Geo-technical Investigation and Characterization of Sub-soils in Yenagoa, Bayelsa State, Central Niger Delta, Nigeria

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Abstract
This study aims at establishing the sub-soil types and profile to ascertain the geotechnical characteristics of the underlying soils in parts of Yenagoa, Bayelsa State, Nigeria and recommend appropriate foundation design and construction of projects in the area. Four boreholes were drilled using hand auger and representative disturbed samples were taken at regular intervals of 1.0m depth, and also when a change in soil type was observed. Standard laboratory procedures were used in the analysis of the samples. Water levels recorded in the site BH-1 (1.50m), BH-2 (1.50m), BH-3 (4.00m) and BH-4 (1.00m), respectively. Geotechnical result reveal that the area is underlain predominantly by medium to firm silty clay (although) in BH-1, silty sand and medium to fine silty clay in BH-2 and medium to firm silty clay at the top, silty sand (middle) and fine to medium sand at the bottom of BH-3 and BH-4, respectively. Water level (WL) recorded in the site for BH-1 (1.50m), BH-2 (1.50m), BH-3 (4.00m) and BH-4 (1.00m), respectively. The soil material presented average Moisture Content (MC) of 27%; 35% average Liquid Limit (LL); 22% average Plastic Limit (PL); 13% average Plasticity Index (PI) with average Liquidity Index of 0.387. Average Hydraulic conductivity K (Permeability) obtained from grain size analysis for BH-3 and BH-4: 3.2×10^{-3}m/s and 1.8×10^{-3} m/s respectively, with an average of $K = 2.5 \times 10^{-3}$m/s. BH-3 and BH-4 were considered for sieve analysis only because of the appreciable sand presence which were not available in BH-1 and BH-2. The hydraulic conductivity values are high within the typical permeability values for fine to medium sand to gravel. The implication of high K values is that the aquifer system in the area is prolific. It is recommended that studies on the geotechnical characteristics of the area be carried out as it provides valuable data that can be used for foundation design and other forms of construction for civil engineering structures in order to minimize adverse effects and prevention of post construction problems.

Key Words: Geotechnical, Hydraulic conductivity, Sub-soil, Yenagoa, Niger Delta.

Introduction

The geotechnical characterization through subsoil investigation is very important in generating relevant data inputs for the design and construction of foundations for proposed structures. The knowledge of the geotechnical characteristics of Yenagoa, Bayelsa State, Nigeria is very desirable for design and construction of foundation of civil engineering structures in order to minimize adverse effects and prevention of post construction problems. Some studies have been carried out on geotechnical properties of the subsoils generally (Nwankwoala & Amadi, 2013; Oke & Amadi, 2008; Oke *et al.,* 2009).

The study area is within the coastal zone. The coastal zone which comprises the beach ridges and mangrove swamps is underlain by an alternating sequence of sand and clay with a high frequency of occurrence of clay within 10m below the ground surface. Because of the nearness of these compressible clays to the surface, the influence of imposed loads results to consolidation settlement. The impact of the imposed load is exacerbated by the thickness and consistency of the compressible layer. This, in addition to other intrinsic factors contributes to the failure of civil engineering structures (Youdeowei & Nwankwoala, 2013; Amadi *et al,* 2012). For the purpose of generating relevant data inputs for the design and construction of foundations for proposed structures, it is imperative that the site (s) be geo-technically characterized through sub-soil investigation. This paper therefore, aims at establishing significant subsoil types and profile, investigation and characterization of the engineering characteristics of all such sub-soils to generate the required data relevant to the foundation design and construction of structures.

Geology/Hydrogeology of the Study Area

The study area lies between latitudes $4^0 55'$ and $5^0 05'$N and longitudes $6^0 15'$ and $6^0 20'$E (Fig.1). The area is situated in the Central Niger Delta Sedimentary basin of Southern Nigeria. Access to the area is the Mbiama – Yenagoa road. There are other networks of roads linking the different parts of the area and its environs. The area is bounded on the north by Mbiama town in Ahoada West Local Government Area of Rivers State and on the South by Ikoli Creek. It is bounded on the West by Epie Creek and on the East by Kolo Creek.

Yenagoa, the capital city of Bayelsa State, Nigeria lies in the coastal Niger Delta sedimentary basin. It is endowed with the sedimentary rocks characteristic of the Niger Delta. The detailed geology of the area has been described by Allen (1965), Reyment (1965), Short and Stauble (1967). Litho-stratigraphically, the rocks are divided into the oldest Akata Formation (Paleoceone), the Agbada Formation (Eocene) and the youngest Benin Formation (Miocene to Recent). The wells and boreholes tap water from the overlaying Benin Formation (Coastal plain sands). This formation comprises of lacustrine and fluvial deposits whose thicknesses are variable but basically exceeds 1970meters (Asseez, 1989). The Benin Formation has lithologies consisting of sands, silts, gravel and clayey intercalations.

The hydrogeology of the study area has been described by several researchers such as; Etu- Efeotor, (1981); Amadi *et al,* (1989); Etu-Efeotor & Akpokodje (1990), Edet (1993), and Udom *et al* (1999).

The Benin Formation is the water bearing zone of the area. It is overlain by Quaternary deposits (40-150m) thick, and generally consists of rapidly alternating sequences of sands and silty clay which later become increasingly prominent seawards (Akpokodje, 1987). Generally multi-aquifer systems have been identified in the Delta based on strata logs (Etu-Efeotor, 1981). The first aquifer is mostly unconfined, while the rest are confined. The averages depths of boreholes in Yenagoa are between 20 and 50 metres (Udom & Amah, 2006). Deep boreholes in the area tap water from depths up to about 200m or more. In terms of water quality, (Udom *et al*, 2013) have noted that groundwater in most parts of Yenagoa is high in iron content. The static water level in the area ranges from 0-1m during the rainy season and 1-3m during the dry season. Rainfall is the major source of recharge for aquifers in the area.

Methods of Study
Sub-Soil Investigation - Boring

The investigation comprised mainly four (4) geotechnical boreholes with soil sampling executed with hand auger and measurement of water table. The procedure adopted for boring was opening of the ground with the auger by rotating in clockwise direction the T-handle of the auger extension. Additional extension is attached to the auger after advancing 1m down-hole until required depths are achieved.

Representative disturbed samples were taken at regular intervals of 1.0m depth, and also when a change in soil type was observed. More importantly, the depth at which groundwater is encountered is noted and recorded. The samples obtained were used for a detailed and systematic description of the soil in each stratum in terms of its visual and haptic properties and for laboratory analysis.

Laboratory Tests

Detailed laboratory tests were carried out on the representative samples recovered from the explored holes for basic geotechnical properties of sub-soils and classification tests. The laboratory exercise was carried out in accordance with BS 1377 (1995) – Methods of Tests for Soil for Civil Engineering Purposes. Laboratory procedures on the tests are given below:

Moisture Content

The water content was determined by drying selected moist/wet soil material for at least 12 hours to a constant mass in 110^0C drying oven. The difference in mass before and after drying was used as the mass of the water in the test material. The mass of material remaining after drying was used as the mass of the solid particles. The ratio of the mass of water to the measured mass of solid particles was the water content of the material. This ratio can exceed 1 (or 100%). Reference test standard: BS 1377: Part 2: 1990.

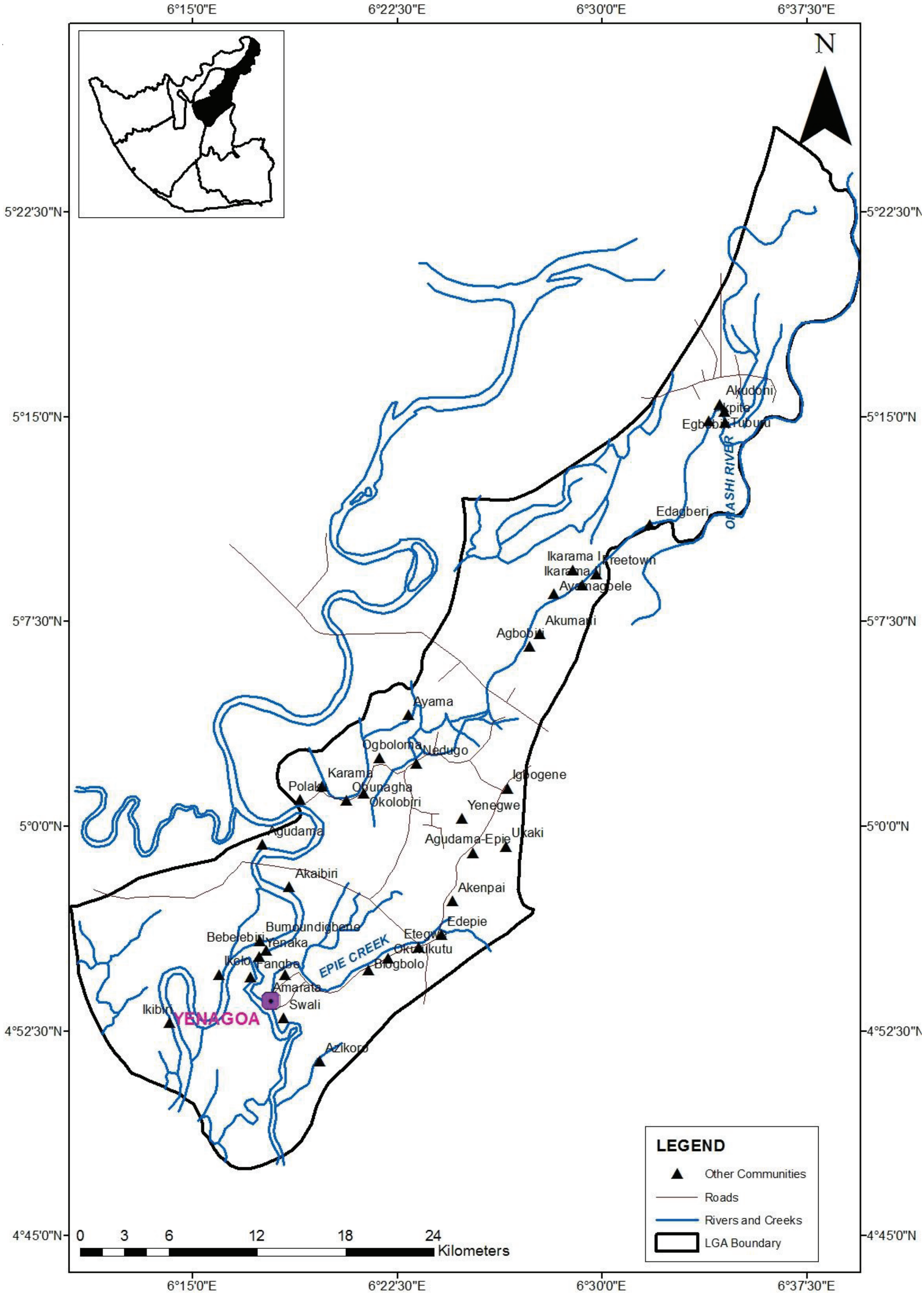

Fig. 1: Map of Yenagoa Showing the study locations

Atterberg Limits

Atterberg limits were determined on soil specimens with a particle size of less than 0.425mm. The Atterberg limits refers to arbitrary defined boundaries between the liquid limit and plastic states (Liquid Limit, W_L), and between the plastic and brittle states (Plastic Limit, W_L) of fine-grained soils. They are expressed as water content, in percent.

The liquid limit is the water content at which a part of soil in a standard cup and cut by a groove of standard dimensions flow together at the base of the groove, when the cup is subjected to 25 standard shocks. The one-point liquid tests were carried out and distilled water was added during soil mixing to achieve the required consistency.

The plastic limit is the water content at which a soil can no longer be deformed by rolling into 3mm diameter threads without crumbling. The range of water contents over which a soil behaves plastically is the Plasticity Index, I_P. This is the difference between the liquid limit and the plasticity limit ($W_L – W_P$). Reference test standard: BS 1377: Part 2: 1990.

Determination of Aquifer Hydraulic Conductivity, K (Permeability)

Laboratory tests were also carried out on soil samples from some boreholes based on British Standards (BS) 1377 and ASTM (1975) standards. The particle size distribution was determined by washing a known weight of oven-dried sample through ASTM sieve No.200 (0.074mm), vibrated with a shaker until no fines were retained. The hydraulic conductivity of the aquifer materials was determined from gain size analysis of the aquifer materials. The percentage passing through the successive sizes were found from the difference between the initial weight and the weight retained by each sieve. The percentage passings were plotted against grain size to obtain grain size distribution curves. The curves were used to calculate permeability of uniform sands with the empirical formula as proposed by Hazen (1983):

$$K = Cd_{10}^2 \qquad (1)$$

where

K = hydraulic conductivity (cm/s)

C = Constant (if k is in cm/s and D_{10} in mm, C = 1 (Freeze and Cherry, 1979)

d_{10} = Effective diameter (mm) defined as the diameter such that 10% by weight of the porous matrix consists of grains smaller than it.

Results and Discussion

Table 1: Summary of Field Measurements for the Boreholes

BH No.	Maximum Depth Drilled (m)	Water Table (m)	Elevation (ft)
BH-1	4.00	1.50	57
BH-2	4.00	1.50	62
BH-3	3.00	4.00	44
BH-4	4.00	1.00	22

Table 2: Laboratory Test Results for Atterberg Limits

BH No.	Depth (m)	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquidity Index	USCS Classification
BH-1	1.00	26	35	21	14	0.357	CL
BH-2	2.00	32	40	26	14	0.429	CL
BH-3	1.00	21	27	18	9	0.333	CL
BH-4	1.00	28	36	22	14	0.429	CL

Table 3: Particle Size Statistics

BH No	Depth (m)	Effective Particle Size D_{10} (mm)	D_{30} (mm)	Mean Particle Size D_{50} (mm)	D_{60} (mm)	Coef. of Uniformity $Cu=D_{60}/D_{10}$	Coef. of Curvature $Cc=D_{30}^2/(D_{10}*D_{60})$	Coef. of Permeability $K=C*D_{10}^2$ (m/sec)
BH-3	3.00	0.200	0.390	0.500	0.550	2.750	1.383	0.00320
BH-4	4.00	0.150	0.360	0.470	0.530	3.533	1.630	0.00180

Water Levels in the Area: Water levels recorded in the area BH-1 (1.50m), BH-2 (1.50m), BH-3 (4.00m) and BH-4 (1.00m), respectively. Table 1 shows the summary of field measurements for the boreholes. Generally, static water level in most parts of the study area ranges from 0 - 1m during the rainy season and 1 - 3m during the dry season. Rainfall is the major source of recharge for aquifers in the area. The water table is affected by climate, rainfall and drainage condition. The study area is characterized by unconfined aquifers which contain a phreatic surface (water table) as an upper boundary that fluctuates in response to recharge and discharge (such as from a pumping well). Unconfined aquifers are generally close to the land surface and, for the most part, constitute shallow groundwater, with continuous layers of materials of high intrinsic permeability extending from the land surface to the base of the aquifer. In the unconfined aquifer, water table increases during the rainy seasons and falls during the dry season. The aquifers in this area obtain steady recharge through direct precipitation and major rivers (e.g. River Nun). Very limited water table fluctuation is expected in the areas where there is heavy rainfall nearly all the year round.

Sub - Soil Type: Field investigation reveal that the area is underlain predominantly by medium to firm silty clay (although) in BH-1, silty sand and medium to fine silty clay in BH-2 and medium to firm silty clay at the top, silty sand (middle) and fine to medium sand at the bottom of BH-3 and BH-4, respectively. The soil materials in the site presented average Moisture Content (MC) is 27%, with 35% average Liquid Limit (LL) and 22% average Plastic Limit (PL) while average Plasticity Index (PI) is 13% with average Liquidity Index of 0.387. Table 2 shows the laboratory test results for Atterberg limits while Table 3 shows the particle size statistics.

Hydraulic Conductivity, K (Permeability): The calculated average hydraulic conductivity (permeability) K obtained from grain size analysis for BH-3 and BH-4: 3.2 x 10^{-3}m/s and 1.8 x 10^{-3} m/s respectively, with an average of K = 2.5 x 10^{-3}m/s. BH-3 and BH-4 were considered for sieve analysis only because of the appreciable sand presence which were not available in BH-1 and BH-2. In similar geologic materials outside the Niger Delta, hydraulic conductivities have also been estimated to range from 4.4 x 10^{-5} to 1.5 x 10^{-4}m/s (Onuoha and Mbazi, 1988), for the Ajali sandstone aquifer north of the Niger Delta. These values are high within the typical permeability values for fine to medium sand to gravel (Garg, 2005). The implication of high K values is that the aquifer system in the area is prolific (Etu-Efeotor, 2000; Nwankwoala *et al*, 2008). Figures 1 – 4 shows the plasticity chart for the different boreholes while Fig. 5 shows the grain size distribution curve of BH 3 @ 3.00m depth.

The hydraulic conductivity, effective porosity, and hydraulic gradient are all, therefore, important in determining the volumes and rates of movement of groundwater. Other important factors that define the groundwater flow system in the area are the sources of water (inputs) to the groundwater resource and the stresses (outputs, including pumping wells) on the system. The external boundaries of the groundwater system, such as streams and recharge areas, affect the paths of water movement and the hydraulic head distribution. The location of wells and rates of pumping also impacts where water moves within the groundwater system. Therefore, a groundwater flow system cannot be accurately understood until spatial and temporal aspects of all flows including inputs and outputs (from natural as well as human influences) are assessed.

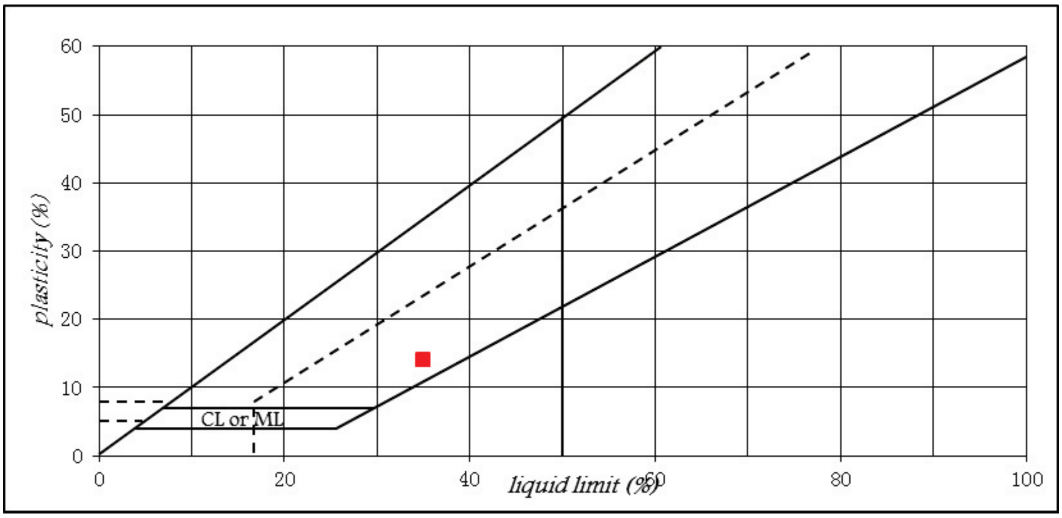

Fig. 1: Plasticity Chart for BH 1

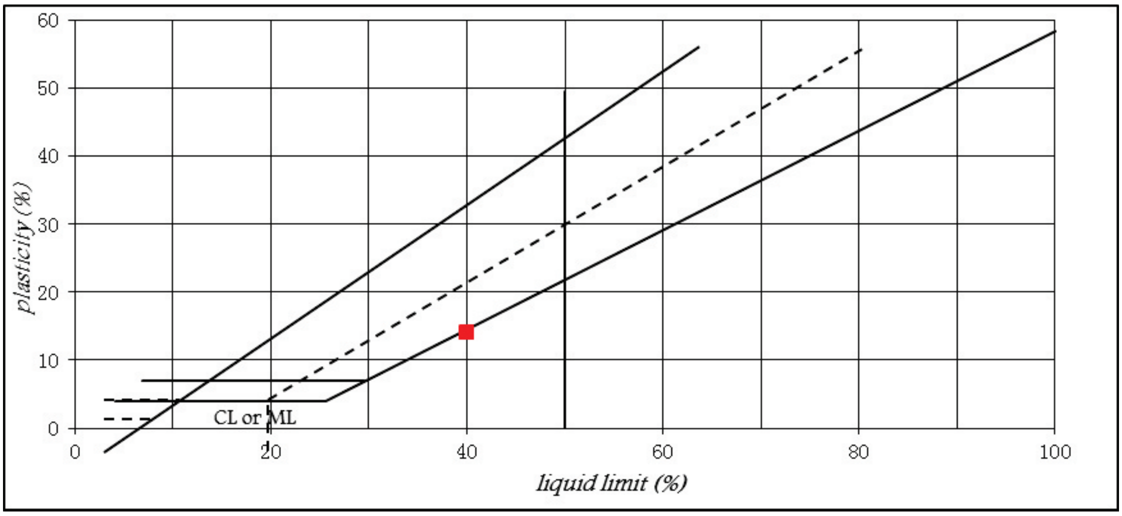

Fig. 2: Plasticity Chart for BH 2

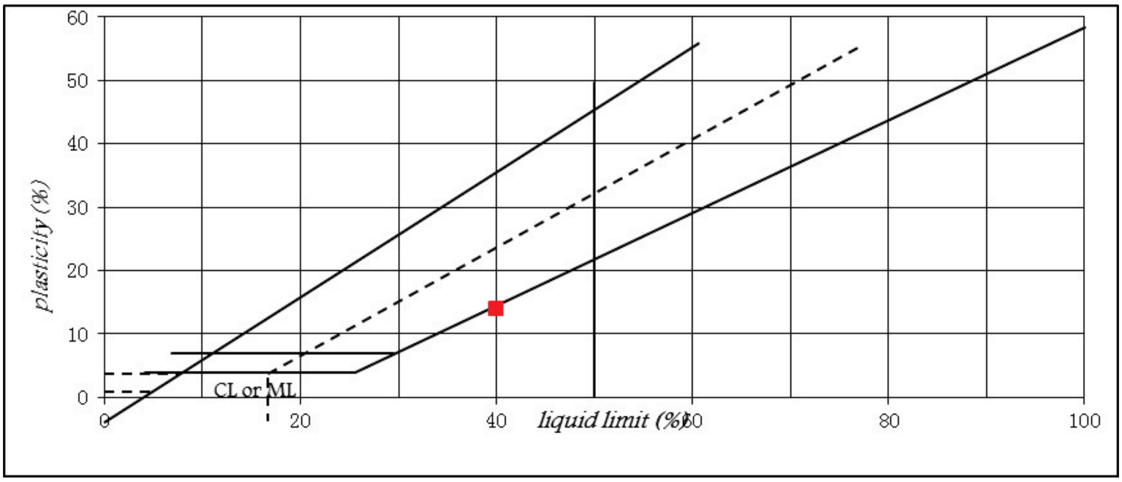

Fig. 3: Plasticity Chart for BH 3

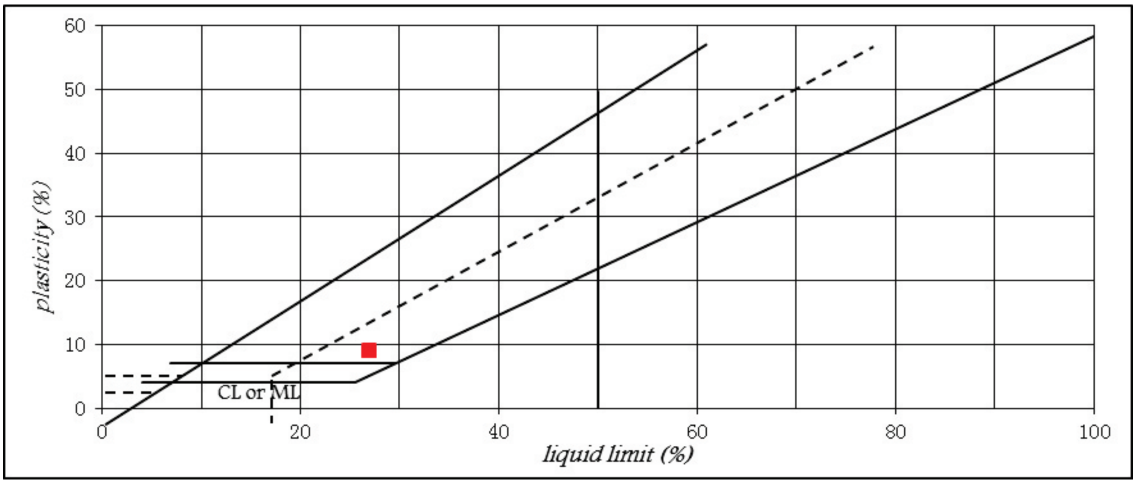

Fig. 4: Plasticity Chart for BH 4

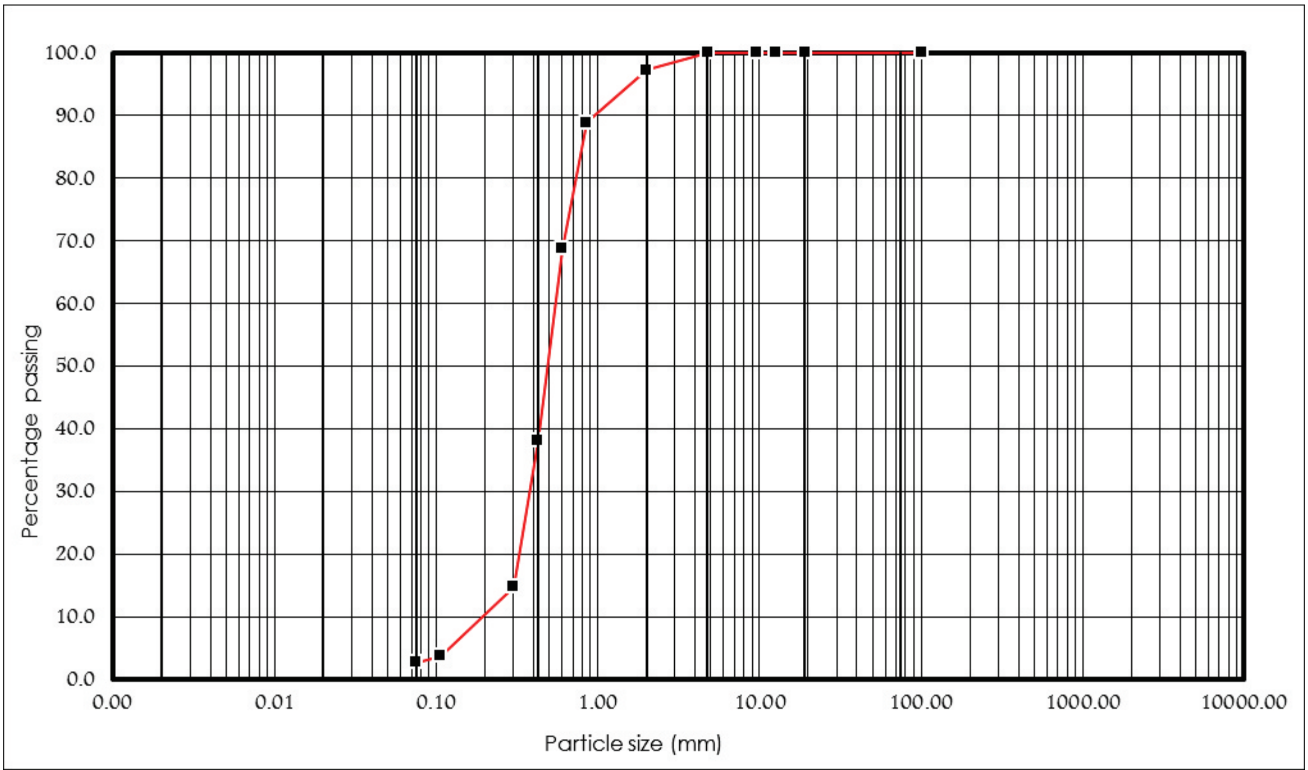

Fig. 5: Grain size distribution curve of BH 3 @ 3.00m depth

Conclusion

This study revealed that the area is underlain predominantly by medium to firm silty clay (although) in BH-1, silty sand and medium to fine silty clay in BH-2 and medium to firm silty clay at the top, silty sand (middle) and fine to medium sand at the bottom of BH-3 and BH-4, respectively. Water level (WL) recorded in the site for BH-1 (1.50m), BH-2 (1.50m), BH-3 (4.00m) and BH-4 (1.00m), respectively. The soil material presented average Moisture Content (MC) of 27%; 35% average Liquid Limit (LL); 22% average Plastic Limit (PL); 13% average Plasticity Index (PI) with average Liquidity Index of 0.387. Average Hydraulic conductivity K (Permeability) obtained from grain size analysis for BH-3 and BH-4: 3.2 x 10^{-3}m/s and 1.8 x 10^{-3} m/s respectively, with an average of K = 2.5 x 10^{-3}m/s.

Generally, this study has shown that the knowledge of the geotechnical characteristics of the area as obtained from field and laboratory analysis of recovered soil samples have provided valuable data that can be used for foundation design and other forms of construction for civil engineering structures in order to minimize adverse effects and prevention of post construction problems.

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