Subsurface Soil Characterization of a Site for Infrastructural Development Purposes in D/Line, Port Harcourt, Nigeria

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Abstract

The study aims at characterizing the sub-soil types and profile to ascertain the geotechnical properties of the underlying soils in a site in D/Line, Port Harcourt, Nigeria for appropriate foundation design considerations for infrastructural development purposes in the area. Borings were accomplished using a percussion rig with the aid of augers. Representative samples were analyzed in the laboratory in accordance with relevant geotechnical engineering standards. The study revealed that the surface is underlain by a soft – firm sandy clay (about 6m) of moderate-high compressibility with undrained Strength of 46KN/m^2 overlying a firm-stiff sandy layer. Beneath these layers, are loose sandy layers (with an angle of friction, of 29^o) overlying a medium dense sandy layer (with an angle of friction of 31^o). Underlying these layers is a dense sandy layer (with an angle of friction of 36^o). The allowable bearing capacity profile of the sub-surface shows low bearing capacities characteristics (1m - 2m: <110KN/m^2). These values are relatively lower than the projected foundation loading. Pile driven to at least 5m into the sand layer is recommended as the foundation option for consideration for civil engineering structures in the study area.

Keywords: Sub-soil, geo-technical, lithology, foundation, Port Harcourt, Nigeria

Introduction

The soils in wetlands are generally low-bearing-capacity foundation materials with the voids saturated with water with major engineering problems including: excess surface and groundwater, poor drainage, high compressibility, low bearing capacity and differential settlement, among others (Oghenero *et al*, 2014). Quaternary soils which are the foundation materials in the Niger Delta were deposited in a wide variety of environmental conditions with unique gemorphological features which have rendered them vertically and laterally heterogenous in form and anisotropic in engineering properties.

The geotechnical evaluation of subsoil condition of a site is necessary in generating relevant data inputs for the design and construction of foundations for proposed structures (Oke & Amadi, 2008; Oke *et al*., 2009; Nwankwoala & Warmate, 2014). Sub-soil geotechnical data are required for proper design and construction of civil engineering structures to prevent adverse environmental impact or structural failure/prevention of post construction problems ((Oghenero *et al,* 2014; Youdeowei & Nwankwoala, 2013; Ngah & Nwankwoala, 2013; Nwankwoala & Amadi, 2013; Amadi *et al*., 2012). This is desirable in view of the rapid urbanization, resulting in extensive infrastructural development. This study therefore determines the stratigraphy of the superficial deposit underlying the area as well as the relevant engineering characteristics of the deposits to enable appropriate foundation design of structures for infrastructural development.

Methods of Investigation

The Study Location

Geologically, the site is underlain by the Coastal Plain sands, which in this area is overlain by soft-firm silty clay sediments belonging to the Pleistocenic Formation. The general geology of the area essentially reflects the influence of movements of rivers, in the Niger delta and their search for lines of flow to the sea with consequent deposition of transported sediments (Reyment, 1965; Short & Stauble, 1967). In broad terms, the area may be considered flat. The surface deposit in the area comprises silty-clays (Etu-Efeotor & Akpokodje, 1990). The near surface silty clays are subjected to mild desiccation during the dry season. Substantial seasonal variations in moisture are expected in the area. This could result in some false enhancement of strength in the dry season. The sandy layers underlying the top clay are predominantly medium to coarse grain sizes, fairly well graded and found to exist in various states of compaction.

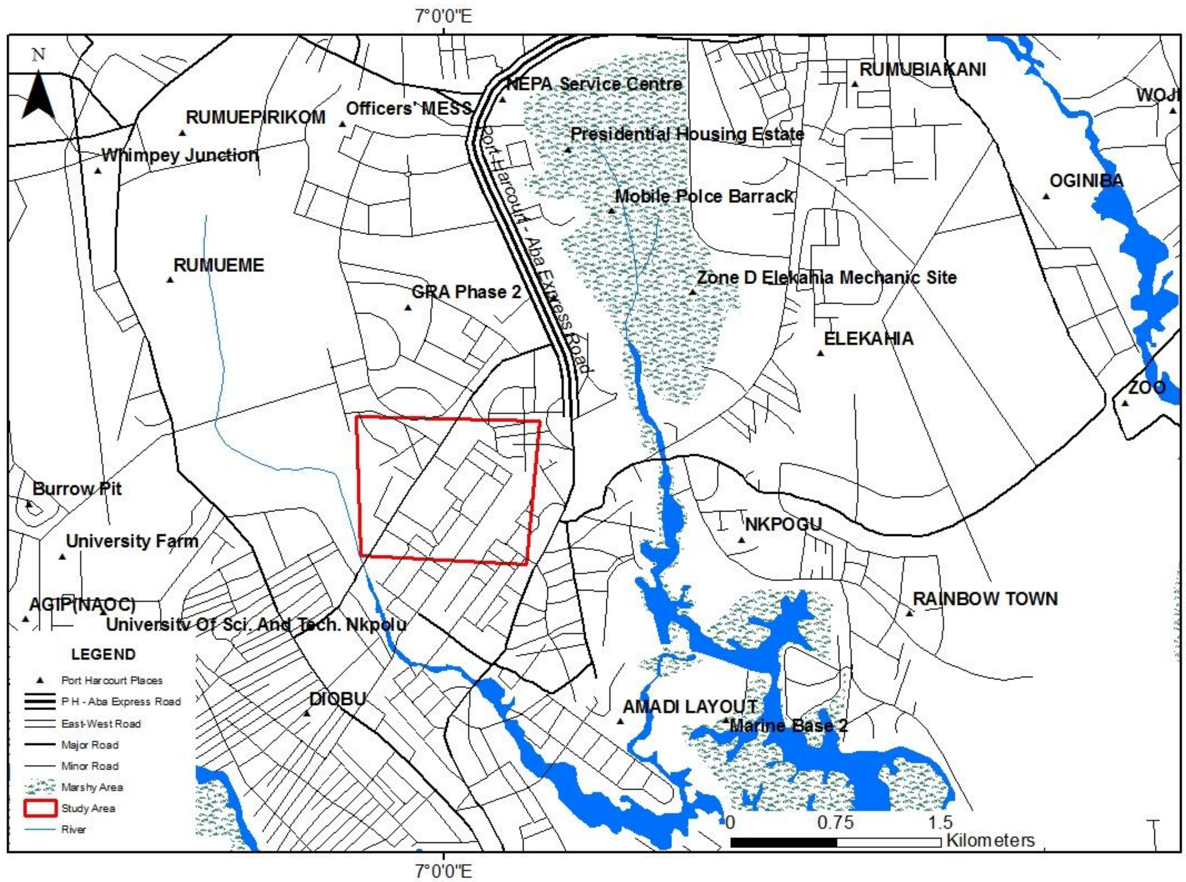

Fig.1: Map of Port Harcourt Showing D/Line Area

Boring Methods

Acquisition of soil samples for geotechnical studies was done by conventional boring method using light shell and auger hand rig. The samples were examined, identified and roughly classified in the field and later taken to the laboratory for tests. A series of classification, strength and compressibility tests were carried out on the samples in strict compliance with relevant geotechnical engineering standards including British standards (BS 1377; Peck *et al* 1973; Vickers, 1978; Tomlinson, 1984; Murthy, 1984). Laboratory classification tests were conducted on a number of soil samples to verify and improve on the field identification. These tests include natural moisture content, unit weights, specific gravity, Atterberg limits (liquid and plastic) and grain size distribution. The bearing capacity analysis for the underlying soils is limited to the near surface sandy clay. In general, the sandy clay is partially saturated and when tested in unconsolidated and undrained conditions, exhibits both cohesion and angle of internal friction for its shear strength characteristics.

However, the frictional component of shear strength is neglected for the clay encountered within normal founding depths for shallow foundations when estimating ultimate bearing pressures for the clay. Undrained cohesion of 46kPa and angle of internal friction of zero are adopted for the bearing capacity analysis.

Terzaghi's Method

The ultimate net bearing capacity qn of a shallow foundation is given by Terzaghi, (1943):

(for strip) $q_{nu} = CN_c + P_o (N_q-1) + 0.5\gamma BN_\gamma$ ---------- --- (1a)

(for square or Rectangular foundation) $q_{nu} = 1.2CN_c + P_o (N_q-1) + 0.4\gamma BN_\gamma$ ----- (1b)

where: γ = the bulk density of the soil below the foundation level
C = the undrained shear strength of the soil
P_o is the effective overburden pressure at the foundation level
N_c, N_q, N_γ = Terzaghi's bearing capacity factors obtained from charts

Meyerhof's Method

Static ultimate bearing pressures can be computed using the relationship proposed by Meyerhof (1951):

$q_u = C.N_c.S_c.d_c + q\ N_q.S_q.d_q + 0.5\gamma BN_\gamma s_\gamma d_\gamma$ ---------- (2a)

where q_u = ultimate bearing capacity
C = undrained cohsion
q = effective overburden
N_c, N_q, N_γ = Meyerhof's bearing capacity factors
S_c, S_q, S_γ = Meyerhof's shape factors
d_c, d_q, d_γ = Meyerhof's depth factors

The ultimate bearing capacity equation reduces to that shown below when the frictional component of the shear strength is neglected and the soil considered saturated.

$q_u = C.N_c.s_c.d_c + q$ -------- (2b)

Skempton's Method

Static ultimate bearing pressures of clay soils as per Skempton (1956) for square foundation is:

$q_u = C.N_c$ ---------- (3)

where

C = Cohesion
Nc = Bearing capacity factor of clay given as Nc = 5(1+ 0.2 B/L)(1+0.2D/B)

Using these relationships, the ultimate bearing pressures can be obtained for various foundation depths, footing widths and aspect ratios (L/B). Safety factors of about 3 are applied to the ultimate bearing pressures to obtain the maximum safe pressures of the soil.

Piled Foundation

Ultimate Pile capacity for axial loading was estimated for driven, single, straight-shafted, close-ended, tubular steel pile 406mm in diameter using API or conventional method. This method, which is currently the most widely applied, uses the results of the laboratory tests on soil sample and the blow counts from standard penetration tests in the prediction of the ultimate axial pile capacity. The following relationships proposed for the API method were used for the calculations:

(i) ultimate base resistance in clay
$Q_{bs} = 9.c_u.A_b$ --------- (4a)
(ii) Ultimate base resistance in sand
$\mathbf{Q_{bs} = P^1_0.N_q.A_b.}$ -------- (4b)
(iii) Ultimate shaft resistance in clay
$\mathbf{Q_{sc} = \alpha\ c_c.A_s}$ ------------ (4c)
(iv) ultimate shaft resistance in sand
$\mathbf{Q_{ss} = K_s.P_0.tant\ \delta.A_s}$ ------ (4d)

C_u = average undrained cohesion at the pile base
A_b = base area of the pile
P_0 = effective overburden pressure at the pile base
N_q = bearing capacity factor
A_s = exposed area of shaft
K_s= coefficient of lateral earth pressure (K_s/K_0 = 1 to 2), for small displacement piles ratio varies from 0.75 to 1.75, K_0 = 0.6
P_0 = average effective overburden pressure over soil layer
α= pile wall adhesion
δ = effective soil/pile friction angle (smooth surface = 0.5 ϕ to 0.7ϕ)

Undrained strength to which a factor of safety of 1.8 has been applied as recommended by Eurocode (yr) C_{ub} = $\underline{Cu}$

(Fs = 1.5 – 1.8)

Ultimate carrying capacity Q_{ult} = Q_b + Q_s ------- (5a)
Allowable Q_a = $\underline{Q_b + Q_s}$; $\underline{Q_b}$ + $\underline{Q_s}$ ----- (5b)

Results and Discussion

Soil Stratigraphy

The data from the cone resistance soundings were carefully evaluated for the determination of the stratification of the underlying soils. The evaluation uncovered five primary soil zones beneath the site. A typical soil profile characterizing the site is described below:

(i) A Soft-firm sandy clay layer (0.0m-6m)
(ii) A firm-stiff sandy clay layer (6m – 12m)
(iii) A loose sandy Layer (10m-15m)
(iv) A Medium Dense Sandy Layer(15m-24m)
(v) A Dense Sandy Layer(24m)

The soils within normal shallow foundation levels (1.0 – 2.0m) have low - moderate bearing characteristics. The angle of internal friction of the clay soil within 5m is virtually zero and the bearing capacity factor Ny is zero, the contribution of overburden to the enhancement of the bearing capacity is reduced to zero. Consequently, spread foundation is not likely to achieve much improved bearing capacity. The surface is underlain by a soft –firm sandy clay (about 6m) of moderate-high compressibility with undrained Strength of 46KN/m^2 overlying a firm-stiff sandy layer. Beneath these layers, are loose sandy layers (with an angle of friction, of 29^o) overlying a medium dense sandy layer (with an angle of friction of 31^o). Underlying these layers are dense sandy layer (with an angle of friction of 36^o). The allowable bearing capacity profile of the sub-surface shows low bearing capacities characteristics (1m - 2m: <110KN/m^2). These values are relatively lower than the projected foundation loading. Pile driven to at least 5m into the sand layer is recommended as the foundation option for consideration for civil engineering structures in the study area. Table 1 show the classification test (Atterberg Limit) while Table 2 shows the allowable bearing capacities for shallow foundations. Table 3 shows the pile bearing capacity while Fig. 2 depicts the cone penetration profile (CPT of BH-1), Fig. 3, the cone penetration profile (CPT of BH-2), Fig.4, Log of BH-1, Fig.5, Log of BH-2, Fig. 6, Log of BH-3, and Fig.7, 8 and 9, respectively shows the particle size distribution curve for BH-1, BH-2 & BH-3.

Table 1: Classification Test (Atterberg Limit)

Borehole No.	Depth(m)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index
1	1.5	37.8	18.1	19.7
1	6	38	17.9	20.1
1	9	32.2	15.1	17.1
2	1.5	38	18.2	19.8
2	4.5	37.5	18.1	19.4
2	7.5	37.8	17.9	18.9
3	3	35	17	19
3	6	35.7	17.4	18.3
3	7.5	37	17.4	19.6

Table 2: Allowable Bearing Capacities for Shallow Foundations

Foundation Depth (m)	Width (m)	Undrained Shear Strength (KN/m^2)	Ultimate Bearing Pressure (KN/m^2)			Allowable Bearing Pressure (KN/m^2)		
			L/B =1	L/B= 1.5	L/B = 5	L/B=1	L/B=1.5	L/B=5
1	1	46	298.9	299.1	299.38	99.63	99.70	99.79
1	1.5	46	300.7	301.05	301.54	100.23	100.35	100.51
1	2	46	302.5	303	303.7	100.83	101.00	101.23
1	2.5	46	304.3	304.95	305.86	101.43	101.65	101.95
1	5	46	313.3	314.7	316.66	104.43	104.90	105.55
1	10	46	331.3	334.2	338.26	110.43	111.40	112.75
1.5	1	46	307.9	308.1	308.38	102.63	102.70	102.79
1.5	1.5	46	309.7	310.05	310.54	103.23	103.35	103.51
1.5	2	46	311.5	312	312.7	103.83	104.00	104.23
1.5	2.5	46	313.3	313.95	314.86	104.43	104.65	104.95
1.5	5	46	322.3	323.7	325.66	107.43	107.90	108.55
1.5	10	46	340.3	343.2	347.26	113.43	114.40	115.75
2	1	46	316.9	317.1	317.38	105.63	105.70	105.79
2	1.5	46	318.7	319.05	319.54	106.23	106.35	106.51
2	2	46	320.5	321	321.7	106.83	107.00	107.23
2	2.5	46	322.3	322.95	323.86	107.43	107.65	107.95
2	5	46	331.3	332.7	334.66	110.43	110.90	111.55
2	10	46	349.3	352.2	356.26	116.43	117.40	118.75

Table 3: Pile Bearing Capacity

Depth of Embedment (m)	Ultimate Capacity (KN)	Allowable Capacity (F.S=3)
	300 mm X 300mm (square Pile)	
10	667	222.3333
15	928	309.3333
20	987	329
25	1470	490
	350mm X 350mm (square Pile)	
10	840	280
15	1221	407
20	1322	440.6667
25	2341	780.3333
	356mm –Diameter	
10	677.8	225.9333
15	989	329.6667
20	1073	357.6667
25	1937	645.6667
	406mm – Diameter	
10	829	276.3333
15	1247	415.6667
20	1375	458.3333
25	2837	945.6667

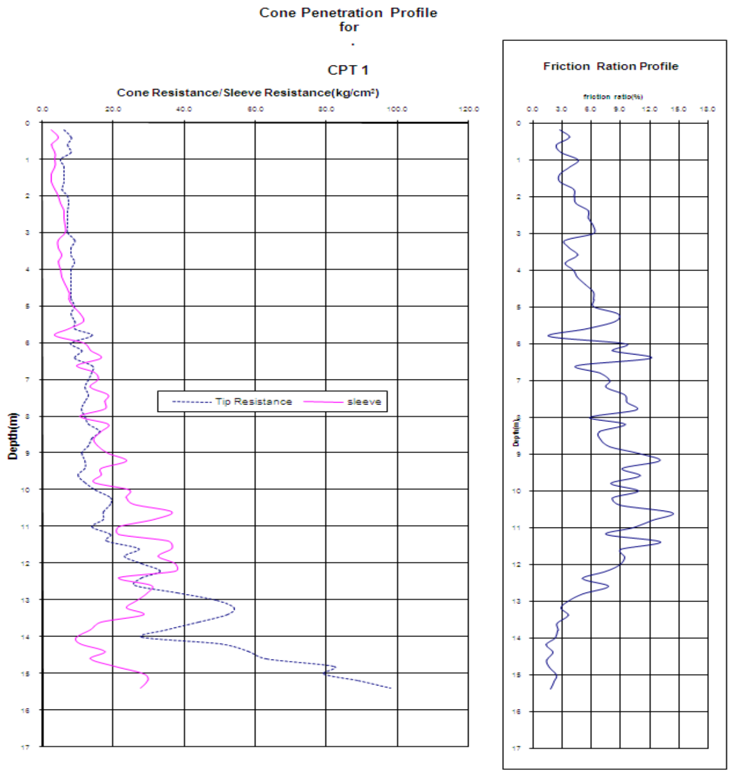

Fig. 2: Cone Penetration Profile (CPT of BH-1)

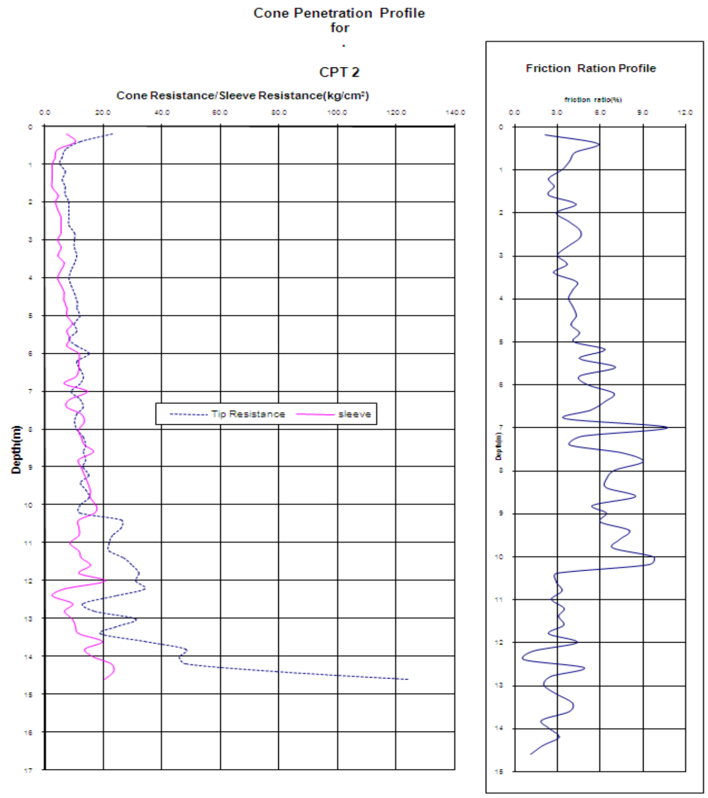

Fig. 3: Cone Penetration Profile (CPT of BH-2)

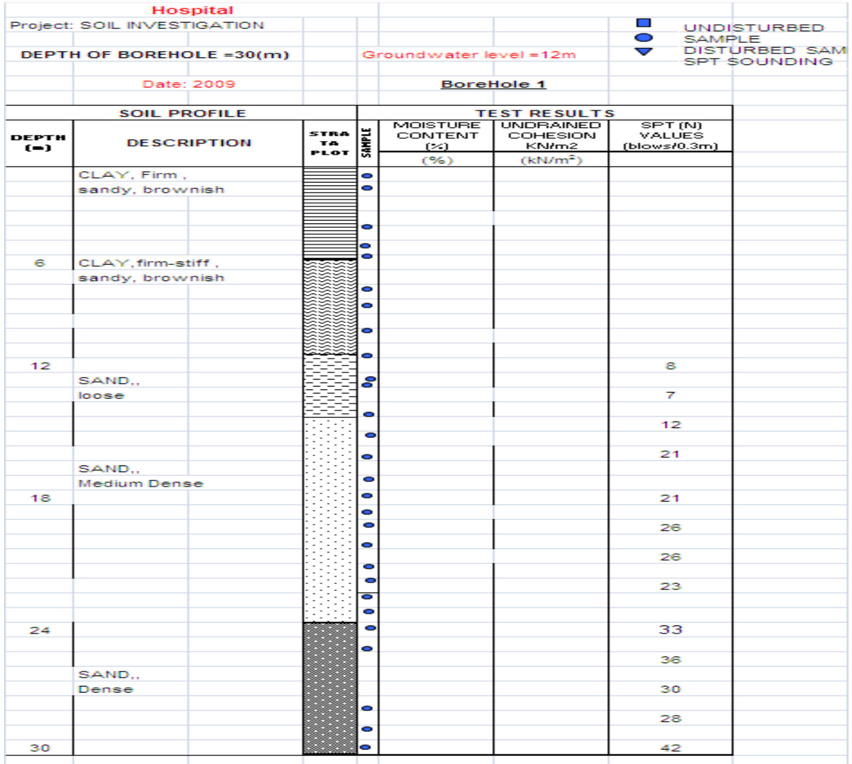

Fig.4: Log of BH-1

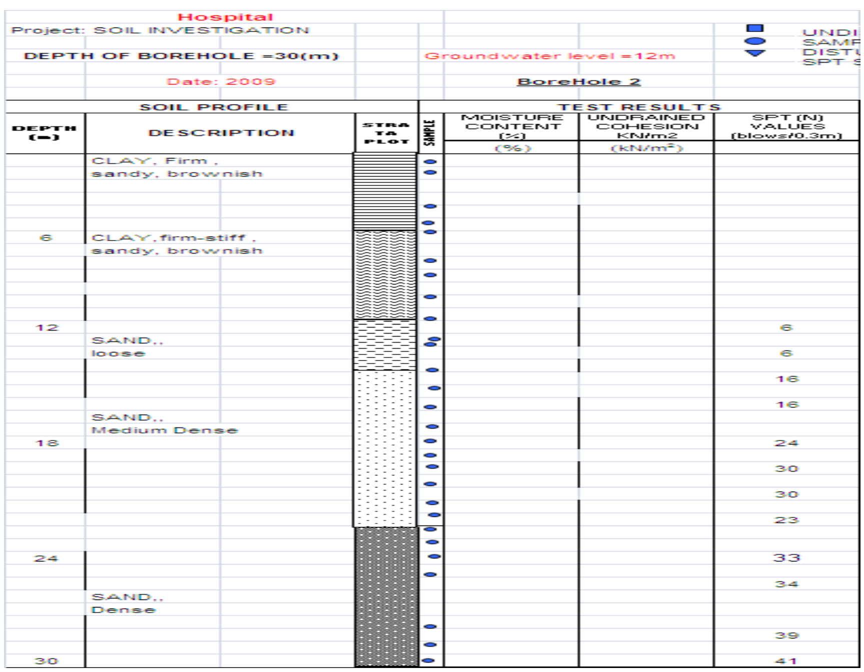

Fig.5: Log of BH-2

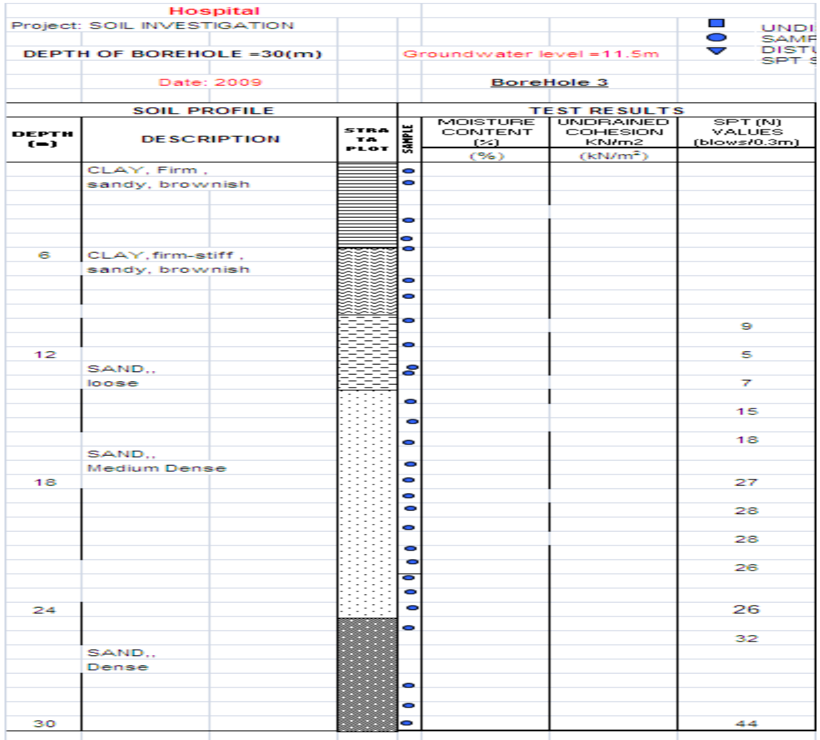

Fig. 6: Log of BH-3

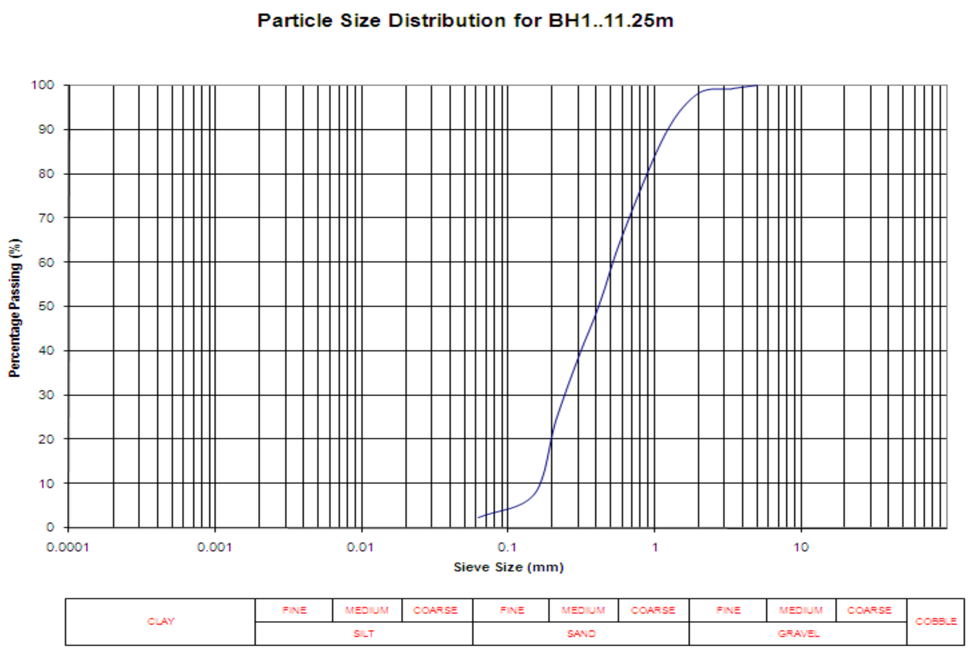

Fig.7: Particle Size Distribution Curve for BH-1

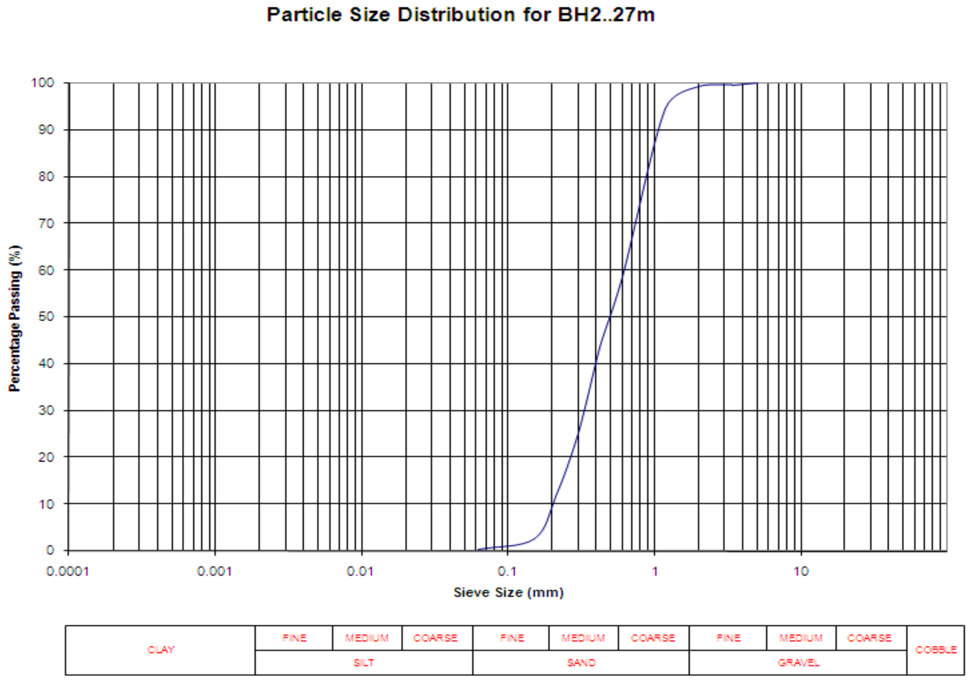

Fig. 8: Particle Size Distribution Curve for BH-2

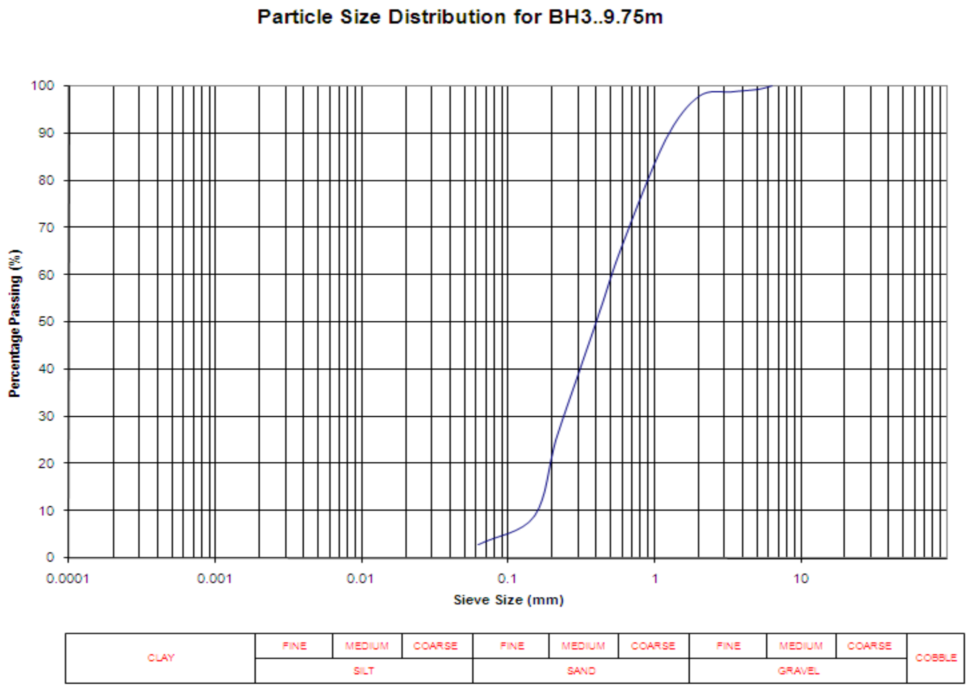

Fig. 9: Particle Size Distribution Curve for BH-3

Conclusion

The study revealed that the surface is underlain by a soft –firm sandy clay (about 6m) of moderate - high compressibility with undrained Strength of 46KN/m^2 overlying a firm-stiff sandy layer. Beneath these layers, is a loose sandy layer (with an angle of friction, of 29^o) overlying a medium dense sandy layer(with an angle of friction of 31^o). Underlying these layers is a dense sandy layer (with an angle of friction of 36^o).

The allowable bearing capacity profile of the sub-surface shows low bearing capacities characteristics (1m - 2m: <110KN/m^2). These values are relatively lower than the projected foundation loading. Pile driven to at least 5m into the sand layer is recommended as the foundation option for consideration.

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