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Comparative Study of Sensitivity and Thixotropic Behavior of Various Clayey Soil Using Unconfined Compression and Lab Vane Shear Test

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Abstract

Loss of strength of the soil after remolding is measured by the term sensitivity. After the removal of external forces or disturbing stress soil tries to come to a new equilibrium condition, with time inter-particle arrangement, adsorbed water and distribution of ion gets adjusted and shear strength of soil increase with time. The phenomenon of regain of shear strength by the remolded soil with time is termed as thixotropy.Undisturbed and remolded samples were collected from three different sites.The samples thus collected were preserved and tested in CMTL (Pulchowk Campus, Lalitpur) and Geotech and Associates lab (Bakhundol, Lalitpur). The soils under study are the major load Bearing layers in the cities like Kathmandu, Kaski and Nawalparsi districts in Nepal. Due to booming construction it is necessary to study its sensitivity characteristics in order to safety predict the structure against disturbance of soil during construction and seismic shock. The result shows that the Red clay soil (Local name: Ratomato) has higher shear strength than Black cotton soil (Local name: Kalomato) and White soil (Local name: Kameromato). Kameromato being insensitive, no need for the study of its thixotropic properties.It was observed that Vane shear test generally gave the higher values of un-drained shear strength compared to the results from unconfined compression test. In our case there is 5% rise in shear strength result from UCS to VST. The thixotropic strength regain in strength percent of original undisturbed strength was found to be higher for Ratomato than Kalomato but possesses similar thixotropic strength ratio. Based on the detail mineralogical identification, Quantification and Mohs values Quartz content is more for Ratomato and least for Kameromato. Major minerals of Ratomato are hard, while for Kalomato it is intermediate hard and soft for Kameromato as major mineral (chlorite) has low Mohs value.

Keywords

Clay mineral, Sensitivity, Thixotropy, Unconfined compression test (UCS), Vane shear test (VST), XRD

1. Background

Nepal lies in high earthquake prone zone, if the soil in the site is sensitive, the disturbance during construction of foundation and earthquake may cause significant effects in soil strength parameters. Thixotropic behavior of the soil plays important role in soil engineering, it is the loss in the strength of soil by disturbance and ability to regain the lost strength with time. Study of such regain in shear strength have large application in the design of pile raft foundation.

Red soils are tropically weathered soils with a high concentration of sesquixides of iron and/or alumina. They have correspondingly low content of alkalis and alkaline earths. The presence of iron oxides in various states of hydration gives red soils a range of colors [1].

Kalomato soil found in Kathmandu valley is formed by lacustrine deposit. Because of its high swelling and shrinkage characteristics, the Kalomato soil has been a challenge to the Engineers. It is very hard in dry condition but loses its strength completely in wet condition. Kalomato soils are made of varying Properties of minerals like Montmorinolite and kaolinite, chemicals like Iron Oxide and Calcium Carbonate and organic matter like humus [2]. Kameromato soil found in Ghattekhola, Kaski is also residual deposit. Very few researches were done on the kameromato, so its detailed geotechnical investigation is yet to be carried out.

1.1 Unconfined compressive strength and sensitivity of clays

The unconfined compressive strength, q_u, is defined as the ultimate load per unit cross sectional area that a standard cylindrical specimen of soil can take under compression without any lateral pressure. Sensitivity is the measure of loss of strength with remolding. Sensitivity, St is defined as the ratio of unconfined compressive strength of clay in undisturbed state to unconfined compressive strength of a same clay in remolded state at unaltered water content.

1.2 Thixotropic behavior of clay

Numerous studies have been conducted to investigate the thixotropic behavior of geological materials. Boswell,1949 found that all sediments, except coarse sands and gravels, can exhibit thixotropic behavior.The degree of thixotropic depends on the grain size, the grading, the mineralogical composition, and the presence of electrolytes. Thixotropic effects may increase the strength of materials by greater than 100% after remolding and could be important from an engineering standpoint for elucidating the phenomenon [3]. For example, in the region of Nizhnevartovska, Western Siberia, the thixotropic strengthening of soil after pile driving occurs most intensely during the first 10 d;as early as on the 8th–10th d, the average bearing capacity of the piles reaches 85% of the bearing capacity after resting for one month.With regard to this condition,[4] suggested that 18 d is the optimal resting time for static piles in thixotropic soil. Previously, a research paper on comparative study of thixotropic characteristics of yellow, red and black soilshows that red, yellow and black soil shows the thixotropic characteristics but the strength gain rate is faster in black soil and slow for yellow soil [5]. Thixotropic strength ratio is higher for the clay of higher sensitivity and Sensitivity generally increases with decrease in plasticity index. Similarly, [6] studied the geotechnical properties of red residual soil deposit at Sanga, Kavre shows that the result of unconfined compression strength of the compacted sample at same dry density with lower water content produces higher strength than that of higher water content and Swelling appears to be larger for the sample compacted in dry of optimum.

2. Material and Method

2.1 Soil sampling technique

Open excavation were done, undisturbed and disturbed samples were collected in thin walled sampler tube. Sampling tubes were sealed at both ends by wax along with the plastic to preserve moisture content. All the sample tubes were kept in a container and covered with wet jute bag followed by plastic sheet cover to preserve its natural state. Location of sample collection:Kalomato (Chardobato, Bhaktapur Building site), Ratomato (Chormara, Nawalparasi),and Kameromato (Ghatte Khola, Kaski).

Figure 1: Soil Sampling

2.2 Soil testing methods

The testing program includes the determination of the shear strength by means of the lab vane shear and the unconfined compression tests.

2.2.1 unconfined compression test

For each soil type, undisturbed sample was obtained using extruder and (UC) test was conducted to determine the unconfined compression strength. Length and diameter of the specimen were measured and Placed centrally on the lower plate on the machine. Deformation and load gauge were adjusted to zero value and reading of load at dial gauge for every 20 divisions on deformation dial gauge was recorded. loading was continued until the failure occurred. After failure, same sample was remolded again and filled in standard (UC) mould maintaining same weight and volume as prior to undisturbed sample to obtain sensitivity of that clay. Additional 4 samples for each soil type were prepared maintaining weight and volume properties of their respective undisturbed samples and stored for the study of thixotropic regain with time.

Figure 2: Unconfined Compression Test Setup

Compute the axial strain (ε),the corrected area (Ac) and the compressive axial stress (σ_1) for all readings to define stress strain curve (Is : 2720 (part 10) - 1978).

$$\varepsilon = \frac{\delta L}{Lo} * 100, A_c = \frac{A_0}{(1-\varepsilon)}, (q_u) = (\sigma_1) = \frac{P}{A_c}$$

So, the un-drained shear strength (Su) of the soil is,

$$Su = C = \frac{qu}{2}$$

Where, (ε)=axial strain,(δL)= change in length,L_o= initial length of specimen, P= axial load at failure,A_c=corrected area,q_u = the axial stress at which the specimen fails.

2.2.2 Lab Vane shear test

For Vane shear test, gently push the vane blade into Sampler tube to their full length without disturbing the soil specimen, the top of the vanes should be at least 10 mm below the top of the specimen. No hammering shall be permitted. Note the initial readings of the angle of twist on gear wheel. Allow a minimum period of five minutes after insertion of the vane. Turn the gear handle so that the vane is rotated at the rate of 0.1 deg$/sec$. Note the maximum torque indicator dial gauge reading attained. If necessary, note the torque indicator dial gauge readings at half-minute intervals and continue rotating the vane until the reading drops appreciably from the maximum, also record final reading on gear wheel to determine the angle of rotation required for failure. Just after the determination of the maximum torque, remove the disturbed length of sample and refill it to same height maintaining weight and volume properties of their respective undisturbed samples for determining remolded shear strength.

Figure 3: Vane Shear Test Setup

The un-drained shear strength of the soil is determined from the equation(Is : 4434 - 1978).

$$Su = C = \frac{T}{\pi(\frac{D^2H}{2} + (\frac{D^3}{6})}$$

Where,S_u=Un-drained shear strength,$(kgf/cm)^2$

T= torque in kgf.cm. D= overall diameter of vane,cm. H= Height of vane,cm. Torque (T), was obtained from the standard calibration chart provided by the instrument supplier based on the dial gauge reading recorded.

2.2.3 X-ray Power Diffraction (XRD) test

Two grams each, of Oven dried fine powdered samples of Ratomato, Kalomato and Kameromato were provided to Nepal Academy Of Science And

Technology (NAST), Khumaltar, Lalitpur for X –Ray diffraction analysis. The graphs Obtained were analyzed using xpert highscore plus (software) to identify and quantify the minerals it contained. Minerals present were identified by comparing with established data and patterns available in the Mineral database (COD 2016 Conv45).

3. Results and Discussions

3.1 Basic Geotechnical Properties

Detail description of Various soil sample tested are presented in Table:1.

3.1.1 Grain size Distribution

Figure 4 shows the detail grain size pattern of various soils tested. Hydrometer analysis done for finer particles of Ratomato, Kalomato and Kameromato shows 57%,16% and 8.73% of clay particles (i.e, finer than 0.002mm) respectively.

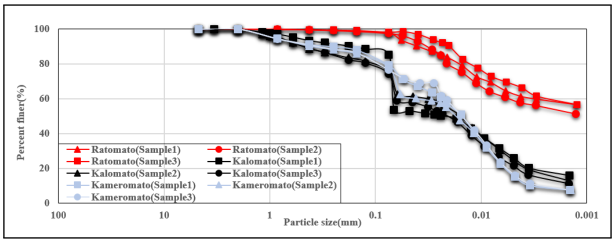

Figure 4: Grain size Distribution

3.1.2 Activity

Based on Plasticity index and clay fraction Ratomato was classified as Inactive whereas, Kalomato and Kameromato were classified as Normal active soil.

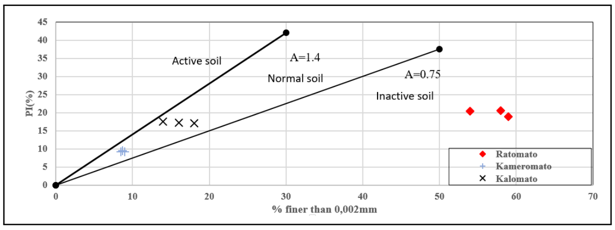

Figure 5: Plasticity index Vs Clay fraction

3.2 PropertyInterrelationshipwith Sensitivity

1. Depending upon the sensitivity values obtained from UCS and VST, Ratomato and Kalomato can be classified as low sensitive clays and Kameromato as insensitive clays (according to Skempton and Northey).

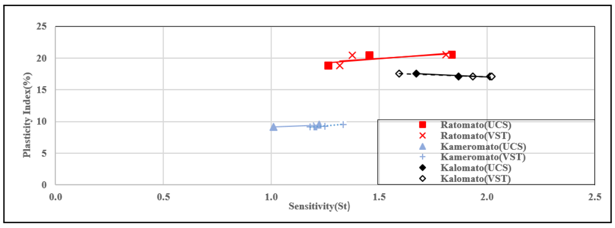

Figure 6: Sensitivity Vs Plasticity Index

2. Fig 6, reveals that for Ratomato and Kameromato sensitivity increases with increase in plasticity index, whereas sensitivity decreases with increase in plasticity index for Kalomato. Results of kalomato resembles with Norwegian clay Presented by Bjerrum, 1954 [7].

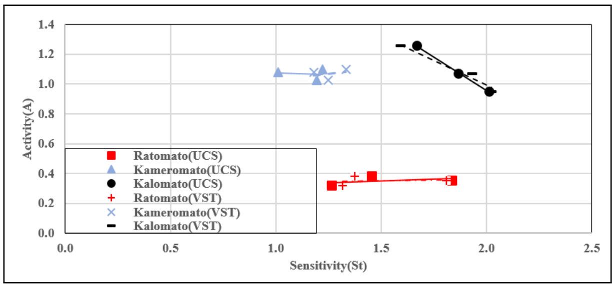

Figure 7: Sensitivity Vs Activity

3. Fig 7, shows that for Ratomato and Kameromato Sensitivity increases with increase in activity whereas sensitivity increases with decrease in activity for Kalomato.

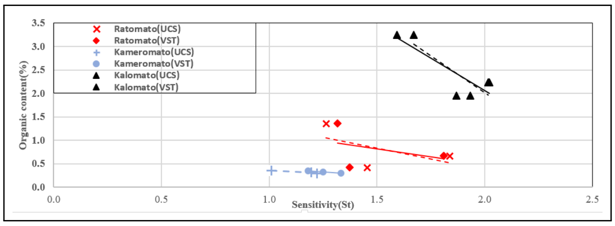

Figure 8: Sensitivity Vs Organic content

4. Fig 8, reveals that for all the soil samples (Ratomato, Kalomato and Kameromato) Sensitivity decreases with increase in organic content.

Table 1: Geotechnical properties of various soil sample.

Properties	Ratomato	Kalomato	kameromato
Moisture Content(%)	30.90	42.28	20.69
Organic Content(%)	0.82	2.48	0.32
Sp.gravity	2.55	2.45	2.66
Liquid Limit(%)	53.80	47.29	30.80
Plastic Limit(%)	33.85	30.02	21.47
Plasticity Index(%)(%)	19.95	17.27	9.33
Shrinkage Limit(%)	23.37	20.63	19.39
(%) Clay Fraction	57	16	8.73
Activity	0.35	1.09	1.07
Soil Type	*MH*	*ML*	*CL*
Soil Phase	*SemiSolid*	*Plastic*	*Semisolid*
Liquidity Index(IL)	-0.16	0.71	-0.08
(IL)Classification	*Hard*	$V.soft - Soft$	*Hard*

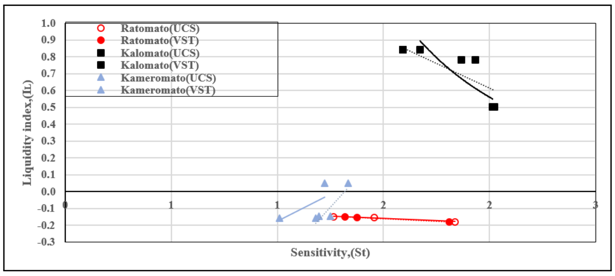

Figure 9: Sensitivity Vs Liquidity Index

5. Fig 9, shows that for Ratomato and Kalomato sensitivity increases with decrease in liquidity index whereas, sensitivity increases with increase in liquidity index for Kalomato.

3.3 Failure Analysis

1. Fig 10, reveals that axial load at failure is greater for Ratomato and lowest for Kameromato.

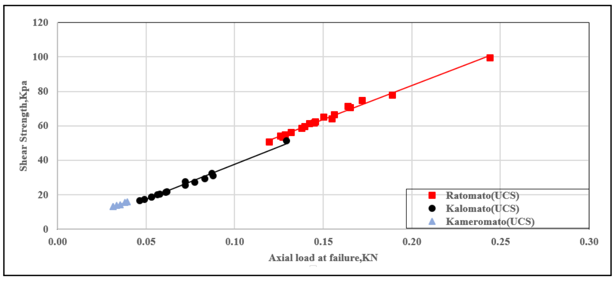

Figure 10: Shear Strength Vs Axial Load

2. Fig 11, shows that for Ratomato, axial strain at failure decreases with increase in shear strength whereas for kameromato axial strain at failure increases with increase in shear strength.

Kalomato soil sample being very soft to soft consistency, axial strain at failure is taken when 20% strain is reached. Axial strain at failure for Kalomato decreases with increase in shear strength. Failure occurs at lower axial strain for Ratomato and higher axial strain for Kalomato.

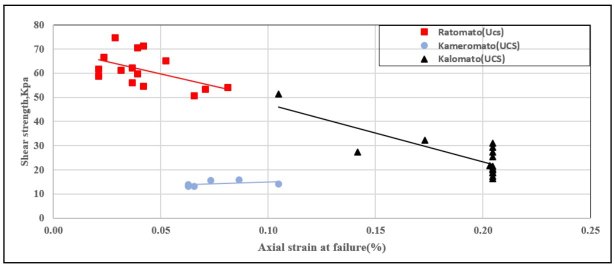

Figure 11: Shear Strength Vs Axial Strain

3.4 Thixotropic Behaviour

3.4.1 Thixotropic strength gain

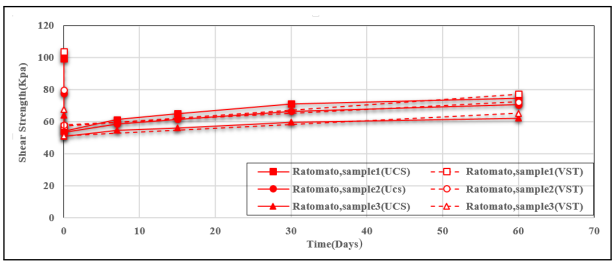

Figure 12: Thixotropic strength gain(Ratomato) Vs Time

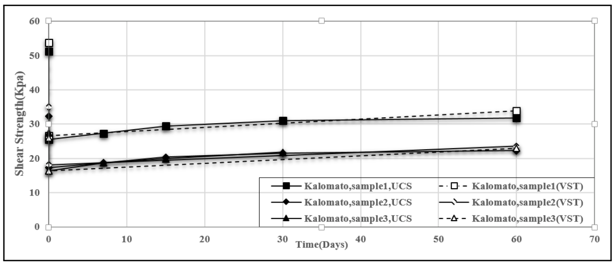

Figure 13: Thixotropic strength gain(Kalomato) Vs Time

1. Fig 12 and fig 13,shows the regain of strength of Ratomato and Kalomato with time at different time after remolding respectively. Results obtained from VST were slightly higher compared to UCS test. After two months of remolding strength regained for Ratomato and Kalomato were observed to be 1.30 and 1.29 (avg)times that of remolded strength respectively.

3.4.2 Strength Percent of original Undisturbed Strength

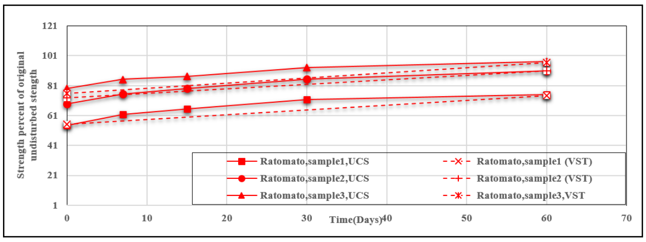

Figure 14: Strength Percent of original Undisturbed Strength (Ratomato) Vs Time

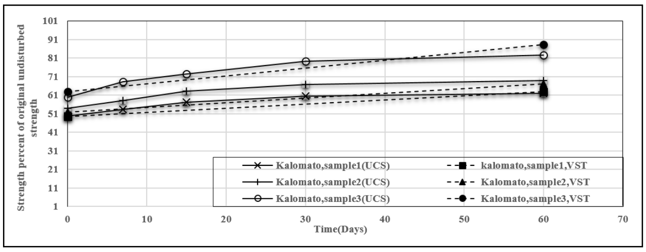

Figure 15: Strength Percent of original Undisturbed Strength (Kalomato) Vs Time

1. Fig 14 and fig 15, shows the thixotropic strength regain of Ratomato and Kalomato in the form of strength percent of original undisturbed strength with time.Results obtained from VST were similar when compared to UCS test results.After two months of remolding, Ratomato and Kalomato regained 87% and 71% (avg.) of its original undisturbed strength respectively.

3.4.3 Thixotropic Strength Ratio

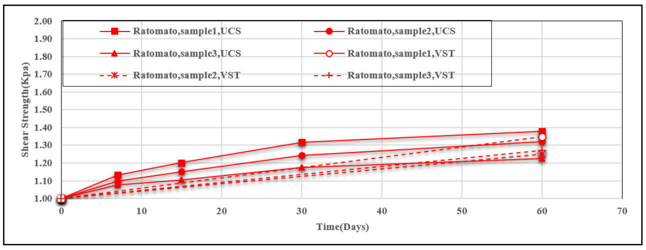

Figure 16: Thixotropic Strength Ratio (Ratomato) Vs Time

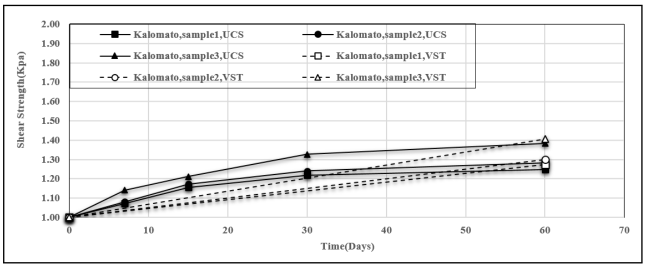

Figure 17: Thixotropic Strength Ratio (Kalomato) Vs Time

1. Fig 16 and fig 17, shows the thixotropic strength ratio for Ratomato and Kalomato soil samples with time and shows similar strength gain rate as Pittsburg Sandy clay. Results obtained from VST were similar to UCS test results.

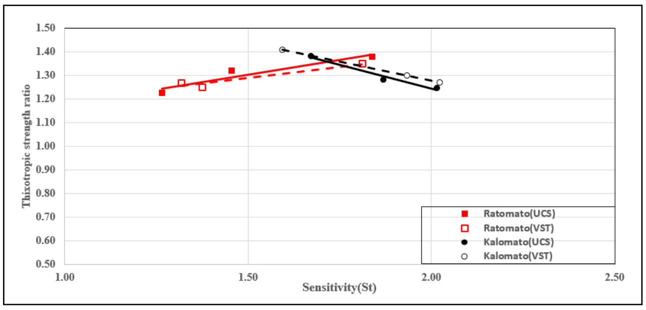

Figure 18: Thixotropic Strength Ratio Vs Sensitivity

2. Fig 18, reveals that for Ratomato, thixotropic strength ratio increases with increase in sensitivity but for Kalomato, thixotropic strength ratio decreases with increase in sensitivity.

3.5 Minerals Identification and Quantification

Majority of clay minerals found in Ratomato, Kalomato and Kameromato are not in pure form it is somewhat disturbed or in complex form. Based on the detail mineralogical identification ,Quantification and Mohs values mentioned in Fig (19-24) it shows Quartz content is more for Ratomato and least for Kameromato. Chlorite(57%) is found to be the major constituents of Kameromato.Based on this findings we can conclude that major mineral of ratomato are hard, while for Kalomato it is intermediate hard and for Kameromato it seems soft as major chlorite minerals has low Mohs value.

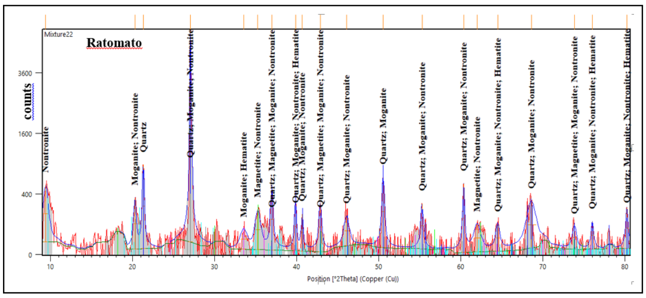

Figure 19: Ratomato Minerals Identification

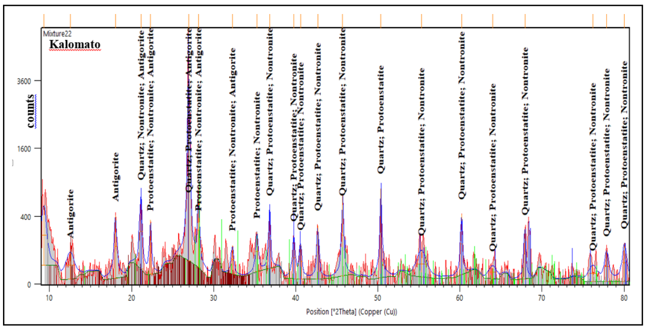

Figure 20: Kalomato Minerals Identification

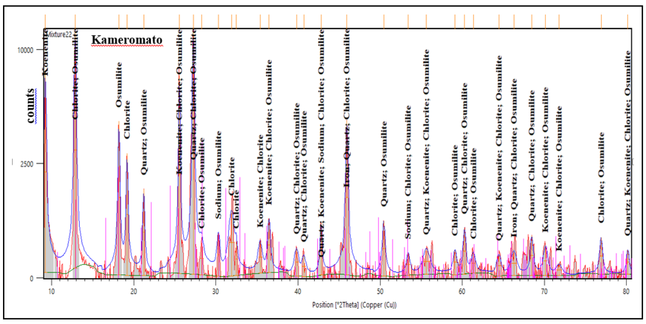

Figure 21: Kameromato Minerals Identification and Quantification

(Ratomato)Minerals	Mohs scale
Quartz(Si_3O_6)	5-6
Moganite($Si_{12}O_{24}$)	6
Nortornite($Fe_4Si_8O_{24}$)	1.5-2
Magnetite($Fe_{24}O_{32}$)	5.5-6
Hematite($Fe_{12}O_{18}$)	5.5-6.5

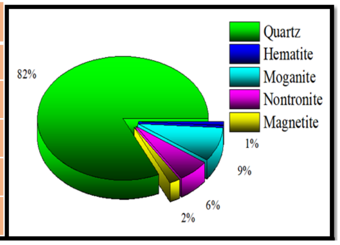

Figure 22: Ratomato Minerals Quantification and Hardness

(Kalomato) Minerals	Mohs scale
Quartz(Si_3O_6)	5-6
Protoenstatite ($Mg_8Si_8O_{24}$)	Undefined
Antigorite ($Si_3Mg_{48}O_{147}H_{62}$)	3.5-4
Nortronite ($Fe_4Si_8O_{24}$)	1.5-2

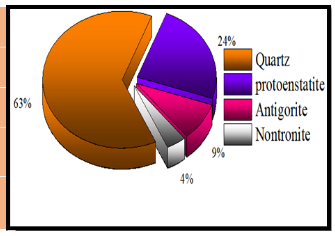

Figure 23: Kalomato Minerals Properties

(Kameromato) Minerals	Mohs scale
Chlorite($Mg_{12}Si_8O_{36}$)	2-2.5
Osumilite($K_{1.38}Fe_{0.52}Mg_{3.96}Si_{20.40}Al_{9.12}O_{60}$)	5-6
Quartz(Si_3O_6)	5-6
Iron(Fe_2)	4
Koenenite($Mg_{0.6}Al_{0.36}O_2$)	1.5

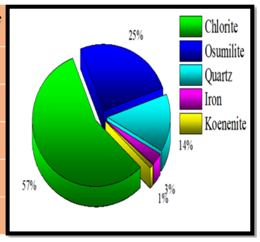

Figure 24: Kameromato Minerals Properties

3.6 Correlation between Unconfined compression and Vane shear test results

Based on the number of results obtained from Unconfined compression and Lab vane shear test done on various samples of three different types of clayey soil, simple correlation was developed, which was the main objectives of this research paper.It was observed that Vane shear test generally gave the higher values of un-drained shear strength compared to the results from unconfined compression test. Fig 19,shows that there is 5% rise in shear strength result from UCS to VST. Shear strength values determined by the vane shear test are always greater than those determined by the unconfined compression test as explained by John Arthur Mathes, 1968 [8]. Numerically,

$$y = 1.049X - 0.5581$$

Where,
y=Un-drained shear strength obtained from (VST)

x=Un-drained shear strength obtained from (UCS)
The instrument available for this study required manual control of the rotation speed. Consequently, the rotation speeds were not necessarily constant during an individual test, nor were the rotation speeds of successive tests exactly the same. The tests, however, were conducted under conditions as similar as possible with the available equipment, but the variations could explain the difference between the vane shear and unconfined compression results. Clading et al., [9] also found that a rotation speed of $1.0\deg/sec$. produces vane shear strength values 20% greater than those at a rate of $0.1\deg/sec$. For our case, approximately there was 5% rise in shear strength result from UCS to VST which is acceptable.

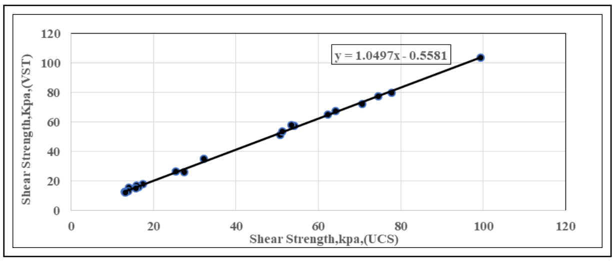

Figure 25: Correlation between UCS and VST

4. Conclusion

1. Based on the sensitivity values, Ratomato and Kalomato are classified as low sensitive clays and Kameromato as insensitive clays.

2. Thixotropic Strength ratio of both Red and Black clayey soils shows similar strength gain rate as Pittsburg Sandy clay.

3. It was observed that Vane shear test generally gave the higher values of un-drained shear strength compared to the results from unconfined compression test. Approximately there is 5% rise in shear strength result from UCS to VST.

4. Based on the detail mineralogical identification , Quantification and Mohs values Quartz content is more for Ratomato and least for Kameromato. Major mineral of Ratomato are hard, while for Kalomato it is intermediate hard and soft for Kameromato as major minerals(chlorite) has low Mohs value.

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