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Investigation into some of the engineering properties of soil in Damot Gale district

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ABSTRACT

Investigation of the sub-surface condition is used for the effective design of the structural elements. It is also very crucial to obtain information on type, characteristics and distributions of soil and rock underlying a site for proposed structures. I investigate into some of the engineering properties of soils collecting 20 disturbed and 10 undisturbed soil samples from 10 different test pits at the average depth of 1.5m to 3m and laboratory tests conducted. The natural moisture content of soil ranges from 24% - 44.47% and bulk unit weight ranges from 16.4 to 19.7 kN/m^3. Specific gravity of soil vary from 2.57 to 2.84 and the particle size analysis showed that the dominant proportions of soils in the study area is clay. Consistency limit test result in the research area showed, liquid limit ranges from 46 to 73%, plastic limit ranging from 13 to 38% and plasticity index ranging from 13 to 38 %. The unconfined compressive strength of the soils in the study area ranges from 80 -215kN/m^2 and undrained shear strength ranges from 40 – 107.5 kN/m^2. Finally, one-dimensional consolidation test was done.

Keywords— *Soil Investigation, Engineering Properties, Disturbed, Undisturbed, Test Pit*

1. INTRODUCTION

In the field of civil engineering, nearly all projects are built on, or into, the ground. Thus, during the planning, design, and construction of foundations, embankments, tunnel and earth-retaining structures, geotechnical engineers must study the properties of soils, such as origin, grain-size distribution, permeability, compressibility, shear strength and load-bearing capacity (Biruk, 2014). In nature, soil can exhibit a wide range of color: gray, black, white, reds, browns, yellows and under the right conditions green (Alemayehu and Mesfin, 1999). Engineering properties of soils play a major role in construction works particularly a structure built on ground like; road constructions, foundations, embankments and dams to mention a few. These made imperative, the testing of soil, on which a foundation or super structure is to be laid. This would determine its geotechnical suitability as a construction material (Belayhun Y., 2013). In recent times, the alarming rate at which lives are being lost due to collapse of buildings and road failures requires strong solution. The solution could be brought by detail geotechnical testing of the engineering soil.

The sub-surface conditions at a site is prerequisite to the effective and economical design of the structural elements on ground. Therefore, it is necessary to do detail investigation on sub-surface condition for feasibility and economic studies of the proposed project.

Poor investigations of ground conditions, faulty interpretation of results may contribute to inappropriate designs, less service year for structures and construction modifications. Therefore, to obtain information on type, characteristics and distributions of a soil, geotechnical investigations should be done properly on soil. i) To investigate some of the index properties of soil. ii) To determine the shear strength characteristics of the soil. iii) To determine the consolidation characteristics of soils in the district. IV) To classify the soil based on USCS (Unified Soil Classification System) and AASHTO (American Association of State Highway and Transportation Official) classification method.

2. LABORATORY TESTS

To achieve the above-mentioned objectives ten sampling areas were selected which represent all types of soils found in the district. From the selected sampling areas test pits were excavated to a depth of three meters for a visual observation of the sub-surface condition and to take representative samples. Disturbed and undisturbed samples of soils were collected for laboratory testing. The undisturbed samples were taken from the test pits by manually driving a Shelby tube, which is a thin-walled sampling tube, slowly in to the desired depth. While preparing the tube length and diameter were adjusted to make sample extrusion easy. An inside clearance ratio of about 1% was provided for tip relief of the soil and to reduce the friction between the soil and inner edge of the sampling tube during the sampling process. A thin film of oil was applied at the cutting edge and inside the sampler to reduce the friction between the soil and metal tube during sampling operations and to make sample extrusion easy. Undisturbed soil samples recovered from the test pits were kept within the sampling tube. The soil sampling tube was tightly sealed with wax thoroughly sealed in containers to prevent a loss of moisture during transportation to the laboratory.

2.1 Laboratory Tests

The soil samples recovered from the site were be subjected to the following tests:

- Moisture content Test
- Specific gravity Test
- Consistency (Atterberg's) Limit Tests
  - Plastic Limit
  - Liquid Limit
- Grain Size distribution Test
- Free Swell Test
- UCS (Unconfined Compressive Strength Test)
- One dimensional consolidation test

The tests were done according to ASTM (American Society for Testing and Materials) standard.

3. IN-SITU PROPERTIES AND LABORATORY TEST RESULTS

The soil specimens for this study were collected from Damot Gale district. Prior to sampling, visual site investigations and information from residents and construction firms were collected to consider the different soil types and to take representative samples evenly in the district.

3.1 Natural Moisture Content

According to ASTM D 2216 standard moisture content of soil is an indication of the amount of water present in soil. A test specimen is first weighed in its natural or wet state is then dried in oven at a temperature of 105°C to a constant mass for 24 hrs.

Table 1: Natural moisture content

Test pits	Sample depth (m)	Natural moisture content (%)
TP-1	1.5	31.22
	3	33.96
TP-2	1.5	44.47
	3	29.34
TP-3	1.5	39.7
	3	26.79
TP-4	1.5	24.7
	3	40.51
TP-5	1.5	31.6
	3	24
TP-6	1.5	29.3
	3	28.3
TP-7	1.5	34.7
	3	39.2
TP-8	1.5	32.4
	3	30.2
TP-9	1.5	28.4
	3	32.2
TP-10	1.5	27.3
	3	29.7

3.2 Bulk Unit Weight

The bulk unit weight (also known as the total unit weight) is the natural in situ unit weight of the soil; therefore, it should only be obtained from undisturbed soil specimens.

Table 2: Bulk unit weight of samples from Damot Gale district.

Test pits	Sample depth (m)	Bulk unit weight (kN/m^3)
TP-1	1.5	18.1
	3	17.2
TP-2	1.5	16.4
	3	16.9
TP-3	1.5	17.2
	3	16.5
TP-4	1.5	17.9

	3	18.4
TP-5	1.5	19.3
	3	18.5
TP-6	1.5	19.7
	3	16.6
TP-7	1.5	17.2
	3	16.5
TP-8	1.5	18.4
	3	19.2
TP-9	1.5	18.1
	3	17.3
TP-10	1.5	17.2
	3	16.5

3.3 Particle Size Analysis

The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger sized particles, and the hydrometer method is used to determine the distribution of the finer particles.

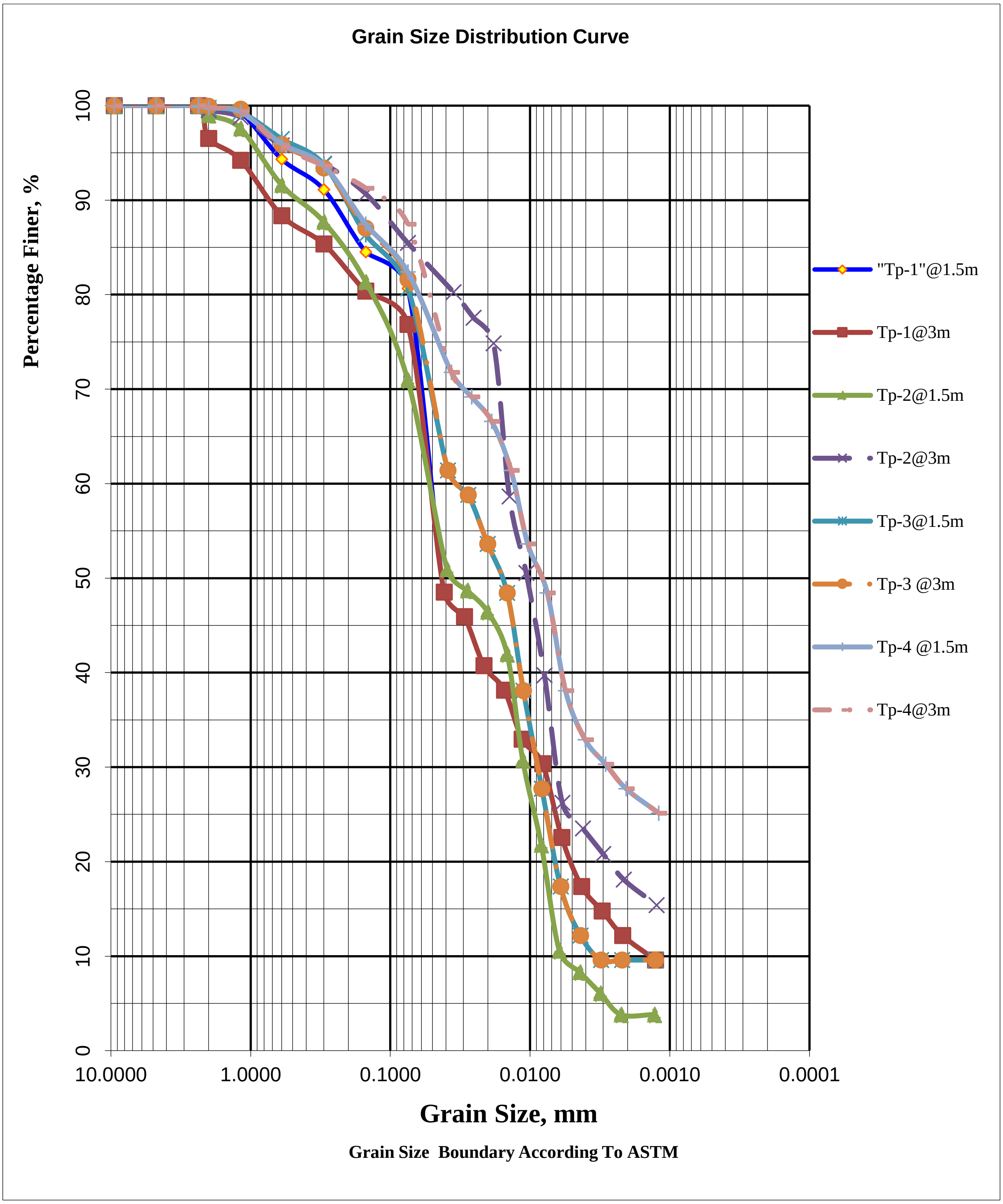

Fig. 1: Grain size distribution curve for samples from Tp-1 to TP-4

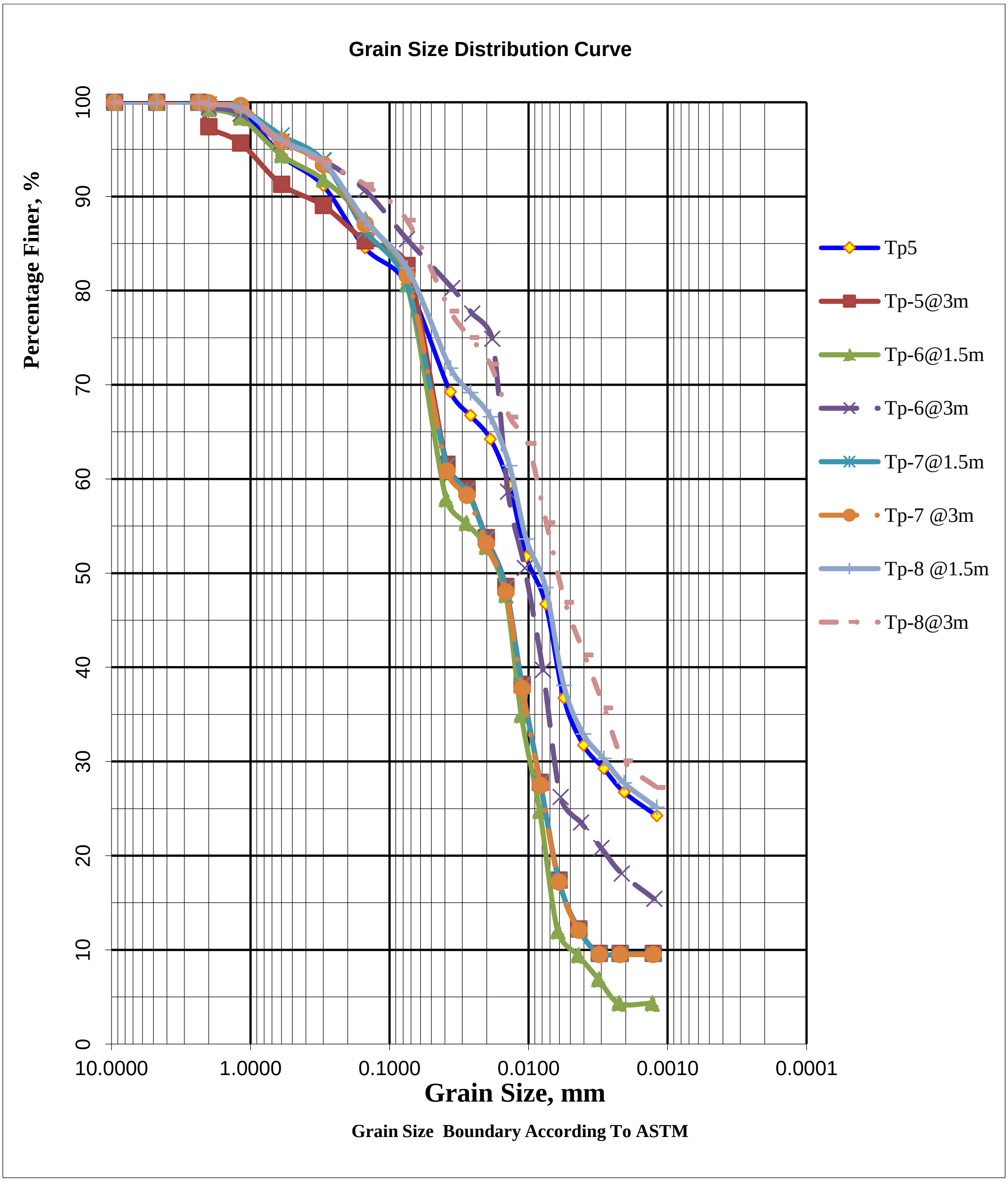

Fig. 1: Grain size distribution curve for samples from Tp-5 to TP-10.

3.4 Atterberg's Limit

This lab is performed to determine the plastic and liquid limits of a fine-grained soil.

Table 3: The summery of Atterberg's limit test of the study area.

Test pit	Depth (m)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Pit 1	1.5	54	22	32
	3	65	42	23
Pit 2	1.5	58	29	29
	3	56	25	31
Pit 3	1.5	48	27	21
	3	49	24	25
Pit 4	1.5	47	34	13
	3	63	34	29
Pit 5	1.5	72	34	38
	3	58	22	36
Pit 6	1.5	73	37	36
	3	65	37	28
Pit 7	1.5	46	21	25

	3	58	24	34
Pit 8	1.5	48	28	20
	3	47	27	20
Pit 9	1.5	53	30	23
	3	57	26	31
Pit 10	1.5	56	26	30
	3	67	33	34

3.5 Specific Gravity

In general, specific gravity is the ratio of the mass of a given volume of a material to the mass of an equal volume of water. In effect, it tells us how much the material heavier than or lighter than water (Das, 2008).

Table 4: The specific gravity of samples

Test Pit	Sample depth (m)	Specific gravity
Tp-1	1.5	2..64
	3	2.62
Tp-2	1.5	2.72
	3	2.84
Tp-3	1.5	2.57
	3	2.65
Tp-4	1.5	2.84
	3	2.72
Tp-5	1.5	2.82
	3	2.84
Tp-6	1.5	2.75
	3	2.69
Tp-7	1.5	2.76
	3	2.80
Tp-8	1.5	2.74
	3	2.67
Tp-9	1.5	2.69
	3	2.72
Tp-10	1.5	2.68
	3	2.75

3.6 Compaction Test

Compaction of a soil improves the engineering properties, i.e. it increases the shear strength of the soil and hence, the bearing capacity (Arora, 2004). The laboratory standard proctor and modified proctor tests are performed as per (AASHTO T 99 or ASTM D 698) and (AASHTO T 180 or ASTM D 1557) respectively.

Table 5: Summary of optimum moisture content and dry density of Damot Gale district.

Test Pit	Sample depth(m)	Optimum Moisture content (%)	Dry density (g/cm^3)
Tp-1	1.5	27.4	1.43
	3	31.9	1.35
Tp-2	1.5	27.7	1.34
	3	19.6	1.52
Tp-3	1.5	27.63	1.33
	3	26.02	1.49
Tp-4	1.5	30.9	1.39
	3	24.78	1.36
Tp-5	1.5	25.6	1.44
	3	27.2	1.46
Tp-6	1.5	35.83	1.22
	3	22.6	1.25
Tp-7	1.5	26	1.42
	3	28.5	1.41
Tp-8	1.5	20.4	152
	3	27.5	1.55
Tp-9	1.5	28.5	1.48
	3	25	1.28
Tp-10	1.5	25.5	1.34
	3	27.1	1.49

3.7 Free-Swell

Free swell also termed as free swell index. It is the increase in volume of soil without any external constraint when subjected to submergence in water (Punimia et al, 2006).

Table 6: Summary of free swell index of the study area

Test pit	Sampling Depth (m)	Sample condition	Water used	Free swell (%)
Pit 1	1.5	Oven dried	Tap water	70
	3	Oven dried	Tap water	50
Pit 2	1.5	Oven dried	Tap water	45
	3	Oven dried	Tap water	25
Pit 3	1.5	Oven dried	Tap water	25
	3	Oven dried	Tap water	18
Pit 4	1.5	Oven dried	Tap water	28
	3	Oven dried	Tap water	48
Pit 5	1.5	Oven dried	Tap water	40
	3	Oven dried	Tap water	35
Pit 6	1.5	Oven dried	Tap water	28
	3	Oven dried	Tap water	34
Pit 7	1.5	Oven dried	Tap water	85
	3	Oven dried	Tap water	55
Pit 8	1.5	Oven dried	Tap water	75
	3	Oven dried	Tap water	45
Pit 9	1.5	Oven dried	Tap water	30
	3	Oven dried	Tap water	22
Pit 10	1.5	Oven dried	Tap water	25
	3	Oven dried	Tap water	16

3.8 Shear Strength of Soils

The most common laboratory methods employed to obtain shear strength parameters are direct shear test, tri-axial compression test and unconfined compression test. For this research UCS is conducted.

Table 7: Unconfined compressive strength test results and consistency of soils.

Sample designation	Sample depth	Moisture content	Unconfined compressive strength, *qu* (kN/m^2)	Un-drained shear strength	Consistency
Tp1	1.5	48.6	166	83	Medium
	3	33.96	204	102	Very stiff
Tp2	1.5	44.47	184	92	Medium
	3	29.34	215	107.5	Very stiff
Tp3	1.5	39.7	80	40	Soft
	3	26.79	190	95	Medium

3.9 Consolidation

The compression of the soil mass due to the imposed stresses may be almost immediate or time dependent according to the permeability characteristics of the soil. The coefficient of consolidation and coefficient of compression determined at a depth of 3m in different sites of study area.

Table 8: Summary of one-dimensional consolidation test results

Test pit	depth (m)	Bulk unit weight (kN/m^3)	Pressure (KPa)	Coefficient of consolidation Cv (cm^3/min)	Compression index Cc	Pre-consolidation pressure (KPa)	Over-consolidation ratio (OCR)
Tp-1	3	17.19	50	0.084	0.110	190	3.68
			100	0.38			
			200	0.85			
			400	0.42			
			800	0.64			
			1600	0.53			
Tp-2	3	16.91	50	0.192	0.246	150	2.95
			100	0.235			
			200	0.158			
			400	0.326			

Tp-3	3	16.51	50	0.431	0.182	250	5.05
			100	1.053			
			200	0.937			
			400	0.854			
Tp-4	3	18.38	50	1.570	0.186	140	2.54
			100	3.533			
			200	2.672			
			400	1.710			

4. DISCUSSION ON LABORATORY RESULTS

From the laboratory tests the natural moisture content of the samples ranges from 24- 44.47%. The water content is higher in some parts of the district around areas where sample TP-2@1.5m and TP-4@3m is taken. This indicates that the underground water level in some parts of the district is around three meters and in some parts of the study area the moisture content high at depth of 1.5 meter this because of the time where sample taken was in summer therefore it may have the effect of rain fall. The bulk density and unit weight of soils in the study area ranges from 1.64 – 1.97 kN/m^3 and 16.4 – 19.7 kN/m^3 respectively. The specific gravity of soils ranges from 2.57 – 2.84 as stated in M.D. Braja. The results of the maximum dry density and the optimum moisture content are ranges from 1.22 -1.55 g/cm3 and 20.4-35.83% respectively. The particle size analysis result indicate that the dominant proportion of soil particle in the study area is clay.

The Atterberg limit of the soil samples on study area have done by using oven dried samples. The liquid limit of soil the study area ranges from 47 – 73%, plastic limit ranges from 21 – 42% and plasticity index ranges from 13 – 38%. It has been found that both liquid limit and plastic limits depend upon the type and amount of clay in the soil. However, the plasticity index depends mainly on the amount of clay. Soils with plasticity index of more than 35% have very high swelling potential (Seed, Woodward, and Lundgren (1 – 42)).

Free swell test results for oven dried samples at a temperature of 105 $^{O}{}_{C}$ shows that the free swell of the soil under investigation ranges from 16% to 85%. Those soils having a free swell less than 50% are considered as low in degree of expansion, free swell between 50%-100% are considered as marginal and soils having free swell greater than 100% are considered as expansive. Therefore most of the soil samples under investigation are non-expansive this may be due to kaolinite minerals that are very stable with strong structure and absorb little water.

4.1 Classification of the Soil

4.1.1 General: The purpose of any classification system is to categorize soils by relating their appearance and behavior with previously established engineering properties and performance. Attributes of a good classification system include simplicity, reproducibility under variable conditions, and applicability to all soils likely to be encountered. A good system should make distinctions of practical importance to local designs. (Belayhun, 2012) Table below shows the USCS classification of the study area.

Table 9: USCS classification of Damot Gale district.

Test Pit	Depth (m)	Particle size passing sieve size 200 (%)	Liquid limit (LL) %	Plastic Index (PI) %	USCS Classification
Pit 1	1.5	80.66	54	32	CH
	3	76.87	65	23	MH
Pit 2	1.5	70.95	58	29	CH
	3	85.47	56	31	CH
Pit 3	1.5	80.67	48	21	CL
	3	81.63	49	25	CL
Pit 4	1.5	82.40	47	13	ML
	3	87.47	63	29	MH
Pit 5	1.5	85.5	72	38	CH
	3	87.5	58	36	CH
Pit 6	1.5	82.6	73	36	MH
	3	80.5	65	28	MH
Pit 7	1.5	87.7	46	25	CL
	3	86.4	58	34	CH
Pit 8	1.5	85.5	48	20	CL
	3	77.4	47	20	CL
Pit 9	1.5	86.8	53	23	MH
	3	78.9	57	31	CH
Pit 10	1.5	88.5	56	30	CH
	3	87.47	67	34	CH

4.1.2 Plasticity Chart: The information provided in the plasticity chart is of great value and is the basis for the classification of fine grained soils in the unified soil classification system. The important feature of this chart is the empirical A-line that is given by equation PI=0.73(LL-20). A-line separates the inorganic clays from the inorganic silts. Inorganic clay values lie on or above the A-line, and values for inorganic silts lie below the A-line. Organic silts plot in the same region (below the A-line and with LL ranging from 30 to 50) as the inorganic silts of medium compressibility. On the chart, organic clays plot in the same region as inorganic silts of high compressibility (below the A-line and LL greater than 50).

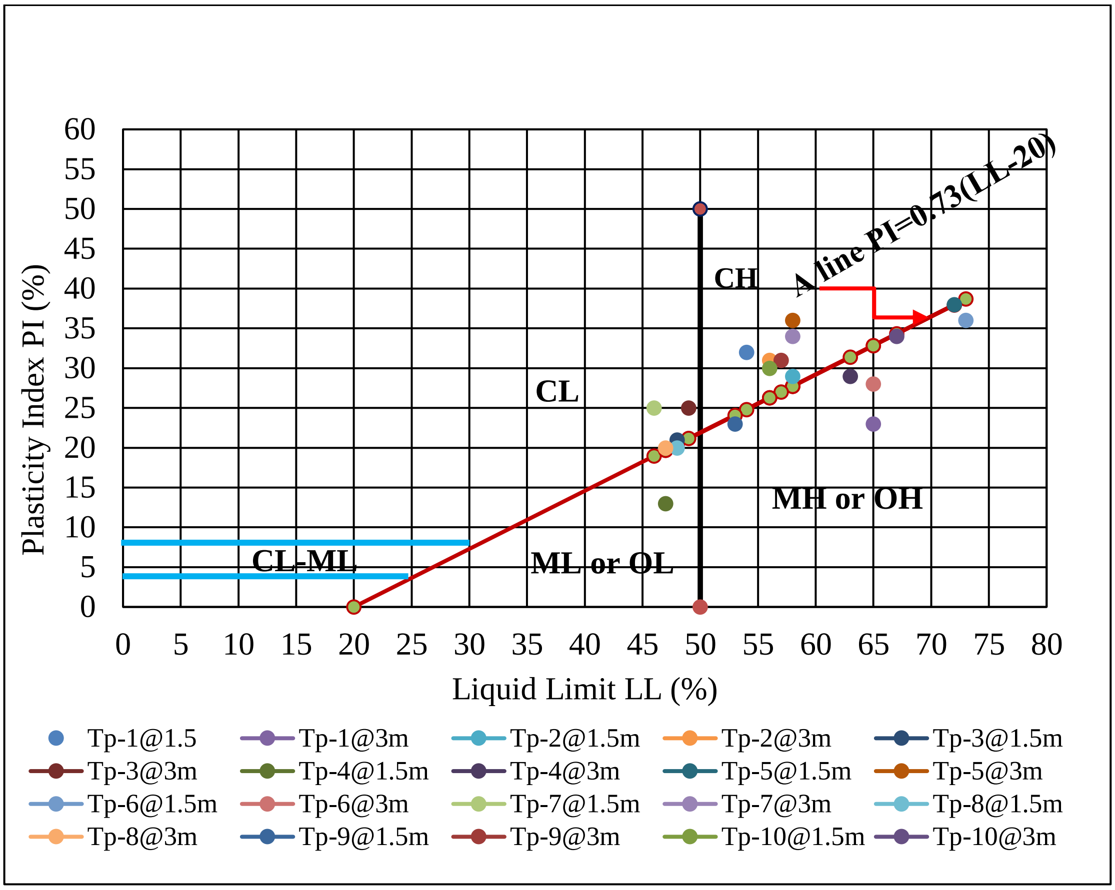

Fig. 3: Plasticity chart of study area according to USCS

4.1.3 Activity of Damot Gale Soils: Skempton's colloidal activity is determined as the ratio of the plasticity index of the clay content to fines, based on this Damot Gale soils classification shown in table 10.

Table 10: Activity of Damot Gale soils

S.No	Test pit designation	Clay Fraction (%)	PI	Activity (A)	Soil descrption
1	Tp1@1.5m	17.19	32	1.86	Active
2	Tp1@3m	17.05	23	1.35	Active
3	Tp2@1.5m	15.81	29	1.83	Active
4	Tp2@3m	26.11	31	1.19	Normal
5	Tp3@1.5m	32.21	21	0.65	Inactive
6	Tp3@3m	36.4	25	0.69	Inactive
7	Tp4@1.5m	27.72	13	0.47	Inactive
8	Tp4@3m	27.72	29	1.05	Normal

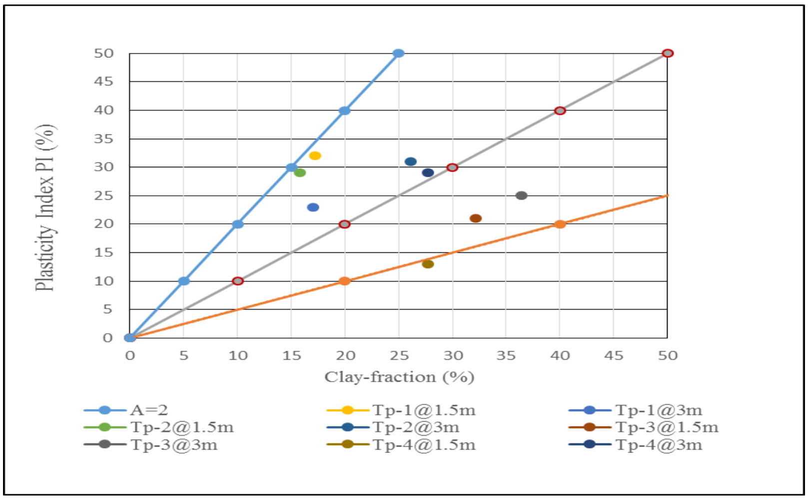

Fig. 4: Soil classification based on activity of clay

4.1.4 Soil Classification by Using AASHTO Classification System: The soil in the study area classified based on American Association of State Highway and Transportation Official (AASHTO) classification system is useful for classifying soils for highways by using particle size analysis and the plasticity characteristics of soil.

Table 11: Shows AASHTO soil classification of the study area

Test pit	Depth (m)	Sieve analysis percent passing			LL (%)	PI (%)	GI	Group classification	Significant Constituent of Materials	General rating as sub-grade materials	AASHTO classification
		No.10	No.40	No.200							
Tp1	1.5	99.8	94.3	80.66	54	32	21	A-7-6	Clayey Soil	Poor	A-7-6 (21)
	3	96.5	88.4	76.87	65	23	19	A-7-5	Clayey Soil	Poor	A-7-5 (19)
Tp2	1.5	99	91.6	70.95	58	29	18	A-7-6	Clayey Soil	Poor	A-7-6 (18)
	3	99.5	95.8	85.47	56	31	23	A-7-6	Clayey Soil	Poor	A-7-6 (23)
Tp3	1.5	99.8	96.5	80.67	48	21	15	A-7-6	Clayey Soil	Poor	A-7-6 (15)
	3	99.9	95.9	81.63	49	25	17	A-7-6	Clayey Soil	Poor	A-7-6 (17)
Tp4	1.5	99.8	96	82.40	47	13	12	A-7-5	Clayey Soil	Poor	A-7-5 (12)
	3	99.8	95.7	87.47	63	29	24	A-7-5	Clayey Soil	Poor	A-7-5 (24)
Tp5	1.5	98.9	96.3	85.5	72	38	38	A-7-5	Clayey Soil	Poor	A-7-5 (38)
	3	97.7	96.2	87.5	58	36	34	A-7-6	Clayey Soil	Poor	A-7-6 (34)
Tp6	1.5	99.9	94.5	82.6	73	36	35	A-7-5	Clayey Soil	Poor	A-7-5 (35)
	3	96.5	90.5	80.5	65	28	27	A-7-5	Clayey Soil	Poor	A-7-5 (27)
Tp7	1.5	95.8	92.43	87.7	46	25	23	A-7-6	Clayey Soil	Poor	A-7-6 (23)
	3	98.6	91.7	86.4	58	34	32	A-7-6	Clayey Soil	Poor	A-7-6 (32)
Tp8	1.5	99.5	95.8	85.5	48	20	19	A-7-6	Clayey Soil	Poor	A-7-6 (19)
	3	96.5	88.4	77.4	47	20	16	A-7-6	Clayey Soil	Poor	A-7-6 (16)
Tp9	1.5	94.8	91.52	86.8	53	23	23	A-7-5	Clayey Soil	Poor	A-7-5 (23)
	3	96.5	88.4	78.9	57	31	26	A-7-6	Clayey Soil	Poor	A-7-6 (26)
Tp10	1.5	99.7	96.4	88.5	56	30	32	A-7-6	Clayey Soil	Poor	A-7-6 (32)
	3	99.4	95.3	87.47	67	34	35	A-7-5	Clayey Soil	Poor	A-7-5 (35)

Shear strength characteristics of the soil was determined by using unconfined compressive strength test. During the test, stress was plotted versus strain to identify qu. For stiff clays, qu is defined as the peak of the stress – strain curve. For soft clays, qu is defined as stress at a strain level of 15%. Since the consistency of the soil under investigation ranges from medium to hard qu is defined as the peak of the stress – strain curve.

Unconfined compressive strength and undrained shear strength of soils of the study area ranges from 80 to 215kN/m^{2}and 40 to 107.5kN/m^2. This shows that Tp3-@1.5m, soils have soft consistency but at depth of three meter the soil consistence ranges from medium to stiff.

Soils become highly compressive when there are high void spaces between the soil particles. The soil under investigation has a pre-consolidation pressure of 140 - 250kPa. Over-consolidation ratios of the soils are more than one, so the soil in the study area is over consolidated in its natural state. It was also recognized larger amount of deformation for steps of higher loadings, especially for loadings beyond Pc.

The compression index and re compression index of the soils is calculated from the straight line portions of the e-logp curve. The compression index, Cc, ranges from 0.110-0.246.

The coefficient of consolidation (Cv) of the samples were determined using square root of time fitting method. Then CV square root method is determined for each incremental load and an average value of CV for the desired load range was determined 0.84 to 3.533 (x10-3) cm2/min.

5. CONCLUSION

From this study black and red clay soils were investigated in Damot Gale district which are expansive and non-expansive respectively. The specific gravity of soils in the study area ranges from 2.57 to 2.84. Grain size analysis tests revealed that, starting from few centimeters below the ground level to the depth of investigation which is three meters, the soil in Damot Gale district is black and red clay soils. Some of the soil samples in district have free swell value of greater than 50%. This shows the soil in the study area ranges from non-expansive to expansive with free swell value ranging from 16 - 85%. The black clay soil samples (TP-1, TP-7, and TP-8@3m) show expansive behavior with free swell index value ranging from 50 to 85% but the others are non-expansive soils with a free swell index ranging from 16 to 48%.

The soils in the study area have low to high Atterberg limit values which show the soils are low to highly plastic. From Atterberg limit test results the liquid limit of black and red clay soils ranges from 46 - 73%, plastic limit ranges from 13 - 38% and plasticity index ranges from 13 - 38%. High values of consistency limits indicate the presence of high clay content. Based on the Unified Soil Classification the Damot Gale district soil is predominantly inorganic clay of high plasticity (CH), inorganic clay of low plasticity (CL) and Inorganic clay of high plasticity (MH) while the district soil is clayey soil with poor quality when rating as subgrade material. These reveals that the investigated soil has poor quality when using as sub grade material and needs stabilization or other techniques if recommended for using as sub grade material.

The unconfined compressive strength of the soils in the study area range from 75 to 260kN/m^2 and undrained shear strength value range from 37.5 to 130kN/m^2. Based on unconfined compressive strength the approximate consistency of the soil ranges from soft to stiff. As determined from the one-dimensional consolidation test conducted on undisturbed soil samples, compression index, Cc, ranges from 0.110 to 0.246 and coefficient of consolidation, CV, from 0.84 to 3.533 (x10-3) cm^2/min.

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