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# Quickness and Sensitivity of Black Clays Around Bole Area, Addis Ababa

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## Abstract

The main objective of this study is to identify the extent of sensitivity and quickness of black clay soils found in Addis Ababa. The outcome of this study is helpful for land use planning, particularly in building construction, road alignment and other civil construction activities. The methodologies employed to achieve the objective are, field data collection on black clay soil, laboratory testing of soil samples and data analysis and interpretation. Disturbed and undisturbed soil samples were analyzed for UCT, index tests, namely, particle size distribution, Atterberg limits, and free swell, in laboratory based on ASTM. This study shows the relationship between undrained shear strength of remolded soil and water content of the soil, the numerical representation of the sensitivity of black clay soil, the relationship between quickness and moisture content. The result for the sensitivity of the soil is between 1.3 and 1.45 which is in between 1 and 2 which shows we have less sensitive soil according to CFEM (2006).

**Key words**: Black clay, quickness, sensitivity, remolded.

## 1. Introduction

Black clay soil can be found in several countries, including Australia, Canada, Ethiopia, Ghana, India, South Africa, and the United States. Black clay soils are also found in Ethiopia's northern and central Plateaus, the Rift Valley, inter-mountain depressions, and alluvial plains. Even in the capital city, Addis Ababa, multiple areas of Bole, Kotebe, CMC and Mekanisa, are covered by black clay soils. (Alemayehu Teffera, 1986).

Sensitive clays are often presented as materials that become semi-liquid when subjected to remolding. As a result of their sensitivity to flow slides, such clays are considered a severe threat to neighboring infrastructure. The term 'sensitive clay', on the other hand, refers to a wide variety of clays that exhibit considerable differences in engineering behavior, such as remolded shear strength (Sur).

Quickness and sensitivity are essential for assessing landslides in soft sensitive clay. Sur and Q both use distinct test methodologies to explain the same soil feature. The sensitivity test is a method for determining the soil's undrained shear strength in various states. On the other hand, the quickness test is a qualitative method that provides a more accurate picture of the volume of soil analyzed. Its ability to visualize flow slides is also beneficial when trying to understand the concept of slope.

Several studies have been carried out regarding different behaviors of black clay soils, for instance, Teklu (2003), Ketema (2015), Tesfu(2018), Marren (2015), Lemi (2015), Berhane (2018), Asres (2017) have studied and presented physical properties as well as index properties of black clay soils in Addis Ababa. No research has been done explaining sensitive of black clays' behavior and level of quickness in areas found in Addis Ababa, Ethiopia.

Sensitive soils' vulnerability to large flow slides is a severe geotechnical issue. If future losses of life and property are to be prevented, scientific research on this natural phenomenon is required. Rational landslide evaluation methods are necessary for project planning and development. This study aims to conduct a test on quickness and sensitivity of black clay soils in Addis Ababa to better understand the susceptibility of sensitive soils to flow sides, which is important for project planning and development regarding civil engineering works.

The following are the research questions addressed:

1. What is the extent of sensitivity of the black clay found in Addis Ababa?
2. What is the extent of Quickness of the black clay found in Addis Ababa?
3. What is the effect of moisture content on remolded shear strength?
4. What is the relationship between moisture content and Quickness?
5. What is the effect of Remolding on Sensitivity?
6. What is the relationship between sensitiveness and Quickness?

Since no prior investigation and studies have been compiled, carrying out this study is crucial in identifying areas prone to quick and sensitive black clays located in Addis Ababa could be possible areas vulnerable to landslide and failure of structures. This study describes the degree of sensitivity and quickness in black clay soils in numerical terms, as well as the link between undrained shear strength, water content, sensitivity, and quickness. The outcome of this study would be helpful for land use planning, particularly in road alignment and other civil construction activities.

## 2. Quickness

Sensitive clays are a group of clays that exhibit considerable differences in engineering behavior, such as remolded shear strength. Slight numerical changes in $c_{ur}$ alone are difficult to evaluate in terms of fluidity of sensitive clays, as small variations result in considerable changes in soil behavior. The quickness test was created to investigate the possibility of flow slides in sensitive clays and the significance that remolded shear strength plays. The quickness test follows the similar concept to the slump test used for concrete, which measures the consistency of freshly mixed concrete. It is performed by filling an open-ended cylinder with a thoroughly remolded material. The cylinder is then lifted upwards allowing the material to flow out. The final deformation height, $H_f$ (mm), and lateral spread, $D_f$ (mm), are measured. The quickness value, $Q$ (%), of a remoulded clay, is then calculated as the ratio between initial height, $H_0$ (mm), and deformation height and expressed as:

$$Q = \frac{Hf - H}{Ho} * 100 \quad \text{---------} \quad \textit{Equation 1}$$

where $Q$ is calculated as a percentage and $H_0$ and $H_f$ *measured* in mm. A $Q$ value of 100% represents complete collapse while 0% represents no visual deformation.

Quickness tests performed by Thakur and Degago (2012) found that sensitive clays with a $c_{ur}$ < 0.2 kPa behaved more like a soup, as predicted by Mitchell et al. (2005). Semi-solid behavior was observed for clays with 0.5 < $c_{ur}$ < 1.0 kPa. Deformation was negligible for $c_{ur}$ > 1.0 kPa which reinforces the slide threshold limit proposed earlier. Typical slump shapes and quickness values for corresponding remolded shear strengths can be seen in Figure 2.

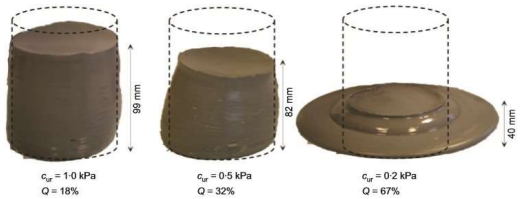



*Figure 1 Slump of the remolded sensitive clays (Thakur and Degago, 2014)*

Studies comparing various cylinder sizes used for quickness tests reveal the largest cylinder yields the most accurate results (Thakur and Degago, 2012). The largest cylinder used was a Standard Proctor test mold (100 mm x 120 mm), readily available in most geotechnical laboratories.

Principally, both $c_{ur}$ and $Q$ explain the same soil characteristic; however, the quickness test gives a value that is representative of the volume of soil tested as opposed to a point measurement as determined by the fall-cone test. Furthermore, the quickness test gives the possibility of amplifying the small range of $c_{ur}$ to a scale that varies from 0 to 100%. Therefore, the result is a better visualization of the flow behavior of sensitive clays, which improves the understanding of flow slides (Thakur and Degago, 2012).

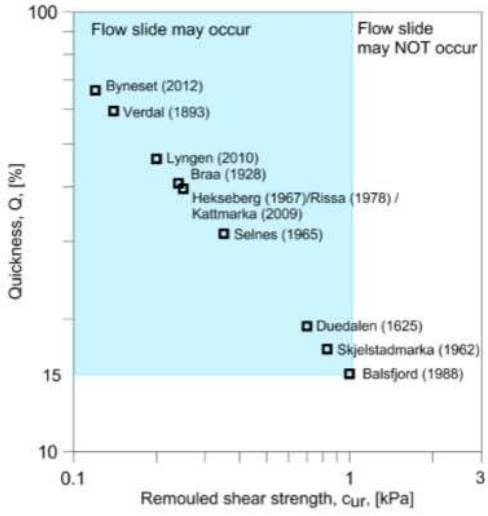



*Figure 2 Proposed range of cur and Q for assessing flow slide potential. No flow slides if Q < 15% or cur > 1.0 kPa. From Thakur and Degago (2014)*

Laboratory testing, as well as back-calculation on 14 significant Norwegian quick clay slides, showed that for $c_{ur}$ = 1 kPa, $Q$ = 15% (Thakur and Degago, 2012). It was therefore proposed that flow slides were not possible when $Q$ < 15%.

## 3. Materials and Methods

### 3.1 Test Setup and Procedure

The test procedure is like the slump test used for concrete. A Standard Proctor mold (height: 123 mm, diameter: 100 mm, volume: 966 $cm^2$) was coated with a thin layer of silicon oil internally to provide a non-stick surface. Oil was also applied to the test surface to reduce frictional forces during testing.

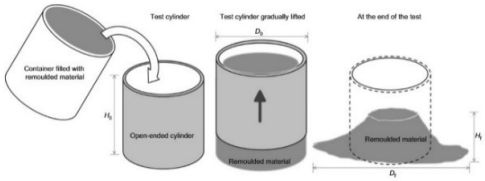



*Figure 3 Quickness test procedure (Adopted from Thakur and Degago, 2012)*

The remolded material was poured into the mold, and the top surface was leveled. Material having a remolded shear strength greater than 0.5 kPa required additional stirring within the mould to ensure no air gaps, which could compromise the test and lead to inaccurate findings.

The mold was manually raised vertically in a smooth, fluid motion, allowing the material to flow out without being supported. The quickness test procedure is illustrated in Figure 3.

On a clear plastic sheet, the quickness tests were conducted in the laboratory at room temperature. The experiments were filmed and documented using a high-definition camera, and grid paper (10mm x 10mm squares) was placed on both the horizontal and vertical planes to provide scale.

After testing, final height measurements were taken by comparing the mold's height with the sample, on four directions of the sample to compensate if there was misalignment using a 30 cm ruler. Base measurements were taken using a 1 m ruler. The quickness value, $Q$ (%), was then calculated using equation 2.8. Figure 2 (a-d) shows the slump progression for a typical quickness test.

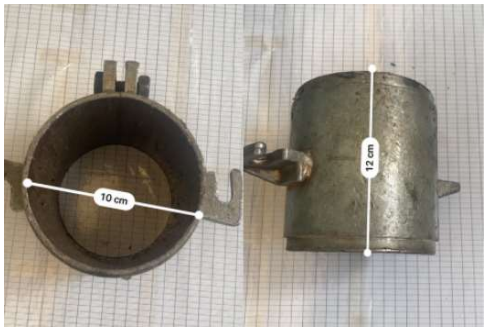



*Figure 4 Quickness test laboratory set-up*

The water content was determined by 200-400mL of the slurry taken.



(a) t = 0 (b) t = 2.0 (c) t = 6.0 (d) t = 8.0 seconds

*Figure 5 Slump and spread progression with time for a quickness test performed on Tiller Clay 1, cur = 0.39 kPa. Final deformation shape reached after 8 seconds.*

### 3.2 Sample Preparation

De-ionized water (or brine) was intermittently added to the material slurries, increasing the water content and reducing the shear strength. After the addition of water, the quickness test was performed. After the quickness test measurements were taken, and the water content samples obtained, the remainder of the material was placed back into the mixing bowl for re-use and the procedure was repeated.

The cylinder was raised as soon as possible after the mold had been filled and the sample well mixed to remove air spaces. This eliminates the effect of soil segregation, which is especially common in soils with many silts. The cylinder is gradually raised vertically upwards in a steady motion to maintain uniformity between tests and accurate results comparison. It also reduces the impact of any potential friction between the soil and the mold. Furthermore, no friction between the soil and the test surface is assumed, as this could influence the degree of material drop and spread. As soon as the mold is lifted, the sample begins to deform. Shortly after the mold is removed, final deformation shape is achieved (approximately 8 seconds). 30 seconds after testing, the final slump and spread readings are taken. Quickness tests were done as soon as possible after adding water to the remolded soils due to a large number of tests necessary and time restrictions.

#### 3.2.1 Soil Sample Preparation

The site visit and sample extraction were carried out on APR 06,2022 on the selected project site. Excavation work was made by excavators and daily labors. The location of the test pit and elevation above sea level were taken using smartphones with which photographs have also been taken both representative disturbed and undisturbed samples from depths of 1.5m. The disturbed sample was taken simply by using hoe and collected by using shovels. About 150 kg of disturbed samples is taken both from 1.5m. Undisturbed sample were taken using a hydraulic jack of a car to minimize the disturbance of the sample.

Horizontal holes were dug at the depths as mentioned earlier and the soil sampler tube was positioned on the top of the hydraulic jack. A thick flat wooden support was used above the hydraulic jack to distribute the jack's pressure on wider area on the crust of the horizontally dug hole. The soil sampler tube was a diameter of 110 mm, and height of 16.9 cm. Undisturbed sample were coated both by wax and candle and covered with plastic to prevent the disturbance of the soil and loss of the natural moisture content. After sampling, all the samples have been labeled. All the collected samples were carefully taken to the laboratory. We have prepared the soil sample for each test based on the specification on ASTM.

## 4. Results and Discussion

It can be seen from the below graph (Figure 6) that the sample is mainly composed of fine grain soil, and the percentage of passing sieve No.200 is 92.5%, and this also shows that the soil is composed of mainly a fine particle, therefore the soil is uniformly graded soil too.

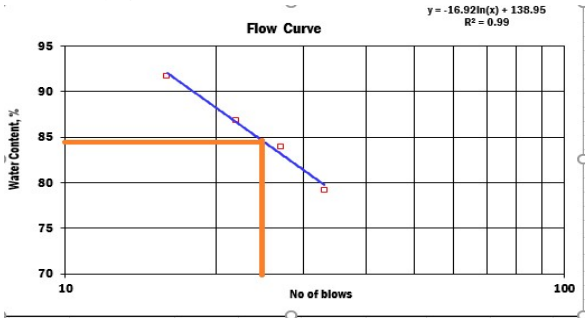



*Figure 6 Moisture content vs. blow count to determine liquid limit*

| | |
|---|---|
| Liquid Limit (LL or *WL*) (%): | 84 |
| Plastic Limit (PL or *WP*) (%): | 51 |
| Plasticity Index (PI) (%): | 33 |

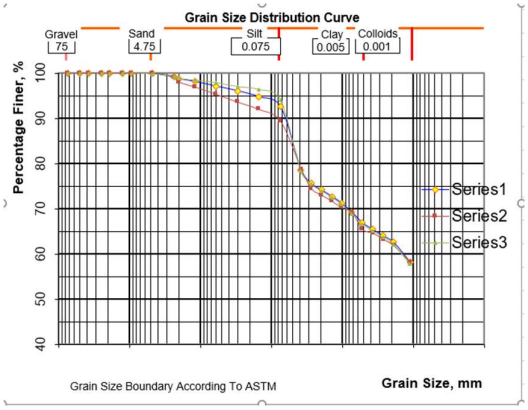



*Figure 7 Grain size distribution curve*

From plasticity index, it is possible to determine the range of water content which exhibits plasticity and the presence of clay. The plasticity index is high which shows that high percentage of clay fraction is available (Figure 7).

*Table 1 Free swell test results*

| Initial Volume (cc) | Final Volume | | Average Final Volume (cc) | Free Swell Index (%) | Description |
|---|---|---|---|---|---|
| | Sample No.1 (cc) | Sample No.2 (cc) | | | |
| 10.0 | 21.0 | 22.0 | 21.5 | 115 | Expansive |

### 4.1 Sensitivity

The Sensitivity calculation is calculated based on these measurements:

1. Determine the Undisturbed shear Strength of the soil using UCT
2. Determine the Remoulded shear strength of the soil using UCT
3. Determine the Moisture Content of Each UCT
4. Then Sensitivity is calculated as:

$$St(uct) = \frac{\text{Su (UC) (undisturbed)}}{\text{Sur (UC) (remoulded)}}$$

The result for the sensitivity of the soil is between 1.3 and 1.45 which is in between 1 and 2 which shows we have less sensitive soil according to CFEM (2006), since the soil is less sensitive it will have less possibility to be affected by natural as well as manmade disturbances (Table 2).

*Table 2 Sensitivity results*

| | | | |
|---|---|---|---|
| Water content | 43.62 | 45.73 | 47.65 |
| Su (Undisturbed) | 97 | 93 | 85 |
| Su (remolded) | 66.98 | 65.83 | 64.95 |
| Sensitivity | 1.45 | 1.41 | 1.3 |
| Sensitivity according to CFEM (2006) | Low Sensitivity | Low Sensitivity | Low Sensitivity |

### 4.2 Quickness

Quickness test should be performed for soils that are highly sensitive, by varying moisture content and undrained shear strength. In our case, the sample from Bole's area is less sensitive. Quickness is not needed to be conducted but we conduct it to determine the flow of soil if it reaches on such moisture contents and verify it isn't quick clay. In total 10 quickness tests were performed on the Black Clay soil. The water content was

varied for each test to explore potential relationships with quickness. The results shows that an increase in moisture content leads to increasing Quickness by keeping other factors constant. Even though the clay soil has shown slight sensitivity, it is hard to conclude that this deformation is related to the quickness of the soil. The deformation of the soil is a bit higher at close range of the liquid limit. The relation between sensitivity and quickness of clay soil requires further investigation and studies.

*Table 3 Quckness Result*

| Moisture Content | Initial Height Ho(cm) | Final Height Hf (cm) | Base Dimensions Df(cm) | Quickness Q (%) |
|---|---|---|---|---|
| 119.12 | 12 | 5.5 | 19.65 | 54.17 |
| Results Photo |  | | | |

### 4.3 Relationship between quickness & moisture Content

Figure 8 shows the relationships between quickness and both the water content.

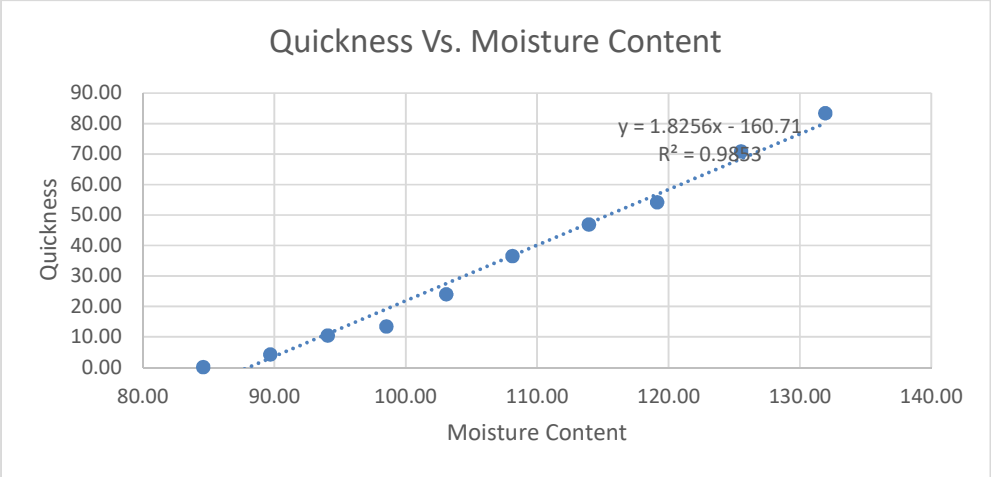



*Figure 8 Quickness Vs moisture content relationships*

### 4.4 Relationship between remolded shear strength and water content

One of the basic reasons that Thakur and Degago started the quickness test is remolded shear strength didn't describe the flow behavior of quick clay found in Scandinavians. In this research we have conducted remolded shear strength tests versus moisture content to compare with quickness on describing the flow behavior of this soil.

The water content for each sample was determined after the remoulded shear strength was measured using the Unconfined Compression Test. Figure 9 shows the results of the remoulded shear strength plotted against water content.

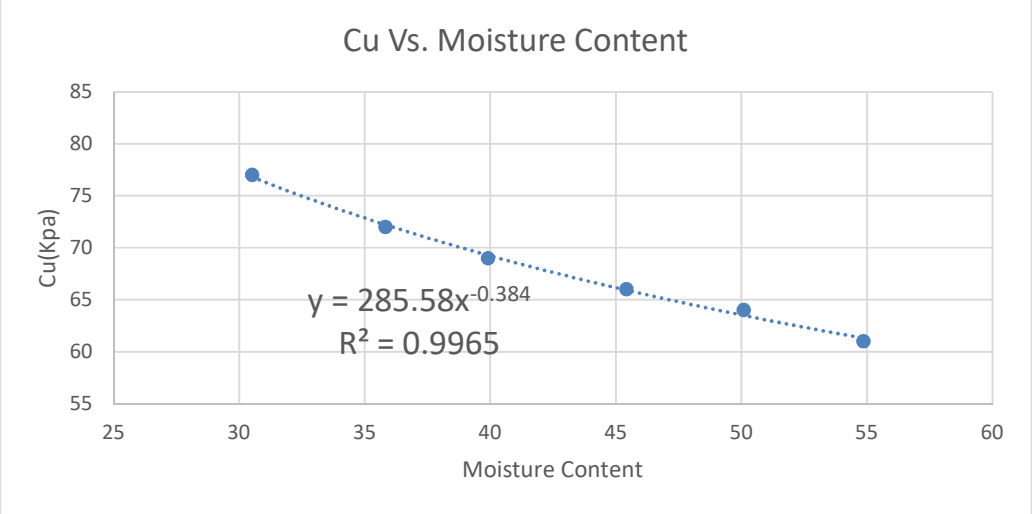



*Figure 9 Remolded shear strength Vs water content relationships*

*Table 3 Results from other studies*

| Author | Meti and Sofia (2019) | Seid and Meron (2018) | Melat & Yeabsira (2019) | Birkit and Rediet (2019) | Lemenew and Biniam (2018) |
|---|---|---|---|---|---|
| Soil type | Expansive soil | Expansive soil | Expansive soil | Expansive soil | Expansive soil |
| Location | Koye feche | Taffo area | Lebu | Tulu Dimtu | Lebu mabrat hail |
| Liquid Limit (%) | 82 | 73-78 | 81 | 108 | 74-77 |
| Plastic limit (%) | 43.08 | 43-46.6 | 44.45 | 24.14 | 38-42 |
| Plasticity Index (%) | 38.92 | 26.2-32.8 | 37.55 | 84.58 | 30-35 |
| Moisture content (%) | 46.6 | 38.87-42 | 32.32 | 43.68 | 27.5 |
| Undisturbed unconfined shear strength | 98.229 | 192-209.6 | 41.235 | 114.58 | 154.33 |
| Remolded unconfined shear strength | 56.46 | 112.9-133.8 | 28.17 | 78.439 | 131.4 |
| Free swell | 105 | 110 | 95 | 120 | |
| Specific Gravity | 2.58-2.65 | 2.57 | 2.71 | 2.75 | 2.502-2.64 |
| Sensitivity | 1.74 | 1.57-1.70 (low) | 1.46(low) | 1.49(low) | 1.23 |

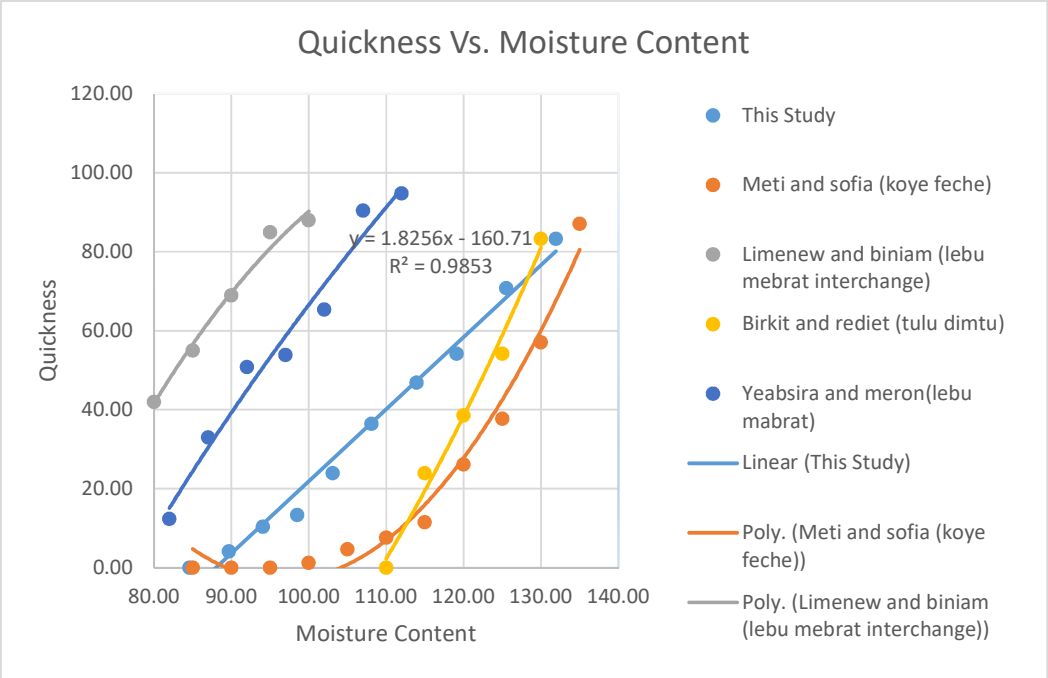



Figure 10 Quickness vs Moisture Content

## 5. Conclusion and Recommendation

The study has been conducted on the Quickness and Sensitivity of black clay soils specially found in Bole sub-city, Addis Ababa. The following conclusions can be drawn from the results of the laboratory tests

- The expansive soil was categorized as an A-7-6 soil class based on the AASHTO and CH as the USCS soil classification system.
- The flow behavior of fine-grained soils has been examined through quickness and Sensitivity, overall, the clay is not quick.
- Slight variations were observed on the sensitivity test with increasing moisture content, this is due to the remolding energy difference. Overall, the soil is classified under less sensitive based on CFEM (2006).
- A total of 10 quickness tests were performed on natural Black clays from Bole sub-city, Addis Ababa. But we couldn't verify the proposed quickness limits Thakur and Degago (2012). Because of fall cone test material weren't available in the lab to measure remolded shear strength (Cu) of such fluid samples.
- It was found that the water content is a suitable to predict Quickness of the study area by keeping external factors constant such as salinity. Proposed quickness can be expressed as a function of water content: $Q = 1.8256W - 160.71$
- The remolding shear strength could describe flow behavior of the black clay soils since Bole's black clay soil has low sensitivity.

Further sensitivity tests should be performed to identify sensitive clays, quick clays from normal clay then investigate Quickness of these soils. In addition, further quickness tests could be performed to investigate the effect of different clay contents. It would also be beneficial to conduct more tests by changing different factors such as remoulding energy, moisture content, salinities and liquidity

indices, for the same soil to further investigate their effect on quickness. For the accuracy of the test, taking soil samples and conducting the test at varying seasons should be considered.

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