Study on Index and Engineering Properties of Soils Found in Konso Town

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***Abstract* - The geotechnical engineers repeatedly facing problems for identification and classification of the various grades of tropically weathered residual soils in Ethiopia. An experimental study was performed to evaluate the geotechnical properties of weathered residual laterite soils of south western Ethiopia (konso town). Residual tropical soils are sensitive to handling and disturbance. Plasticity chart is good reference to evaluate the properties of tropical residual soils. It is observed from the experimental results that increasing trend in natural moisture content, free swell index, specific gravity and density with increase in depths, whereas decreasing trend was observed in liquid limit and plastic limit. Clay fraction varies between 40.7 to 58.6%, the unconfined compression strength test results are ranges between 245 to 332 kN/ m2, the cohesion and angle of internal friction values are varies between 160.76 to 191.34 kN/m2 and 10 to 12º**

***keywords* - index properties, shear strength parameters, tropical residual soils, konso**

1. INTRODUCTION

Tropical residual soils are formed in situ by deep chemical weathering of rocks, usually in a tropical climate. The degree of weathering and extent to which original structure of the rock mass is destroyed varies with depth from the ground surface. Some components are removed as a result, usually leaving a clay-based deposit. This factor causes the behavior and properties of both soils to be different. Besides, behavior and properties of tropical residual soil also vary by location based on geological formation, surrounding environment and climate: the main factors in their formation processes. Because of these differences, testing and sampling procedures in the determination of their properties and strength of tropical residual soils cannot be directly adopted from the conventional method of testing and sampling for sediments type soils, without some modifications. Preparation and handling of samples for tropical residual soil sometimes need special care and methods as conventional methods normally used on sedimentary soils may not be applicable. Residual soils that are frequently encountered in tropical regions require special procedures to obtain reliable and consistent test results. (Bujang B.K.Huat, 2004)

Konso (also known as karat) is town located in Sagan area of the Southern Nations, Nationalities and Peoples Regional State (SNNPRS). It is also located at about 85 km south of Arba Minch Town (the capital of the former Gamo Gofa province) and about 595km south west of Addis Ababa capital of Ethiopia. Its altitude lies between 1800m-2000m amsl whereas the climatic condition is warm with mean annual temperature varying between 16.49 ℃ in winter and 30.24 ℃ in summer and mean annual rain fall of 954.7mm. The location of the study area is shown in Figure 1.1.

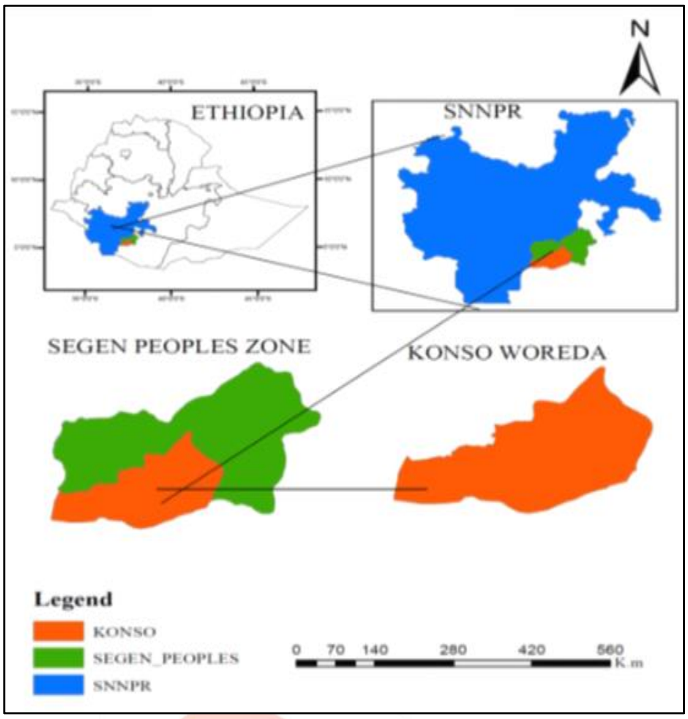

Figure 1.1: Location Map of the Study Area

The Konso area characterized by Sub-Tropical dry and hot climate with general temperature increase towards South West .The average annual temperature is about 25 ℃ .The plateau areas in the north and east are relatively moist, cool and receive more rain fall than the southern and western lowland parts, which are hot and dry. In general the area is characterized by two rain seasons that range from March to May and September to mid of November. The March to May rainy season is the main rainy season and mostly accompanied by East – West blowing heavy wind. The average annual value reaches up to 1000mm.

2. LITERATURE REVIEW

Organic content is generally low, below 2%.The Calcium Carbonate content is either very small or lacking in most lateritic soils profiles. The distribution of such properties as the PH, Base Exchange capacities, hygroscopic moisture Content, calcium carbonate content and chemical composition of soil can form a basis for the understanding of behavior of lateritic soils as a material of construction (Lyon, 1971). It is accepted that residual soil behave differently from conventional soils (e.g. transported soil) as the soils are formed in situ and have only slight changes in stress history. The changes sturdily depend on mineral bonding and soil suction (Bujang B.K.Huat, 2004) The clay mineral most common in lateritic soils is Kaolinite. Halloysite is also reported. Illite and Montimorillonite are rare. The secondary minerals resulting mainly from the laterization process are Gibbsite, Goethite, Limonite and Hematite. Neither Manganese nor Titanium minerals were observed in significant amounts. There is very little information on the pysico-chemical characteristics of lateritic soils. A few data published on this subject have been confined. The conclusions reached show that the lateritic medium is either neutral or acidic and

The oven temperature 110ºc for water content determination was too high for certain clays and particularly tropical soils. These soils contain loosely bound water of hydration or molecular water which could be lost at high temperature, resulting in a change of the soil characteristics (Bowles, 1978).

The soils to be used in this test should be in its natural moisture content. Pre- test drying of the soil should be avoided as this tends to reduce the measured specific gravity. In residual soils the specific gravity may be unusually high or unusually low depending on mineralogy (Blight G.E. and Leong C.E., 2012)

The particle size distribution of residual soils is affected by

i. **Effect of drying** The most widely reported effect of drying is reduce the percentage that is reported as the clay fraction (finer than 2μm).It is accordingly recommended that drying of the soil prior to testing be avoided. Oven dried lateritic soils were found to give the least amount clay fraction, as compared to air dried or as received (natural moisture content) samples (Blight G.E. and Leong C.E., 2012).
ii. **Chemical pretreatment** if it is considered necessary to eliminate Carbonates or Sesquioxides, then pretreatment with hydrochloric acid is recommended
iii. **Sedimentation** is essential to achieved complete dispersion of fine particles prior to Carrying out a sedimentation test. The sample should be immersed in a solution of dispersant such as dilute alkaline Sodium Hexametaphosphate and therefore washed through the standard nest of sieves (Blight G.E. and Leong C.E., 2012).

(Lyon, 1971) found that wet sieving increases the silt and clay fraction from 7 to 20 % as compared to dry sieving .It has been found that Sodium Hexametaphosphate generally gives better dispersion.

Atterberg Limits are arbitrary boundaries through which a soil passes from liquid, to Plastic, semi solid and solid states. These boundaries are defined by moisture contents. They are used to determine the consistency of fine-grained soils.

Because the formation of lateritic soils involves differential weathering as well as movement and deposition of dissolved materials, the variation of plasticity characteristics with depth cannot be predicted even in two similar profiles on different topographical sites. Some of the atterberg limits in some tropical residual soils are shown in table 2.1

Table 2.1: Atterberg limits of some tropical residual soils (Wesley L. , 1988)

Granite	69	33	Malaysia	Taha et al.(1999)
Granite	60	19	Malaysia	Yee et al.(1975)
Schist	25-90	18-38	Malaysia	Komoo(1989)
Schist	59.5	28.5	Malaysia	Raj(1988)
Shale	64	22	Malaysia	Mun(1985)

In general, the greater the duration of mixing (i.e., the greater the energy applied to the soil prior to testing), the larger the value of the resulting liquid limit, and to a lesser extent, the larger the plasticity index. This has been attributed to longer mixing results in more extensive break down of the cemented bonds between the clay clusters and within peds (disaggregation of the particles), and thus formation of greater proportions of fine particles (Blight G.E. and Leong C.E., 2012).

The Unconfined Compression Test procedure similar to the UU test procedure, except that no confining pressure is applied to the specimen (i.e. σ3 is equal to zero).The test is commonly performed in a simple loading frame by applying an axial load to the soil specimen (D.G. Fredlund and H.Rahardjo, 1993) . Unconfined Compression Test was done according to ASTM D 2166. This test method covered the determination of the unconfined compressive strength of cohesive soil in remolded condition, using strain-controlled application of the axial load. The sample was prepared with length to diameter ratio of 2. The load that would produce an axial strain of 1% per minute was applied at the specimen and the load and deformation dial readings were recorded at every 10 to 50 divisions on deformation the dial. The loading was applied until the load (load dial) decreases on the specimen significantly.

General relationship of Consistency and Unconfined Compression Strength (UCS) of clay is shown in Table 2.2

Table 2.2: Relationship between consistency and UCS

Consistency	Unconfined Compressive Strength q_u (N/m2)
Very soft	0-25
Soft	25-50
Medium	50-100
Stiff	100-200
Very stiff	200-400
Hard	>400

Consolidation test is performed to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. From the measured data, the consolidation curve (pressure-void ratio relationship) can be plotted. This data is useful in determining the compression index, the recompression index and the pre-consolidation pressure (or maximum past pressure) of the soil. In addition, the data obtained can also be used to determine the coefficient of consolidation and the coefficient of secondary compression of the soil

The earliest and the most widely used method to determine the pre-consolidation pressure was the one proposed by Casagrande (1936). The method involves locating the point of maximum curvature on the laboratory e-log p curve. From this point, a tangent is drawn to the curve and a horizontal line is also constructed. The angle between these two lines is then bisected. The abscissa of the point of intersection of this bisector with the upward extension of the inclined straight part corresponds to the pre-consolidation pressure. The relative amount of pre-consolidation is usually reported as the over-consolidation ratio.

3. MATERIALS and METHODOLOGY

Accurate values of Index and Engineering properties of the soil samples of the study areas are very much helpful data for construction of any structures. To achieve that information was collected from the city administration which included like town plans to assess the expansion potential of the town and the current distribution of the dwellings and buildings in the town. There were four provinces (namely Doketu, Darra, Duraite and Mechelo). A field visit of the town was conducted to identify suitable locations for pit excavations based on the future expansion plan of the town and the representativeness of the test pit in each province.

Laboratory tests were performed to determine the index and engineering properties of the soil. The tests were conducted according to ASTM standards. Standard procedures for performing laboratory tests were followed. Laboratory tests were conducted in the Soil Mechanics laboratory of Arba Minch University.

Different pre-treatment methods have been applied to a number of samples tested in the laboratory leading to different moisture contents. Samples tested for the four moisture pre-treatment methods were prepared in the following manner

As Received (AR) - at natural moisture content.

Soaked (S) - immersed in water for 24 hours.

Air dried (AD) - dried to constant weight under normal temperature.

In this study soil specimens were collected in different places from Konso-town. The area of the town is judiciously inspected based on visual variation of soil, after prudent inspection, Eight sampling areas were selected at an intervals of around 1.5 to 1.7 km at different parts of the town, which could represent the whole area of the town. Pits were excavated manually. Disturbed and undisturbed soil samples were collected at 1.5m, 3m and 5m depths from Pits No 1 to 4 and at 2m and 5m depths from Pits

No 5 to 8. The soil samples were collected from the following sites: Doketu (TP1 and TP2), Darra (TP3 and TP4), Duraite (TP5 and TP6) and Mechelo (TP7 and TP8).
The soil samples taken from test pits were shifted to Laboratory for further investigation. Different tests were conducted for different cases such **as received** and **air dried** cases for comparison.
The grain-size distribution of mixed soils was determined by combined sieve and hydrometer analyses. Hydrometer analysis was conducted with Sodiumhexameta phosphate dispersing agent for the soil samples passed on NO 200 sieve size. (0.075mm) and the soils were classified by using USCS and AASHTO classification systems.
Atterberg's Limit tests were conducted for air-dried samples (as per the ASTM D4318-00). The air-dried samples were prepared by spreading the Specimen in the air for about 5 days at the temperature about 26°C. The wet preparation is also applied for the as received (AR) samples. The portions of the samples passing the No. 40(0.425mm) sieve were used for the preparation of the sample in order to investigate the effect of temperature on the Atterberg Limits.
For UU Triaxial compression test the specimens were prepared as diameter of 38mm and height of 76mm. The dry soil was mixed with natural moisture content and compacted in three layers until the field density is obtained. Three test samples were prepared at each test pits and the test was conducted by applying initial confined pressure and deviatoric load till the soil specimen failed. Similarly the other two samples were tested by increment of the confined pressure followed by diviatoric stress till the soil failed then Mohr circle was developed for shear strength parameter determination.
For consolidation tests, it is used to determine the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled-stress loading. Undisturbed soil samples were taken by ring sampler and cut the sides of the sample to be approximately the same as the outside diameter of the ring. A soil sample diameter of 63mm and 20mm height were used for determination of C_C and Cr. The loading pressures were applied as 25kPa, 50kPa, 100kPa, 200kPa, 400kPa, 800kPa and 1600kPa and unloading readings were noted at 1600kPa, 400kPa, 100kPa and 25kPa pressures. The dial gauge readings were recorded for 24 hours.

4. RESULTS AND DISCUSSIONS

4.1 Natural Moisture Content

ASTM D: 2216–98, standard test method used for determination of moisture content in was considered suitable for determining the moisture content of Ethiopian laterites. Three duplicate samples of AR soils with weighted average to obtain the good results. The values of the moisture content are summarized in Table 4-1

Table **Error! No text of specified style in document.**-1: Natural Moisture content at temperature 50°C

Sl.no	Test pit	Depth in (m)	Moisture content (%)
1	TP1	1.5	27.29
		3	29.02
		5	30.84
2	TP2	1.5	29.97
		3	38.96
		5	40.37
3	TP3	1.5	14.9
		3	17.1
		5	19
4	TP4	1.5	32.6
		3	31.2
		5	34.9
5	TP5	2	27.44
		5	28.25
6	TP6	2	26.68
		5	25.33
7	TP7	2	24.94
		5	22.4
8	TP8	2	28.13
		5	31.06

4.2 Free Swell

Free swell test results for air dried soil samples are summarized in Table 4.2. From the test result it can be seen that the free swell of the soil under investigation ranged from 13% to 43%. Those soils having a free swell less than 50% are considered as low in degree of expansion. Hence all soil samples under investigation are non-expansive soils

Table **Error! No text of specified style in document.**.2: Free swell test results at air dried Condition

S.No	Test Pit	Depth in (m)	Free Swell (%)
1	TP1	1.5	30
		3	35
		5	41
		1.5	40

2	TP2	3	41
		5	42
3	TP3	1.5	18
		3	19
		5	20
4	TP4	1.5	30
		3	33
		5	38
5	TP5	2	33
		5	36
6	TP6	2	22
		5	23
7	TP7	2	30
		5	32
8	TP8	2	30
		5	31

4.3 Specific Gravity

The specific gravity of laterite soil was found to be increased in specific gravity with depth. This is interpreted as due to a high concentration of iron oxide. There is a clear trend of higher specific gravity for the AR (no pre-drying) samples. The specific gravity was in the range between 2.61 to 2.86 for different pretreatment conditions (Table 4.3).Whereas Specific gravity in TP2 and TP3 it is low this can be the type of minerals the soil constitute like Gypsum

Table **Error! No text of specified style in document.**.3: Values of specific gravity at different Conditions

S.No.	Test Pit	Depth in (m)	Test condition	Specific Gravity
1	TP1	1.5	Air dried	2.62
			As received	2.63
		3	Air dried	2.68
			As received	2.66
		5	Air dried	2.7
			As received	2.7
2	TP2	1.5	Air dried	2.5
			As received	2.51
		3	Air dried	2.6
			As received	2.61
		5	Air dried	2.51
			As received	2.59
3	TP3	1.5	Air dried	2.42
			As received	2.44
		3	Air dried	2.42
			As received	2.45
		5	Air dried	2.45
			As received	2.46
4	TP4	1.5	Air dried	2.72
			As received	2.74
		3	Air dried	2.76
			As received	2.77
		5	Air dried	2.77
			As received	2.79
5	TP5	2	Air dried	2.71
			As received	2.73
		5	Air dried	2.71
			As received	2.74
6	TP6	2	Air dried	2.71
			As received	2.75
		5	Air dried	2.74
			As received	2.78
		2	Air dried	2.66
			As received	2.72
7	TP7	5	Air dried	2.68
			As received	2.74
		2	Air dried	2.75
			As received	2.82

8	TP8	5	Air dried	2.76
			As received	2.86

4.4 Grain size Analysis

The grain size analysis distribution curves for soil samples under investigation at air dried condition are shown in Fig 4-1
The results obtained from the grain size analyses indicated that the dominant proportion of soil particle in the research area was clay. The percentage of soil passed through sieve No. 200 (0.75mm) was ranging from 71.7% to 94.8, which indicated that the soil in the study area was fine grained soil.

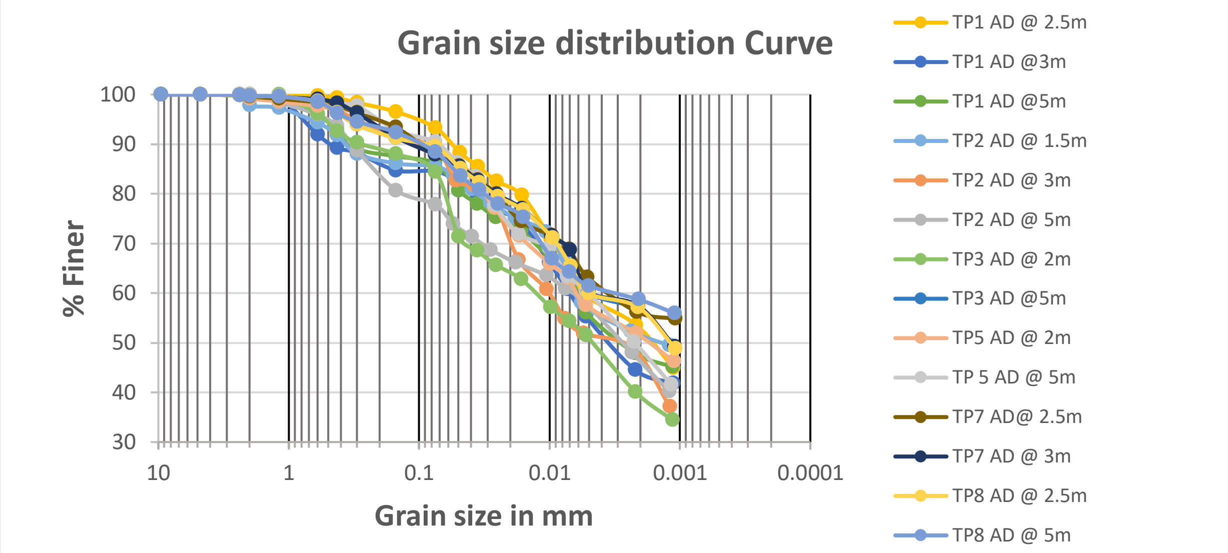

Fig 4-1: Grain size distribution curves at air dried condition

4.5 Consistency Limits

Atterberg Limit values for konso city soil is shown on Table 4.4

Table **Error! No text of specified style in document.**.4: Atterberg Limit values at different testing conditions

Test pits	Sampling depth (m)	NMC (%)	Dry density (kN/m3)	Test condition	Liquid Limit	Plastic limit	Plasticity index
1	1.5	30	16.17	As received	62.2	39.64	22.56
				Air dried	58.9	35.63	23.27
				Unsoaked	49.9	28.65	21.25
	3	31.5	16.81	As received	59.9	37.06	22.74
				Air dried	56.2	34.18	22.02
				Unsoaked	51.6	31.5	20.1
	5	33	17.37	As received	53.7	33.58	20.12
				Air dried	51	32	19
				Unsoaked	47.8	28.7	19.1
2	1.5	34	17.77	As received	62.8	37.35	25.45
				Air dried	57	34.86	22.14
				Unsoaked	56.2	35.79	20.41
	3	40	18.94	As received	56	33.71	22.29
				Air dried	54.2	35.01	19.19
				Unsoaked	53.6	34.77	18.83
	5	43	20.84	As received	55	35.77	19.23
				Air dried	53.2	34.67	18.53
				Unsoaked	53.2	32.8	20.4
3	1.5	15	16.15	As received	54.6	34.37	20.37
				Air dried	47.7	28.14	19.56
				Unsoaked	45.8	26.55	19.25
	5	20	16.34	As received	48.8	29.15	19.25
				Air dried	46.4	27.27	19.13
				Unsoaked	43.4	24.1	19.3
	1.5	33	15.94	As received	64.2	38.9	25.3
				Air dried	62.5	37.29	25.21
				Unsoaked	59.4	38.04	21.36

4	3	34	16.14	As received	59.4	35.65	23.75
				Air dried	56.2	33.81	22.39
				Unsoaked	51.5	33.24	18.26
5	2	27.4	16.19	As received	58.4	37.25	21.15
				Unsoaked	52.5	32	21.5
	5	30.2	17.38	As received	57.8	36.02	21.78
				Unsoaked	52.2	40.16	20.7
6	2	27.2	18.62	As received	61.1	40.03	21.07
				Unsoaked	52.7	33.04	19.66
	5	28.2	18.72	As received	56.5	36.73	19.77
				Unsoaked	46	26.5	19.5
7	2	25.4	17.21	As received	58.7	38.21	20.49
				Air dried	54.4	34.9	19.5
				Unsoaked	49.9	30.78	19.12
	5	26	17.28	As received	56.7	36.84	19.86
				Air dried	56.6	38.37	18.23
				Unsoaked	48.9	29.5	19.4
8	2	31	16.17	As received	58	36.95	21.05
				Air dried	54.8	36.34	18.46
				Unsoaked	53.2	34.24	18.96
	5	32.3	16.25	As received	59.1	38.65	20.45
				Air dried	55.2	35.82	19.38
				Unsoaked	50.5	32.27	18.27

4.6 Triaxial Unconsolidated Undrained (UU) Test

Based on the results obtained from Triaxial compression test for the soil samples at different locations were conducted Unconsolidated Undrained tests and the results are summarized on Table 4.5, The values of internal friction vary from 10° to 12° and cohesion vary from 160.76 to 191.34 kN/m2.

*Table **Error! No text of specified style in document.**.5: Unconsolidated Undrained (UU) test Results*

Location	Test Pit	Depth (m)	Dry density g/cm3	Natural moisture content (%)	Cohesion (kN/m2)	Angle of internal friction Φ(°)
Doketuo	TP2	5	1.75	43	188	11
Darra	TP3	1.5	1.65	15	191.34	11
Darra	TP3	5	1.67	20	190	10.5
Duraite	TP6	2	1.89	27.2	160.76	12
Duraite	TP6	5	1.91	28.2	187.59	10

4.7 Unconfined Compression Strength

Based on the results obtained from Stress-Strain curves the values of unconfined compressive strength varies from 245 to 332 kN/m^2. The results are shown in Table 4.6

*Table **Error! No text of specified style in document.**.6: UCS test results*

Location	Test Pit	Depth(m)	Density (kN/m3)	Natural Moisture Content (%)	Unconfined Compressive Strength(kPa	Undrained Shear Strength Su(kPa)
Doketuo	TP1	3	1.71	30	245	122.5
Doketuo	TP1	5	1.77	33	282	141
Darra	TP4	5	1.79	38	250	125
Duraite	TP7	2	1.75	25.4	332	166
Duraite	TP7	5	1.76	26	326	163
Mechelo	Tp8	2	1.65	31	294	147
Mechelo	Tp8	5	1.66	32.3	315	157.5

4.8 Consolidation test

From one-dimensional consolidation test results, which is summarized in Table 4.7, the values of the compression indices Cc range from 0.273 to 0.37 which were in the normal range of common silty clay soils.

*Table **Error! No text of specified style in document.**.7: Consolidation test results*

Location	Test Pits	Depth (m)	Unit Weights	C_c	C_r	Po		a_v	K 10 $^{-6}$

			(KN/m3				Cv 10^{-6} mm^2/min	m2/ KN	cm/sec
Deketuo	1	5	17.17	0.283	0.033	85.85	0.646	0.322	1.734
Darra	4	5	17.59	0.370	0.044	87.95	0.79	0.184	2.394
Duraite	6	5	18.72	0.340	0.040	93.6	0.646	0.355	1.743
Mechelo	7	5	17.28	0.312	0.037	86.4	0.667	0.328	1.79
Mechelo	8	5	16.25	0.273	0.032	81.25	0.678	0.329	1.81

5. Conclusions

Based on the investigations made on the soils of Konso Town, the following conclusions are drawn.

- ✓ The use of the wet sieving method is preferred with the soil soaked until the coating material is fully softened. The modification of the grading curves using modified mass proportion is not considered important if the wet sieving method is used.
- ✓ It is considered appropriate that laterite soil samples for Atterberg limit testing should be broken down by soaking in water and not by drying and grinding as is conventional practice for temperate zone soils
- ✓ Laterite soils of Konso area are characterized by high concentration of Iron Oxide, Aluminum Oxide (Sesqueoxide) and Kaolinite minerals.
- ✓ The test results of soil samples subjected to fall below A-line under MH (inorganic silt with medium strength).
- ✓ Specific gravity test results of this study varies from 2.42 up to 2.86.
- ✓ The natural moisture content values ranges from 14.9% to 40.37%
- ✓ The liquid limit and plastic limit values varies from 43.2 to 64.2% and 24.1 to 40.16% respectively.
- ✓ Soils variation in percentage of particle sizes in the different test procedures is not significant.
- ✓ The Values of friction angle vary from 10 to 12^o and cohesion vary from 160.76 to 191.34 kN/m^2.
- ✓ The values of unconfined compressive strength range from 245 to 332 kN/ m^2, which was in the ranges of very stiff consistency.
- ✓ From one-dimensional consolidation test, the Compression Index Cc ranged from 0.273-0.37 and coefficient of Permeability ranged from 1.81x10^{-6} to 2.39x10^{-6} cm/sec. which indicates that the soil in the area is relatively impervious.

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