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An Investigation into Some of the Engineering and Index Properties of Soils Found Nearby Lake Abaya of Ethiopia

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Abstract An onshore construction near to lake is typical for recreational area, to accommodate Guests, tourists, and local visitors. Therefore constructions are required for lodges, hotels and related functions to host visitors. Which towns are abundant with natural gifts like lake have the possibility to expand toward the lake in their development plan. Arba Minch city is one of the cities rapidly growing in Southern part of Ethiopia, which has two naturally gifted Lake Chamo and Lake Abaya which are separated by God's natural bridge. For all constructions near to the lakes, it is necessary to identify the engineering and index properties of the subsoil since they are required as design data for foundations, retaining wall and related structures. Thus, the purpose of this study is to investigate engineering and index properties of the soil nearby the Lake Abaya. During the investigation has been started by preliminary site observations to locate the test pit points, then around 13 test pits are systematically defined, and about 20 representatives disturbed soil samples are collected from various depths. Along with sample collection in - situ density test are conducted at respective depth. Laboratory tests are held on the soil samples to obtain engineering and index properties of the soil deposit. The type of tests is selected depending upon the type of soil and conducted according to ASTM soil testing standard. For the study area field density, natural moisture content and specific gravity value range from 1.58 to 1.86 gm/cc, 17.5 to 41.8 % and 2.66 to 2.74, respectively. The optimum moisture content of soil and maximum dry density value range from 16.5 to 25.9 % and 1.31 to 1.67 gm/cc respectively. The amount of gravel, sand, silt, and clay in the soil mass ranges from 0% to 4.16 %, 2.75% to 34.08 %, 23.53% to 61.31 % and 17.39% to 62.95 % respectively. The soils in the study area are grouped under SM, CH, CL and ML soil group based on USCS. Shear strength parameters like cohesion, undrained shear strength and angle of internal friction values range from 0Kpa to 7Kpa, 49Kpa to 127Kpa and 25^0 to 33^0 respectively. The coefficient of consolidation and recompression index values range from 0.3 to 0.41 and 0.03 to 0.05 respectively. Generally, soil SM soil has the functional bearing capacity, whereas ML, CL and CH soils have the weak bearing capacity. Therefore, the soil deposit in the area shall be overlaid by suitable selected soil materials and well compacted before the foundation of the structures would be placed.

Keywords: *engineering properties, index properties, Lake Abaya, USCS, index properties*

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1. Introduction

The civil engineering structures like building, bridge, highway, tunnel, dam, tower, etc. are founded below or on the surface of the earth. For their stability, suitable foundation soil is required. To check the suitability of the soil to be used as a foundation or as construction materials, its properties are needed to be assessed [1].

Soil properties are determined by field exploration directly on the site and laboratory testing on the representative soil samples. The geotechnical soil properties such as consistency limits, Engineering properties, and other physical properties are used to understand the soil bearing capacity, settlement potential, and effect of fine particle contents and effect of variation of water content of the soil performance. Consistency limits like liquid limit, plastic limits, and plasticity index are the essential factors that help an engineer to understand the consistency of clay and to classify the soil based on the unified and AASHTO soil classification system.

Engineering properties like shear strength and consolidation settlement parameter are one of the essential parameters for analyzing bearing capacity and settlement of foundation soil respectively. The engineering properties of the soil and settlement can be improved by compacting the soil with optimum moisture content to attain its maximum dry density.

Investigation of geotechnical properties of foundation soil at the project site is necessary for generating relevant input data for the design and construction of foundations for the proposed civil engineering structures. Insufficient investigation of geotechnical properties of the subsoil, and incorrect interpretation of results in a clear, understandable manner may lead to inappropriate design, modification of construction work, post construction, remedial work, environmental damage to the site, and failure of a structure and subsequent litigation.

Due to the reason, this research investigated some of the geotechnical properties of the soil such as index and the engineering properties of the subsoil nearby the Lake Abaya for future construction work and design of civil structures.

2. Study Area, Materials and Research Methodology

2.1 Description of the Study Area

This research was conducted along the periphery of Lake Abaya for onshore construction of the civil structures. The lake is located in the Southern part of Ethiopia in the Main Ethiopian Rift Valley, east of the Guge Mountains. It is Ethiopia's second-largest lake which is 60 kilometers long and 20 kilometers wide, with a surface area of 1162 square kilometers [2].

A ridge of the lake is covered by a wide range of forest land which accommodates different wild animals like different colorful species of birds, Baboons, Monkey, etc. as well as Crocodiles, hippos, and fishes in the lake. This gives a chance for different visitors like tourists, guests and local people to be attracted by the gifts of nature and prefer the area for their day-to-day recreational host. The lake is surrounded by different Woredas and Kebeles. But this research only covers a few Kebels which are currently in use as a recreational area and which have the possibility for future expansion, such as Abulo, Lante, Chano, and Shara kebele closer to the lake and Salayesh recreational area.

Figure 1. Test Pit location and its distribution of the study area.

1.2. Material and Methodology

To achieve the objectives of the research, visual inspection for the predefined stretch of the Lake about the periphery were made to decide on the study area and test pit locations. Around 13 test pits were systematically demarcated on the selected stretch of the lake, and they were shown in Figure 1. Then an open type of excavations was dug on the, and field tests were comprehensively conducted to determine the field density by core cutter method, subsoil stratification is measured, and representative soil samples were collected for laboratory testing.

The global coordinates of sampling location, i.e. northing, easting, and elevations of the sampling points are shown in Table 1.

From laboratory testings on the remolded saturated soil samples, the shear strength and consolidation settlement parameters of the soil are conducted. Also, the specific gravity, Atterberg's limits, optimum moisture content with maximum dry density, and particle size distribution of oven-dried soil samples are determined according to ASTM standard.

Table 1. Global Coordinate Location of the Test Pits of the Area

Location (Near to lake)	Latitude (Northing)	Longitude (Easting)	Elevation a.m.s.l. (m)
TP-1 (Salayesh)	6^0 01' 35.63"	37^0 35' 47.33"	1194
TP-2 (Salayesh)	6^0 02' 5.72"	37^0 35' 52.29"	1193
TP-3 (Abulo)	6^0 03' 35.63"	37^0 36' 1.93"	1191
TP-4 (Abulo)	6^0 03' 27.85"	37^0 36' 3.13"	1189
TP-5 (Abulo)	6^0 03' 30.50"	37^0 36' 12.15"	1186
TP-6 (Abulo)	6^0 03' 58.40"	37^0 36' 17.90"	1189
TP-7 (Abulo)	6^0 04' 23.69"	37^0 36' 16.27"	1187
TP-8 (Lante)	6^0 07' 20.92"	37^0 37' 21.55"	1188
TP-9 (Lante)	6^0 07' 3.95"	37^0 37' 3.46"	1189
TP-10 (Chano)	6^0 06' 37.75"	37^0 36' 46.12"	1188
TP-11 (Chano)	6^0 06' 14.65"	37^0 36' 40.01"	1186
TP-12 (Chano)	6^0 05' 16.3"	37^0 36' 32.71"	1185
TP-13 (Chano)	6^0 06' 50.83"	37^0 36' 50.65"	1193

3. Results and Discussion

Some of the geotechnical properties of soil in the study area has been determined and characterized based on the result obtained from field tests and laboratory tests.

3.1. In-situ Density and Natural Moisture Content

The in-situ density, natural moisture content, and specific gravity of the soil of the study area obtained from the testing are given in Table 2. In-situ density and natural moisture content of the study area varies from 1.58 gm/cc to 1.86 gm/cc and 17.5% to 41.8%, respectively.

The in-situ density and natural moisture contents of the soil deposit increases with depth for the same soil group. The soil deposit close to the water table is saturated; therefore the in-situ densities is saturated unit weight.

3.2. Compaction Test Result

The maximum dry density and optimum moisture contents obtained from a laboratory standard compaction test are given in Table 2. Optimum moisture contents and maximum dry density range from 16.5% to 25.9 % and 1.31 gm/cc to 1.67 gm/cc respectively.

Table 2. Field density, Natural Moisture content, Optimum moisture contents, Maximum dry density and Specific gravity of the soil in the study Area

Test pit	Depth (m)	NMC (%)	FD (gm/cc)	OMC (%)	MDD (gm/cc)	Specific gravity
TP-1	1	27.20	1.58	16.50	1.64	2.68
	2	30.60	1.66	17.00	1.66	2.67
	3	39.20	1.76	17.20	1.67	2.66
TP-2	1	28.73	1.65	25.70	1.32	2.74
	2	32.49	1.68	25.90	1.31	2.74
	3	41.50	1.83	25.50	1.33	2.72
TP-3	1.5	38.80	1.78	25.80	1.36	2.73
	3	41.80	1.85	25.90	1.38	2.72
TP-4	1	34.20	1.76	25.20	1.34	2.70
	2	35.80	1.79	25.30	1.35	2.70
	3	40.47	1.86	25.40	1.36	2.71
TP-5	2	39.74	1.80	25.10	1.37	2.67
TP-6	2	39.24	1.81	25.20	1.38	2.70
TP-7	2	41.80	1.82	25.90	1.36	2.72
TP-8	1.5	17.90	1.68	19.60	1.55	2.68
	3	40.50	1.80	23.20	1.41	2.71
TP-9	1.5	17.50	1.69	19.30	1.57	2.69
	3	39.20	1.79	24.10	1.42	2.66
TP-10	2	34.96	1.79	22.30	1.52	2.67
TP-11	2	32.77	1.78	21.80	1.53	2.68
TP-12	2	39.72	1.80	20.20	1.51	2.69
TP-13	1.5	29.42	1.66	20.50	1.50	2.70
	3	39.70	1.81	19.50	1.52	2.68

Note: NMC-Natural moisture contents, FD-Field density, OMC-Optimum moisture contents and MDD -Maximum dry density.

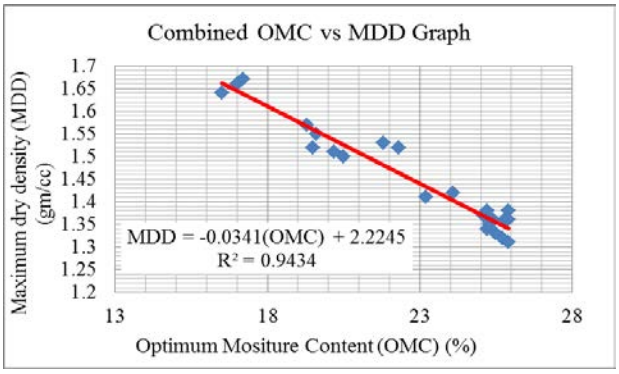

Figure 2. Combined OMC Vs MDD

3.3. Particle Size Distribution Test Result

The particle size distribution curves drawn based on the wet sieve and hydrometer analysis data are depicted in Figure 3 and Figure 4.

From the particle size distribution curve, the amount particle size distribution of the study area is given in Table 3. The amount of gravel, sand, silt, and clay in the soil mass ranges from 0% to 4.16%, 2.75% to 34.08%, 23.53% to 61.31% and 17.39 % to 62.95% respectively.

The amounts of particle sizes distribution with depth are comparably equivalent due to the reason the soil on the study area has similarity in its formation.

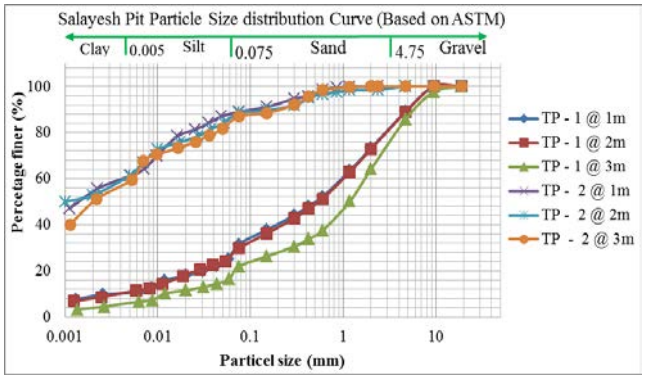

Figure 3. Particle size distribution Curve of TP-1 and TP-2 of the area

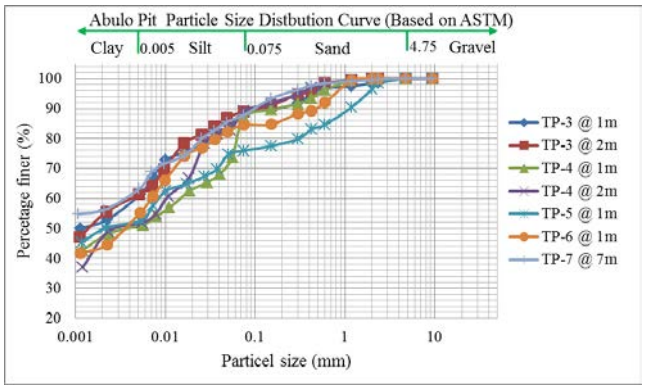

Figure 4. Particle size distribution Curve of TP-3 to TP-7 of the area.

From the particle size distribution curve amount gravel, sand, silt and clay proportion in the soil mass are given in Table 3.

Table 3. Amount of Gravel, Sand, silt and clay fraction in the soil mass of the study area

Test pit	Depth (m)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
TP-1	1	11	58	21	10
	2	11	59	19	11
	3	14	64	16	6
TP-2	1	0	11	28	61
	2	0	12	27	61
	3	0	13	28	59
TP-3	1.5	0	12	27	61
	3.0	0	11	28	61
TP-4	1	0	13	36	51
	2	0	11	38	51
	3	0	14	29	57
TP-5	2	0	24	24	52
TP-6	2	0	16	30	54
TP-7	2	0	12	25	63
TP-8	1.5	3	22	44	31
	3.0	0	10	31	59
TP-9	1.5	0	9	52	39
	3.0	4	34	31	31
TP-10	2	2	16	54	28
TP-11	2	4	33	46	17
TP-12	2	3	8	53	36
TP-13	1.5	0	3	61	36
	3	2	16	52	30

3.4. Consistency Limits Test Results

The liquid limits, Plastic limits, and plasticity index and liquidity index obtained from the test result are given in Table 4. The liquid limits, Plastic limits, plasticity index, liquidity index and activity of the soil ranges from 25.9 to 36.1 %, 39 to 75.9 %, 10.2 to 42.05 %, -1.11 to 1.02 , 0 to 0.88 respectively.

From liquidity index value it shows that the soils are at semi-plastic state except soil deposit for TP-2 at 1m and 2m, TP-8 at 1.5m, TP-9 at 1.5m 2 meters depth which is at semi-solid state.

The activity value of the soil in the study area shows that the soil deposit in the study area has illite and kaolinite clay minerals with low swelling potential [3].

Table 4. Consistency limits of the study area

Test pit	Depth (m)	Plastic limit (%)	Liquid limit (%)	Plasticity index (%)	Liquidity index (%)	Activity
TP-1	1	NP	NP	NP	0.00	0.00
	2	NP	NP	NP	0.00	0.00
	3	NP	NP	NP	0.00	0.00
TP-2	1	33.70	75.70	42.00	-0.12	0.69
	2	33.90	75.90	42.00	-0.03	0.68
	3	32.70	73.70	41.00	0.21	0.70
TP-3	1.5	33.50	75.50	42.00	0.13	0.69
	3.0	33.70	75.70	42.00	0.19	0.69
TP-4	1	32.00	67.70	35.70	0.06	0.70
	2	32.20	68.20	36.00	0.10	0.70
	3	32.90	71.10	38.20	0.20	0.67
TP-5	2	32.60	70.40	37.80	0.19	0.72
TP-6	2	32.50	71.40	38.90	0.17	0.72
TP-7	2	33.40	75.40	42.00	0.20	0.67
TP-8	1.5	30.10	41.10	11.00	-1.11	0.35
	3.0	25.90	49.50	23.60	0.62	0.40
TP-9	1.5	31.10	44.00	12.90	-1.05	0.33
	3.0	28.80	39.00	10.20	1.02	0.33
TP-10	2	30.90	49.50	18.60	0.22	0.65
TP-11	2	30.50	45.80	15.30	0.15	0.88
TP-12	2	31.20	49.70	18.50	0.46	0.52
TP-13	1.5	31.90	49.80	17.90	-0.14	0.50
	3	30.90	41.20	10.30	0.86	0.33

3.5. Classification of the Soils on the Study Area

The soils in the study area are classified by the Unified soil classification system (USCS). The soil groups of the study area and their descriptions are given in Table 5. The soils in the study area are SM, CH, CL and ML soil group based on USCS.

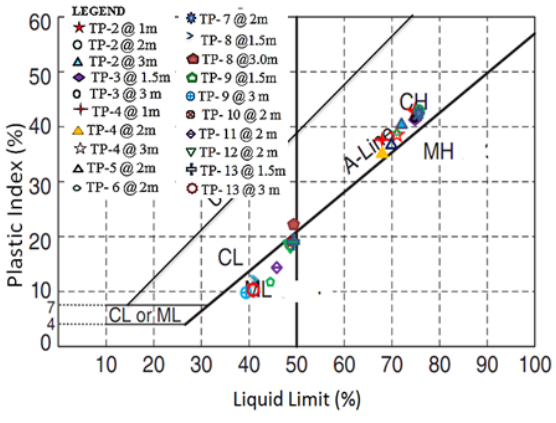

Figure 5. Soil classification of the study area by USCS plasticity chart

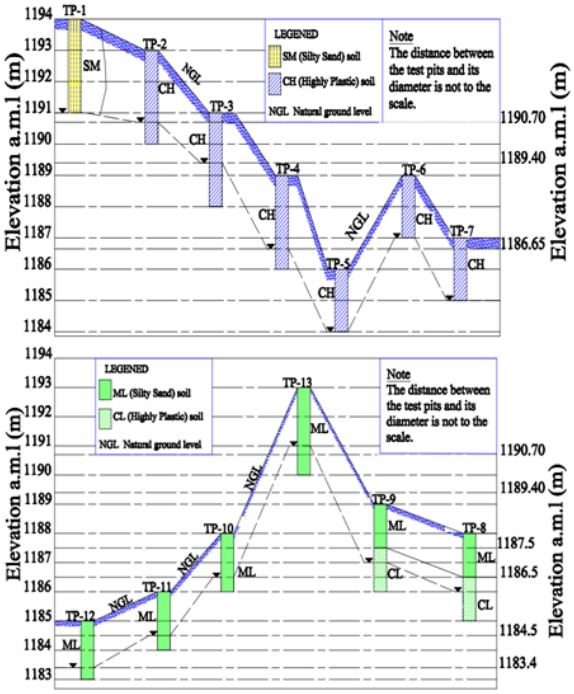

Figure 6. Soil profile and water table location of the study area

Table 5. Unified soil classification group and description of the soils in the area

Test pit	Depth (m)	USCS Soil group	Soil description based on USCS
TP-1	1	SM	Silty sand
	2	SM	Silty sand
	3	SM	Silty sand
TP-2	1	CH	Highly Plastic clay
	2	CH	Highly Plastic clay
	3	CH	Highly Plastic clay
TP-3	1.5	CH	Highly Plastic clay
	3.0	CH	Highly Plastic clay
TP-4	1	CH	Highly Plastic clay
	2	CH	Highly Plastic clay
	3	CH	Highly Plastic clay
TP-5	2	CH	Highly Plastic clay
TP-6	2	CH	Highly Plastic clay
TP-7	2	CH	Highly Plastic clay
TP-8	1.5	ML	Low Plastic Silt
	3.0	CL	Low Plastic Clay
TP-9	1.5	ML	Low Plastic Silt
	3.0	CL	Low Plastic Clay
TP-10	2	ML	Low Plastic Silt
TP-11	2	ML	Low Plastic Silt
TP-12	2	ML	Low Plastic Silt
TP-13	1.5	ML	Low Plastic Silt
	3	ML	Low Plastic Silt

3.6. Engineering Properties of Test Result.

3.6.1. Shear Strength Parameter

The shear strength parameters such as the angle of internal friction and cohesion are obtained from the laboratory tests are given in Table 6. The cohesion, undrained shear strength, and angle of internal friction of the study area varies from 0 kpa to 7 kpa, 49 kpa to 127 kpa and 25^0 to 33^0 for respectively.

3.6.2. Consolidation Test Result

The coefficient of consolidation and recompression index obtained from a laboratory test is given in Table 6. The coefficient of consolidation and recompression index varies from 0.3 to 0.41 and 0.03 to 0.05 respectively. From the result, it was observed that same soil group, the compressibility is increasing with depth due to an increase in the moisture content of the soil.

Table 6. Shear strength and consolidation parameters of soil in the area

Test pit	Depth (m)	C (Kpa)	ϕ (^{o})	Cu (Kpa)	Cc	Cr
TP-1	1	0	31	---	---	---
	2	0	32	---	---	---
	3	0	33	---	---	---
TP-2	1	---		125	0.31	0.035
	2	---	---	125	0.34	0.039
	3	---	---	120	0.40	0.046
TP-3	1	---	---	123	0.39	0.044
	2	---	---	125	0.41	0.047
TP-4	1	---	---	110	0.33	0.038
	2	---	---	112	0.35	0.040
	3	---	---	118	0.39	0.045
TP-5	1	---	---	96	0.38	0.044
TP-6	1	---	---	115	0.38	0.044
TP-7	1	---	---	127	0.41	0.047
TP-8	1	7	28	---	---	---
	2	---	---	70	0.33	0.038
TP-9	1	7	26	---	---	---
	2	---	---	50	0.30	0.035
TP-10	2	6	27	---	0.31	0.035
TP-11	2	5	29	---	0.34	0.039
TP-12	2	6	26	---	0.40	0.046
TP-13	1.5	7	25	---	0.39	0.044
	3	6	28	---	0.41	0.047

Note: - C – Cohesion, ϕ -Angle of internal friction, Cu – Undrained shear strength, Cc – Coefficient of consolidation, Cr – Coefficient of recompression index.

4. Conclusion

In-situ density and natural moisture content of the soil in the study area ranges from 1.58 to 1.86 gm/cc and 17.5 to 41.8 % respectively. While, the specific gravity of the solid particle ranges from 2.66 to 2.74.

The optimum moisture and maximum dry density of the soil in the study area range from 16.5% to 25.9% and 1.31gm/cc to 1.67gm/cc respectively. The maximum value of maximum dry density corresponds to the coarse grained soil and the minimum value of finer grained soil. Whereas as the maximum amount of the Optimum moisture content refers to the finer grained soil and the minimum to the coarse-grained soil.

The amount of gravel, sand, silt, and clay in the soil mass ranges from 0% to 4.16 %, 2.75% to 34.08 %, 23.53% to 61.31% and 17.39% to 62.95 % respectively. The soils in the study area are SM, CH, CL and ML soil group based on USCS.

From the classification result, it shows that CH is the first dominate soil group and ML with the next dominant soil group in the study area. The internal angle friction and cohesion value of the soil vary from 25^0 to 33^0 and 0 Kpa to 7Kpa respectively, while, undrained shear strength ranging from 49 Kpa to 127Kpa for the soil in the study area.

The coefficient of consolidation and recompression index range from 0.30 to 0.41 and 0.03 to 0.05, respectively. The SM and CL soil have good to a poor bearing capacity value depending upon the density. The CH has group of fair to weak bearing capacity, while the ML soil is very poor, susceptible to liquefaction. It means, the soil deposit in the study area is inadequate to use as a foundation material; therefore, it should be filled with selected soil materials and compacted properly below the foundations.

Moreover, for large scale or high-rise building projects, the soil in the study area should be investigated more than 3.0 m deep to obtain complete information on the sub-surface layers.

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