm and 95 mm keeping within optimum moisture content. All test procedures and materials were done according to American Society for Testing Materials (ASTM) standards namely, ASTM 4318, ASTM 854-0, ASTM 698-00 and ASTM 2166-00.

3. LABORATORY TESTS

Index Property Tests

The index properties of soil are: specific gravity, water content, particle size distribution, in-situ density, Atterberg limits, relative density and free swell. The

Atterberg limits for soils in Addis Ababa Bole sub city specifically around Bole Ayat are summarized in Table 1. It indicates that the black clay soil is highly plastic.

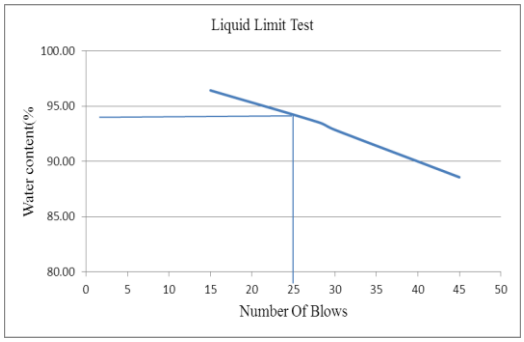


Figure 1 Liquid limit test result curve of black clay soil sample in AA at Bole Ayat

Table 1 Atterberg limit, free swell and specific gravity test results of black clay soil sample from Bole Ayat.

Depth of Sample (m)	1.5
Liquid Limit (%)	93.50
Plastic Limit (%)	50.56
Plasticity Index (%)	42.94
Free swell (%)	80
Specific Gravity	2.65

Table 2 Atterberg limit, free swell and specific gravity test results of black clay soil sample in AA

Location of Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Free swell (%)	Specific Gravity	Reference
Koyefeche	86	43	43	130	-	Berhane, 2018
Mekanisa	84	44	40	120	-	Berhane, 2018
Bole road	108	22	76	140	2.64	Teferra & Yohannes, 1986

Compaction Test

Compaction generally increases the shear strength of the soil, and hence the stability and bearing capacity. It is also useful in reducing the compressibility and permeability of the soil (Arora, 2008). This project was executed by standard proctor test.

The compaction curves of soil samples displayed in Figure 2 were obtained by plotting the dry densities of the compacted samples with reference to their water contents. Soil sample had bell-shaped compaction curves; the values of maximum dry density (MDD) and the optimum moisture content (OMC) were 1.284 g/cm^3 and 40.08% respectively. According to the OMC and MDD the samples were molded for UCT. According to Berhane (2018) these values were 29 and 1.42 g/cm^3 and 30 and 1.32 g/cm^3 for Mekanisa and Koyefeche respectively.

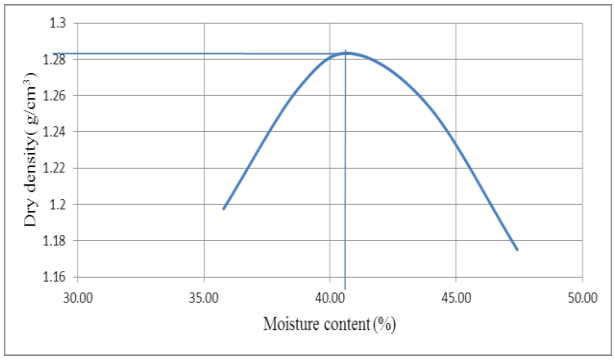


Figure 2 Standard Proctor compaction curves of the soils at Bole Ayat

Unconfined compression Test

Sample preparation

To conduct three trials unconfined compressive strength test the disturbed soil sample collected from the selected site at a depth of 1.5m in one pit and use compacted

soil sample within optimum moisture content of the soil. Compacted soil samples were used in the UCS tests in order to provide homogeneity, and elimination defects could not be determined visually before or after the tests. The clay samples for unconfined compression testing were prepared with the OMC in order to eliminate the effects of factors such as the moisture content (w), void ratio (e), and natural density on the UCS (Chen, 2012).

Air dried disturbed soil sample and sieved with 4.75 mm sieve used by drying the sample at 110 C^0 for 24 hours. Then standard proctor compaction test was executed and determined the OMC and MDD of the soil sample on the compaction curve. After the compaction test by using the OMC of soil prepared the compaction in standard proctor mold. After compaction, three thin walled stainless steel sampling tube with an inner diameter of 38 mm, a length of 76 cm, and a wall thickness of each sampling tubes 1.5 mm was driven into the soil in the Standard Proctor mold with a hydraulic jack. The soil immediately extruded from the standard proctor mold and by using another hydraulic jack extrudes each sample and its ends were cut to make it the required length of 38 mm, 57mm, 76 mm and by following similar procedure with the compacted soil at its OMC the soil sample 95 mm length sample prepared.



Figure 3 Three Prepared specimens with different H/D ratio of 1, 1.5,2 and 2.5

After measuring the specimen's mass, the unconfined compression strength test was performed under strain-controlled conditions at a constant loading rate, according to the requirements of ASTM D 2166-00 which is 1.5 mm per minute was used for all samples test done The unconfined compressive strength of a compacted soil tends to increase as the strain rate during loading is increased. In this study, the range of strain rate values selected was the same in each sample.

The unconfined compressive strength was taken as the maximum load attained per unit area maximum stress which shown on Figure 9, 10 and 11.

The unconfined compressive strength values of black clay soil samples in Addis Ababa Bole sub-city specifically on Bole Ayat with different specimens' height are summarized in Table 2.

Table 3 Unconfined compressive strength values of Bole Ayat black clay soil sample

Height to Diameter Ratio	Unconfined Compressive Strength (kPa)		
	Sample 1	Sample 2	Sample 3
1	100.06	137.56	238.35
1.5	88.84	123.90	156.86
2	87.61	103.88	148.08
2.5	85.11	93.89	112.96

Depending on the relation between consistency and UCS of clay, the black clay soil in Addis Ababa from Bole Ayat area is categorized as stiff clay soil.

The UCS values of black clay soil collected from Bole Ayat area exhibit less values when compared with UCS values determined by different authors.

Table 4 Unconfined compressive strength values of black clay soil sample.

Location	UCS (kPa)	Reference
Bole Medhaneal em church	138.53	Mareen, 2015
Koyefeche	552	Berhane, 2018
Mekanissa	536.5	Berhane, 2018

4. RESULTS AND DISCUSSIONS

Unconfined compressive Strength Properties

Depending on the UCS values, the simple plots which show the effect of sampling heights on unconfined compressive strength of each sample are shown in Figure 4.

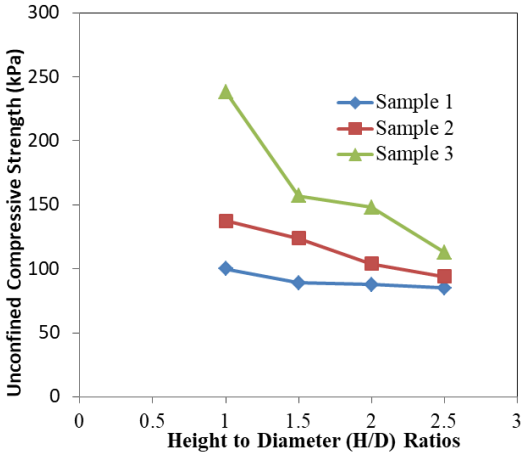


Figure 4 Relationship between the UCS and H/D ratio for the black clay samples.

From the graphs, it can be observed that; the unconfined compressive strength of clay soil decreases as sample H/D ratio increases. The compressive strength of the clay soil was high when the specimen's height is too short, which is H/D ratio is 1. Because, if the specimen height is too large, the sample easily fails since the stress is not equally distributed within the entire length of the specimen and also if the specimen's height is short, the sample will not fail easily because the stress is equally distributed within the short length of the specimens

The undrained shear strength (C_u) of black clay soil from Bole Ayat under investigation are computed from the unconfined compression test results, which is half of the UCS of the soil. According to the values of undrained shear strength of the three sample test and the value from each sample at various H/D ratio of the sample given in Table 3.

For all samples remolded at optimum moisture content, the undrained shear strength decreases with increasing specimen's height to diameter ratio.

Failure Pattern

Different characteristics of failure were observed in specimens of different diameter H/D ratio during and after the UCS tests in three samples taken from one pit. In this project near similar failure pattern was developed for three samples with disturbed specimens, which remolded at its OMC in the same H/D ratios for samples taken at 1.5m depth as indicated on Figures 5.

The smaller specimen with H/D ratio of 1 typically shoes consistently bulging after the UCS test, vertical and diagonal shear failure planes which develop within entire part of the specimen's height. The failed specimens with H/D ratio of 1.5 generally showed the formation of the diagonal shear failure plane within the entire height of the specimen and bulging localized to some portions of specimen height. The failure characteristics that occur within specimens of H/D of 2 and 2.5 is a different failure plane which are diagonal, near vertical shear failures planes and bulging occurred in some part of the specimen. In other words, the specimen would fail in a variety of complex ways. This complex deformation mechanism makes it easier for the specimen to fail. Decreasing in strength observed when the specimens H/D ratio is increased to 2 and 2.5. More compact structure is obtained by shorter specimens more rapidly than longer specimens during loading until failure. This mechanism also accounts for the dramatic increase in strength of shorter specimens (especially when H/D = 1) compared to longer specimens.



Figure 5 Failure patterns of black clay soil samples - Bole Ayat at 1.5m depth

Stress-Strain Curve

On the three trial samples of the specimens H/D ratio of 2 and 2.5 were attain its peak unconfined compressive strength failure at small axial strains which is up to 5% and for specimens height to diameter ratio 1 and 1.5 were attain the peak unconfined compressive strength failure at large axial strains which is above 5% . Generally the stress-strain curves shown in Figures 6, 7 and 8 the peak strengths of all specimens tended to increase with decreasing H/D ratio. The peak strength and axial strain are large for height-to-diameter ratio 1 and decrease as the specimen's H/D ratio increases. And also the pre-peak stress-strain curve increases with decreasing height to diameter ratio.

The failure pattern observed along the specimen height can affect the stress-strain curve behavior of the sample. Accordingly, failure is not complicated and entirely developed with in the specimen. H/D ratio is small, relatively that specimen attains its peak strength at large axial strain and the failure developed within the large specimen H/D ratio is complicated; it indicating that the peak strength value occurs at small axial strains. Additionally, the sharpness of the peak and the drop after the peak in the stress–strain curve increase significantly with increasing L/D ratio indicating tendency of brittleness.

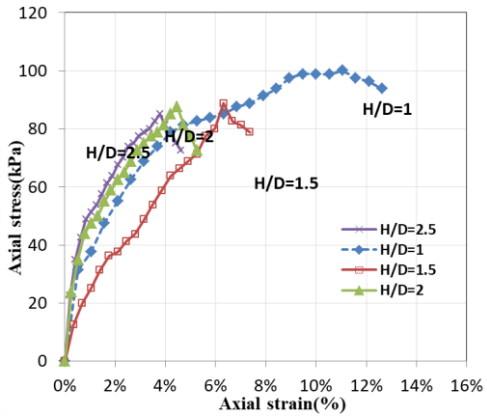


Figure 6 Stress-strain curves for samples of different specimen height (sample No.1)

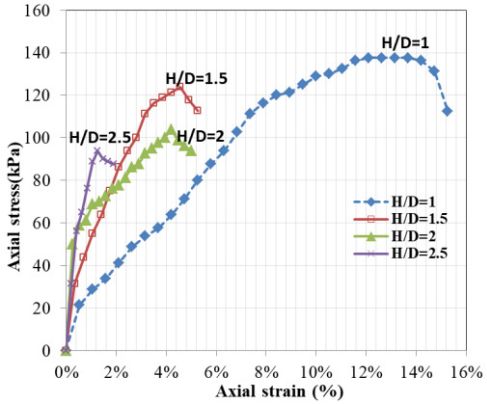


Figure 7 Stress-strain curves for sample 2

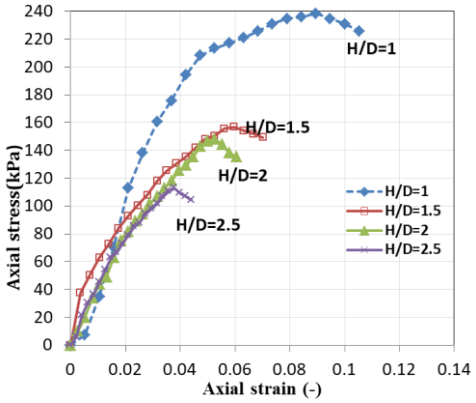


Figure 8 Stress-strain curves for sample 3

5. CONCLUSIONS

Based on the laboratory test results and observations presented in this project, the following conclusions can be drawn:

- The black clay soil samples at depth of 1.5 m from Bole Ayat in Addis Ababa are categorized highly plastic clay (Atterberg limit test results).
- The UCS value decreases with increasing H/D ratio of the specimens.
- The stress-strain curves for the samples with smaller H/D ratio of 1 tended to reach their peak strengths at large axial strains extending up to 8.95 - 12.11 %. The specimen generally tended to reach its peak strengths at smaller axial strains ranges extended between 1.3 % up to 6.32 % as the H/D ratio of the specimens increased from 1.5 up to 2.5. The pre-peak stress-strain curve increases with decreasing H/D ratio.
- The unconfined compressive strength values of black clay soil samples collected from Bole Ayat are small as compared with previous studies.

- The smaller specimen H/D ratio of 1 failure configuration typically contains consistent bulging, vertical and diagonal shear failure planes which develop within entire part of the specimen height. The failure characteristics in the specimens with H/D ratio of 1.5 generally showed the formation of the diagonal shear failure plane within the entire height of the specimen and bulging localized to some portions of specimen height. The failure characteristics that occur within the specimens at H/D ratio of 2 and 2.5 were different and complicated failure planes which are diagonal, near vertical shear failure planes and bulging occurred in some parts of the specimen.

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