FAT OR ELASTIC: AN INQUIRY INTO CLASSIFICATION OF BLACK CLAY SOILS OF ADDIS ABABA AROUND TULU DIMTU AREA

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ABSTRACT

Addis Ababa Black clays are one of two dominant clay found in the city and known for its expansive nature. Using the unified soil classification system, such soil, traditionally, is classified by the group name fat clay and group symbol of CH. But some investigations on local soil have resulted in classifying the soil as elastic silt, MH.

In this research laboratory investigation is conducted to determine if in fact Addis Ababa black clays may end up being classed as elastic silts and if so, what may be the parameters that play a role in such a classification. For the study three samples were collected from Tulu-Dimtu, where previous investigations have resulted in the discrepancy. Simple classification tests were conducted on the samples. In addition, the effect of sample preparation, utilization of tap water, experience level of operator and variations among laboratories investigated.

It was found that Addis Ababa black clay soils mayend up being classified as elastic silts but in general remain within the boundary region of the A-line on both sides. The experience level of the operator was found to have the most profound effect on index tests and classification.

Keywords Black clay, liquid limit, plastic limit, USCS

INTRODUCTION

Currently, two major groups of soil classification systems are available for general engineering use. They are those based on Arthur Casagrande's unified soil classification system (USCS) and those used for specific purposes such as the American Association of State Highway and Transport officials (AASHTO) system for classification of subgrade soils for highway construction purposes. Both systems use simple index properties such as grain-size distribution, liquid limit, and plasticity index of soil (Carter and Bentley 2016).

Even though identification and classification systems specific to expansive soils exist (Chen 1975), engineering classification system such as the unified soil classification system are initially conducted and based on these further testing is done to ascertain expansiveness. It is generally taken that soils classed under CL or CH by the USCS and A6 or A7 by AASHTO may be susceptible to expansibility (Nelson and Miller 1997).

Addis Ababa black clay soil is one of the two dominant clay found in the city, known for its expansive nature. Using the unified classification system, this soil is commonly classified under fat clay (CH) (Alemayehu Teferra 1992; A. Teferra and Yohannes 1986). This correlates to soil whose characteristics are heavily dependent on moisture content, have very low permeability, may be susceptible to swelling and shrinkage and have high compressibility.

But some investigations conducted in Addis Ababa indicate, the soil is classified as an elastic silt (MH), which fall below the A-line at a liquid limit greater than 50 in the Casagrande plasticity chart. This correlates to silty soils of high plasticity which is a departure from the commonly accepted classification of expansive soils.

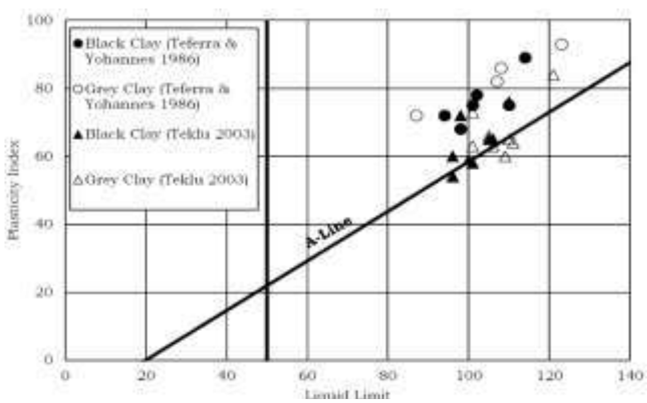

Figure 1 Plasticity chart plot of data from Teferra&Yohannes (1986) and Teklu (2003)

A survey of available literature shows that there is precedent for soils with high swelling and shrinkage characteristics, to be classified as elastic silts. In Israel, where shrinking soils are known to occur, plasticity data (LL and PI) plots below the A-line (Smith et al. 1985).

In a study on expansive soils in Sudan it has been found that such soil plot below the A-line in the elastic silt region (Al Haj and Standing 2015). In a study on Ethiopian soil, it has been reported that Ethiopian black clays plot near or below the A-line grouping them as elastic silts (Morin and Parry 1971). In Addis Ababa, a study conducted on expansive soils reports that plasticity data that plots below the A-line (Teklu 2003).

Laboratory tests used for engineering classification of soil

The simple tests by which the various types of soil are identified and classified for geotechnical engineering use are called index or classification tests and the properties that are associated with them index properties (Terzaghi, Peck, and Mesri 1996; Das and Sobhan 2017).

For most of the common classification schemes both the consistency limits and the particle size distribution are required for classification of a soil. From the consistency limits the liquid and plastic limits are used.

The liquid limit, theoretically, is the transition point on the water content line from a plastic behavior to a liquid behavior. In practice, it is determined at a water content corresponding to arbitrary selected low shear strength (O'Kelly, Vardanega, and Haigh 2017). There exist two methods for the determination of the liquid limit, the Casagrande cup method and the fall cone method (Head 1992). The Casagrande cup method is standardized by the ASTM, AASHTO and BS (D18 Committee 2017; AASHTO 2013b; British Standards Institution 1990). The ASTM and AASHTO standards are equivalent while the BS standard defers from the rest in terms of the specification for the rubber base (O'Kelly, Vardanega, and Haigh 2017).

The Casagrande apparatus is based on Atterberg's initial method for the determination of the liquid limit which relied on the number of blows to close a groove in a soil bed to collapse when struck by hand. This is likened to the collapse of a slope which is related to the shear strength of the soil (Haigh, Vardanega, and Bolton 2013). Casagrande attempted to standardize the approach by specifying the liquid limit as the moisture content at which a groove cut in a soil bed and resting on a spun brass cup closes at 25 blows for 13mm when the cup is impacted on a hardened rubber base from a height of 10mm at a rate of 0.5 blows/sec. The groove is cut using a standard grooving tool (Haigh, Vardanega, and Bolton 2013; Head 1992).

The fall cone apparatus also relies on the shear strength definition of the liquid limit but here penetration resistance is used as a measure. The liquid limit is defined as the moisture content at which a cone of mass 80g with an apex angle of 300 penetrates a soil specimen 20mm (British Standards Institution 1990; Head 1992). This method is standardized in the British standard and is the definitive method in the British standard (Head 1992). The primary advantage of the fall cone method is the reduction in variability. (O'Kelly, Vardanega, and Haigh 2017).

The plastic limit is the lower boundary moisture content for plastic behavior. A. Casagrande proposed rolling method which involves rolling a soil thread to a diameter of 3.2mm and observing for cracks (Haigh, Vardanega, and Bolton 2013).This method is standardized in ASTM, AASHTO and BS (D18 Committee 2017; AASHTO 2013b; British Standards Institution 1990). The method has multiple drawbacks which include its heavy reliance on operator judgment, variable rolling pressure and difficulty in assessing brittle cracking (Barnes 2009; Haigh, Vardanega, and Bolton 2013). Due to such drawbacks other methods have been proposed including the fall cone method where a strength definition of 100 times the shear strength as the liquid limit is considered (Sivakumar et al. 2009).

It has been shown that such an approach is in contradiction of the plastic-brittle transition definition of the plastic limit (Haigh, Vardanega, and Bolton 2013). The plastic limit so determined is therefore not consistent with that determined from rolling and is designated as PL100 (O'Kelly, Vardanega, and Haigh 2017). Another method proposed involves utilization of a mechanical roller (Barnes 2009).

The liquid and plastic limit is influenced by sample preparation techniques, chemistry of water used, and soil fraction tested (O'Kelly, Vardanega, and Haigh 2017).

There exist standardized procedures for sample preparation (D18 Committee 2011a, 2011). There generally two, the dry method and wet method. The dry method is the preferred method for granular soil while, the wet method is recommended for fine grained soils especially those whose characteristics are changed by oven drying. The wet method discussed in ASTM D2217 involves the two methods one by air drying the other by washing.

Alternative Classification scheme

There has been alternative soil classification schemes proposed for fine grained soil, especially relating to the Casagrande plasticity chart (E. Polidori 2003; Ennio Polidori 2015; Moreno-Maroto and Alonso-Azcárate 2018).

E. Polidori (2003) proposed a classification scheme that redefines clay and silt based on proportion of the clay fraction, fraction finer than 2µm, computed from the portion of specimen finer than 425 µm, the fraction used for Atterberg limit testing.

According to this definition clay is a soil containing clay fraction greater than or equal to 50% while silt having clay fraction less than 50%. Using this definition and Atterberg limit tests of mixtures of montmorillonite and kaolinite with sand, the author proposed a new plasticity chart.

The Polidori plasticity chart, shown in Figure 2, consists of the C-line, 0.5C-line and the U-line. The C-line is plotted by connecting the plots of liquid limit versus the plastic index for the 100% clay fraction montmorillonite and kaolinite data tested. The 0.5C-line is plotted by connecting the test data for 50% clay fraction. The U-line represents the upper limit of expected behavior for natural soils. It is determined from data obtained for specimen with larger than 50% sand (E. Polidori 2003).

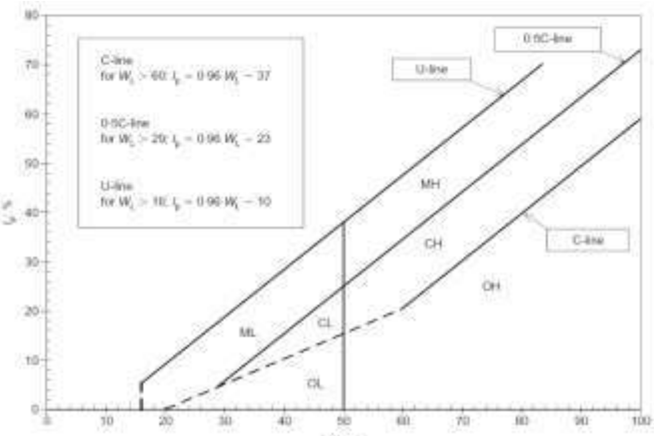

Figure 2 Plasticity chart proposed by E. Polidori (Polidori 2003)

For a given liquid limit, decrease in clay fraction is accompanied by an increase the plasticity index as it requires more plastic clay to maintain the liquid limit at a lower clay proportion. As a result, clays are located below the 0.5C-line and silts above it in the plasticity chart. The dotted line represents the boundary for behavior of inorganic soils.

Organic soils are located below the C-line. In a more recent paper, the author has further expanded on the classification to include coarse grained materials. In this scheme the soils are grouped in to four classes of G Grainy (non-plastic soils), S-G Semi-grainy (mostly non-plastic soils), S-F Semi-fine (plastic soils) and F Fine (plastic soils). Each group is classed based on clay fraction they contain. Within each group there are symbols used to designate the principal and secondary constituents based on particle size distribution (Ennio Polidori 2015).

Table 1 Summary of classification system proposed by Polidori (Ennio Polidori 2015)

Criterion	Soil Group	Clay Fraction (%)	Principal Soil Component	Second Component
Soil behavior dominated by granular phase characteristics	G Grainy (non-plastic soils)	< 10	Gravel > 2-63 mm	Gr sa, si, (cl)
			Sand > 63µm-2mm	Sa gr, si, (cl)
			Silt >2µ-63µm	Si sa, cl, gr
Transitional behavior from grainy to fine	S-G Semi-grainy (mostly non-plastic soils)	10-30	Gravel > 2-63 mm	Gr sa, si, (cl)
			Sand > 63µm-2mm	Sa gr, si, (cl)
			Silt > 2µ-63µm	Si sa, cl, gr
			Clay < 2µ	Cl (si), (sa), (gr)
Soils as CF increases	S-F Semi-fine (plastic soils)	31-50	Gravel > 2-63 mm	Gr (cl), (si), (sa)
			Sand > 63µm-2mm	Sa cl, (si)
			Silt > 2µm-63µm	Si cl, (sa)
			Clay < 2µm	Cl si, sa, gr
Soil behavior dominated by the clay-water system	F Fine (plastic soils)	>50	Clay < 2µm	Cl

gr-gravel, sa-sand, si-silt, Cl-clay
Those in parenthesis are for artificial soils

José Manuel Moreno-Maroto and Jacinto Alonso-Azcárate (2018) have also proposed and a new plasticity chart and a new definition of clays. The proposed system relies on maximum toughness as a quantitative parameter in the delineation of clays with silts along with the liquid limit and the plasticity index. Measures of maximum toughness are based on a modified rolling apparatus developed by G. E. Barnes (2009). The maximum toughness can be viewed as the maximum resistance, measured in energy per unit volume of soil, to deformation offered by the soils while still remaining plastic (Moreno-Maroto and Alonso-Azcárate 2018; Barnes 2009).

A correlation of the maximum toughness ($Tmax$) with the plasticity index to liquid limit ratio (PI/LL) was used by Moreno-Maroto and Alonso-Azcárate. The authors redefined clay as having a maximum toughness of at least 20 $KJm3$ and based on the correlation this corresponds to PI/LL ≥ 0.4937. In addition, the lower limit of $Tmax$ = 0 corresponds to PI/LL = 0.3397. This data was used to plot the new plasticity chart (see Figure 8).

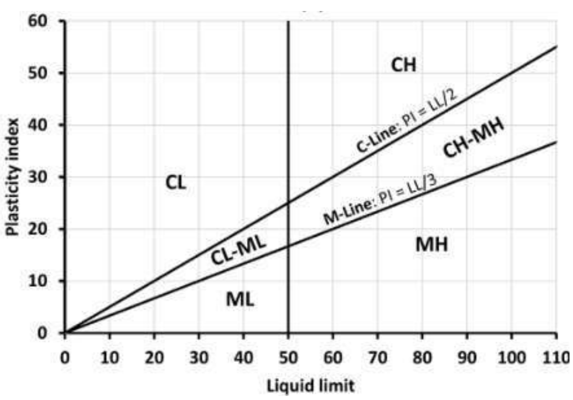

Figure 3 Alternative plasticity chart proposed by Moreno-Maroto and Alonso-Azcárate (Moreno-Maroto and Alonso-Azcárate 2018)

APPROACH

For this study, representative disturbed soil samples were collected from the Tulu-Dimtu area in the outskirts of Addis Ababa form two adjacent open pits at depths ranging from 1.20m to 3.00m. The Tulu-Dimtu area is selected as there is previous known investigation conducted by Best Consulting Engineers PLC that has resulted in the classification of Addis Ababa black clay as an elastic silt.

The samples were distributed to two laboratories, Best Consulting Engineer's laboratory and Ethiopian institute of Architecture, Building Construction and City development's Material Research and Testing Centre.

As stated previously testing was conducted per ASTM methods but in the hopes of understanding the reason for the stated departure, certain controlling parameters were varied. The parameters selected are those believed to cause change in the manner in which Addis Ababa black clays are classified, these include:

1. Sample preparation methods,
2. Purity of water used for liquid limit and plastic limit testing,
3. Experience level of individuals performing Atterberg limit tests
4. Variation between laboratories

To assess the effect of sample preparation, two oven dry specimen and two wet-prepared specimens per ASTM D421 and ASTM D2217, respectively, were prepared at the Materials Research and Testing Centre and tested accordingly. Further from each of the pair tested, one in each experiment group (dry prepared or wet prepared) were tested by a laboratory technician while the other by the researchers. This is used to assess the influence of experience level.

To investigate the influence of the purity of water may have on Atterberg limits, one sample was tested using tap water while another using distilled water at Best consulting and Engineers laboratory. The results collected were analyzed to investigate the influence each parameter has in engineering classification of Addis Ababa black clay and conclusions made.

DATA COLLECTION & ANALYSIS

Test Pits

Two test pits were located as show in the map in Figure 10. The pits are excavation pit dug for building construction purposes. The pits had been dug to a depth of more than 3.00m. The soil observed in both pits was black in color with white nodules, had no odor, was wet, had a soft consistency, very high plasticity, no response to dilatancy and when dry they had very high strength, further, slicken sides were also observed in the cleaved soil blocks.

The while nodules were approximately coarse sand to gravel sized. The nodules could be scratched by fingernails but due to the lack of hydrochloric acid the calcium carbonate presence could not be detected.

Figure 4 Topographic map of Tulu-Dimtu developed using Google Earth and Global Mapper

Three samples were collected from the Tulu-Dimtu area from two pits located relatively close to each other.

Table 2 Location of test pits

Test Pits	Coordinates in UTM		Ground Level Elevation (m)
	Latitude	Longitude	
TP-1	8°53'18.02"N	38°48'50.31"E	2164
TP-2	8°53'20.60"N	38°48'49.72"E	2168

Two samples at depths of 1.20-1.50m and 2.80-3.00m from the natural ground level were collected from TP-1; for the sake of simplicity this samples are designated as S-1 and S-2, respectively. One sample from TP-2 at a depth of 1.50-1.65m from the natural ground level was collected. This sample is designated as S-3. All samples collected were disturbed samples. The samples were manually dug using a pick and a shovel. The collected samples were properly labeled, double packed in common polyethylene bags and transported. Sample S-1 was transported to the Materials Research and Testing Centre while samples S-2 and S-3 were transported to Best Consulting Engineer's laboratory.

Laboratory Experimentation

The laboratory tests conducted for the purpose of this study are those relating to engineering classification of soil, this are particle size analysis, liquid limit, plastic limit and specific gravity. Specific gravity is not used in engineering classification of soils, but it is an input in sedimentation analysis of the particle size analysis. In the laboratory experimentation four relevant parameters were varied in the hopes of better understanding the reason for the departure for the comely accepted classification of Addis Ababa black clay.

The four parameters selected are:

1. Sample preparation methods,
2. Purity of water used for liquid limit and plastic limit testing,
3. Experience level of individuals performing Atterberg limit tests and,
4. Variation between laboratories

RESULTS AND DISCUSSIONS

Classification of the specimen tested is conducted as per ASTM D 2487's unified soil classification system.

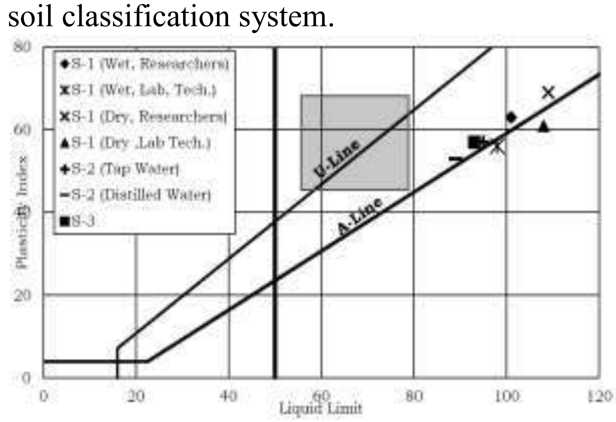

Figure 5 Casagrande plasticity chart with test data plotted

Effects of variations in laboratories and operators on index tests and classification

From the collected data it is noted that there is some variation in all the three index properties measured in the two laboratories and by different operators. To investigate the effect of changes between laboratories and operators may have on index properties and classification, test results compared.

The tests compare are those conducted under similar sample preparation, apparatus and reagent. In addition, variation in results may result from the inherent variation in the soil or from extraneous variables that could not be controlled or were not controlled during the testing. In compering operators, it is assumed that all the researchers have equal experience levels. This assumption is reasonable as the all the researchers have limited testing experience. The specific gravity tests were all conducted by the researchers. Apart from sample S-1, the rest were determined using the dry method. The specific with gravity of specimen by the dry method presents a small variation in results the deviation being 0.01. This is in line with ASTM D 854 acceptable range for multi-laboratory reproducibility.

It may be hypothesized here that as the specific gravity has very little operator dependence, large variation is not expected if testing is conducted in line with equivalent standards. Regarding the particle size analysis, all tests were conducted by the researchers. It is observed that variation in results changes with particle size. Relatively small variation is observed in the coarse-grained fraction with the maximum deference of 2.68% from the No. 200 sieve between sample S-1 (dry prepared) and S-2. In the fine-grained fraction variation is seen to increase with reduction in particle size with the largest difference of 8.34, occurring at a particle size of approximately 0.001mm. This comparison is made between the dry approaches. As the dry approach involves the utilization of pulverization techniques, the force required for breaking the aggregates my vary between laboratories and individuals preparing the samples. Such differences may result in grain size, if excessive force is used to break the aggregation resulting in fracturing the particles. This is especially true for Addis Ababa black clay which has high dry strength and thus requiring considerable pulverization effort. In considering the liquid limit, comparison of sample S-1 (dry, conducted by the researchers using tap water at MRTC) and Sample S-2 (dry, conducted by the researchers using tap water at Best consult), it is observed that there is a difference of 16. This comparison is made assuming the chemical makeup of the water supplied to MRTC and Best consult are identical.

This value is more than the ASTM D4318 value for multi-laboratory reproducibility of high plastic soil by an amount of 12. The ASTM D4318 value for multi-laboratory reproducibility of high plastic soil is obtained ensuring tests are conducted according to the standard. In this regard, the tests deviated from the standard in that they employed tap water. It should also be noted that ware and tare of equipment may also have a part to play. This excessive deference is an indication of the sensitivity of the liquid limit to operator and laboratory variations and the simple following of standardized test procedures alone is not adequate to obtain precise results.

The liquid limit conducted at the Material Research and Testing Centre were also conducted by a laboratory technician. Comparing Samples S-1(wet, conducted by a laboratory technician) with S-1(wet, conducted by researchers) and S-1(dry, conducted by a laboratory technician) with S-1(dry, conducted by researchers).

In addition, assuming all the researchers have equal experience. It is observed that the differences are 1 and 3 for the dry and wet prepared methods, respectively. This variation is within ASTM D 4318 range of acceptable multi-laboratory test results. In contrast to the variation between laboratories these values are small. As the researchers are not complete novices but at least understand, theoretically, the determination of the liquid limit, it may be inferred that variations in operator are minimal, provided that the operator has some limited knowledge of the test. Regarding the plastic limit the multi-laboratory variation of the mean of two PL test runs between dry prepared samples is 4. This variation is within ASTM D 4318 range of acceptable multi-laboratory test results.

It should benoted here the variation within each test and between test runs is larger, the greatest being 10. As two test runs of a given test are conducted by the same researcher in successive order, it shows the lack of repeatability in the test. When evaluating the differences in result between the researchers and the laboratory technician, it is observed that a deference of 4 and 7 for the wet and dry method, respectively.

The differences in between test runs show that the largest deference for the test conducted by the technician is 6 while it is 10 for the researchers. This again shows the lack of repeatability in the test while the repeatability of the lab technician is better it is still high. As is expected the repeatability is dependent up on experience level. In the variation of the plasticity index, which is the result of the propagation of the variations in the LL and PL.? It is observed that maximum multi-laboratory variation for the dry method is 12 which is considerably larger than the ASTM D 4318 acceptable value. The deviation between researchers is 8 and 7 for the dry method and wet method, respectively. In the classification of the soil, which ultimately relied on the plasticity chart, which in turn relies on the LL and PI, it observed that while all samples are located close to the A-line. Two of the samples, S-1, conducted by the laboratory technician using dry and wet method plotted below the A-line. Thus, in cases where the sample plots close to the A-line, it is possible for variations in operator and laboratory to cause misclassification.

Effect of sample preparation on liquid limit, plastic limit, and classification

Two sample preparation techniques were used dry method and the wet method according to ASTM D422 and D2218, respectively. Comparison is made between tests results from samples prepared by the two methods in the same laboratory and tested by similar operators. Regarding the liquid limit the dry method of sample preparation resulted in a higher value than the wet method when both researcher and lab technicians conducted the test. This is also true for the plastic limit as well. This clearly indicates that oven drying, and pulverization have an influence on the liquid and plastic limit. In regard to soil classification test conducted by the researchers resulted in CH classification in both wet and dry prepared samples while MH classification was obtained when laboratory technician conducted the tests.

Effect of water chemistry on liquid limit, plastic limit and classification

To investigate the effect of water chemistry on liquid limit and plastic limit comparison is made between Atterberg limit tests conducted with distilled water and Tap water in the same laboratory, using the same sample preparation schemes and with the same researcher.

For both the liquid and plastic limit, the utilization of distilled water reduced the test results. This is an indication that the utilization of Tap water can have an effect on the Atterberg limits. In The classification of soil both specimen plotted above the A-line. It should be noted that simply because there was no change in the classification does not imply that water chemistry does not affect soil classification but in this case the tap water used was of adequate quality not to cause changes in classification this may not be always true.

Make 'False Elastic' 'Fat' Again

Based on the literature review conducted and based on the limited data from tests, it is possible for Addis Ababa black clay to plot below the A-line in the MH region. But it should be noted, even though the soil may plot below the A-line, it still remains close to it. Based on the conducted experiment it is also possible that operator error may shift the result to CH or MH from the true class. It is further important to point out that such distinction of boundary soil is technical and in practice it is imperative that engineering judgment be employed in interpreting such boundary soil classes. To overcome such irregularities, there are alternative plasticity charts proposed, discussed in the literature review.

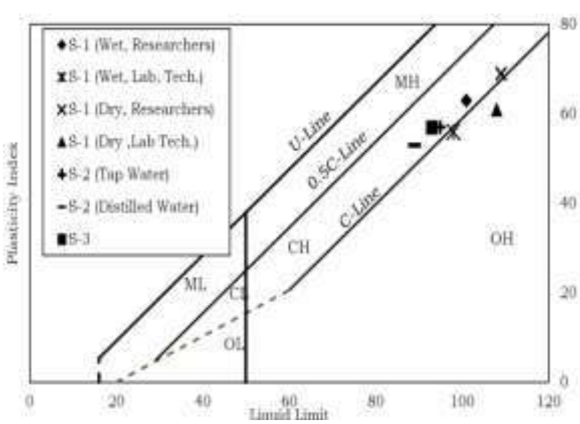

Figure 6 Polidori plasticity chart with test data plotted

The Polidori (2003) plasticity chart which is based on clay size fraction classifies some of the specimen as organic soil which is contradictory to the laboratory tests.

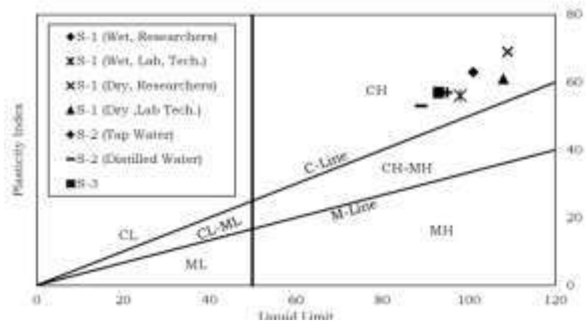

Figure 7 Moreno-Maroto and Alonso-Azcárate plasticity chart with test data plotted

The (Moreno-Maroto and Alonso-Azcárate (2018) plasticity chart which is based on the toughness definition of clays classifies the soil as fat clays. In contrast this chart is more representative of observed phenomenon.

CONCLUSIONS and RECOMMENDATIONS

Based on survey of literature and the limited laboratory tests conducted, it can be stated with a reasonable degree of certainty that Addis Ababa black clays may plot below the A-line. But it should be noted that they remain close to the A-line. From laboratory test conducted it can be stated that test used to determine index properties for classification are dependent on experience of operator and variations between laboratories. This is true especially for Atterberg limits. Due to this dependency and due to the fact that the plot is located at the boundary region of the A-line, it is possible for the plot of the plasticity data to plot on either side of the A-line while its true location is on the other side.

This results in a misclassification. Classification tests are also dependent on sample preparation. Samples prepared by the dry method have higher liquid and plastic limit than those determined by the wet method. In the tests conducted this variation did not cause change in the classification of the soil. A fourth factor considered was the utilization of tap water versus distilled water in the determination of Atterberg limits. It was found that tap water resulted in a higher liquid and plastic limit than distilled water. In the tests conducted this variation did not cause change in the classification of the soil. It should be noted that apart from the possibility of Addis Ababa black clays being plotted below the A-line which is backed by literature survey, the remaining assertion made require further investigation as only limited laboratory testing was done.

Based on the above discussion the following recommendations are given regarding laboratory testing for the determination of index properties and engineering soil classification:

1. Simply following of standardized testing procedures is not enough to ensure accuracy and precision of laboratory testing, it is necessary to regularly maintain and calibrate laboratory equipment.
2. As classification tests, especially Atterberg limits, are operator dependent, regulatory bodies should ensure the qualification of laboratory technicians.
3. Regarding Addis Ababa black clays one should utilize the wet method of sample preparation at the very least Method A (air drying) but preferably Method B (washing method) of ASTM D4318. Furthermore, one should use distilled in the determination of the Atterberg limits.

Soil classification is ultimately way of communication and a means of estimating engineering properties. As Addis Ababa black clays exist at the boundary region of the A-line on either side, it important to recognize this characteristic in reporting and interpreting geotechnical investigations. This study investigated in a limited and general manner the effects of the parameters previously mentioned on engineering soil classification as it applies to Addis Ababa black clays. In future research the effect of each parameters can be investigated in detail and additional factor included.

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