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Geo-technical Assessment of Foundation Conditions of a Site in Ubima, Ikwerre Local Government Area, Rivers State, 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 Ubima in Ikwerre Local Government Area of Rivers State, Nigeria and recommend appropriate foundation design and construction of projects 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 soil deposits within the depths explored are characterized by a near-surface deposit of firm to stiff sandy clay. Beneath is a medium dense sandy layer. The water table was at 11m below ground level. The thickness of this deposit, as confirmed by both the borings and the cone resistance soundings varies within 9m. The clay is mainly of moderate compressibilty with *Mv values > 0.15*m^2*/MN* and *Brownish* in colour, with average Cone Penetrometer Test (CPT) value of 10kg/cm^2. The allowable bearing capacity profile of the sub-surface shows moderate bearing capacity characteristics (1.5m: 132KN/m^2). Settlement predictions based on a loading of 150KN/m^2 indicated a settlement of 10mm. For design purposes, undrained cohesion of 50kPa, angle of internal friction of zero and saturated unit weight of 18kN/m^3 are suggested for this layer. Underlying the lower clay is a layer of predominantly well sorted, medium dense sand. About 11m of the sand deposit was proved. Practically, for design purpose, mean angle of internal friction of 31^o and cohesion zero are recommended for the sand layer. Following the results of this study, it is recommended that shallow foundation and placement of raft/mat foundations are viable options in the area.

Keywords:- Geotechnical Engineering, Sub-soil, Ubima, Niger Delta.

I. INTRODUCTION

The need for adequate and reliable geotechnical characterization of sub-soils is very important. This is because 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 site (s) be geo-technically characterized through sub-soil investigation. 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. The knowledge of the geotechnical characteristics of Ubima in Ikwerre Local Government Area of Rivers 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 (Ngah & Nwankwoala, 2013; Nwankwoala & Amadi, 2013; Youdeowei & Nwankwoala, 2013; Oke & Amadi, 2008; Oke *et al.,* 2009).

Geologically, the site (Fig. 1) in Ubima in Ikwerre Local Government Area of Rivers State, Nigeria 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. In broad terms, the area may be considered flat. The surface deposits in the area comprised silty-clays. 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 in grain sizes, fairly well graded and found to exist in various states of compaction.

Generally, in the Niger Delta geotechnical data on the underlying soils are needed for the design of suitable foundation for structures (Ngah & Nwankwoala, 2013). This study therefore, is aimed at establishing significant subsoil types and profile, determination of the stratigraphy of the superficial deposits underlying the site, determination of relevant engineering characteristics of the deposits for appropriate foundation design, the investigation/characterization of the geotechnical properties of all such sub-soils to generate the required data relevant to the foundation design and construction of structures as well as foundation recommendation for proposed structures in the area.

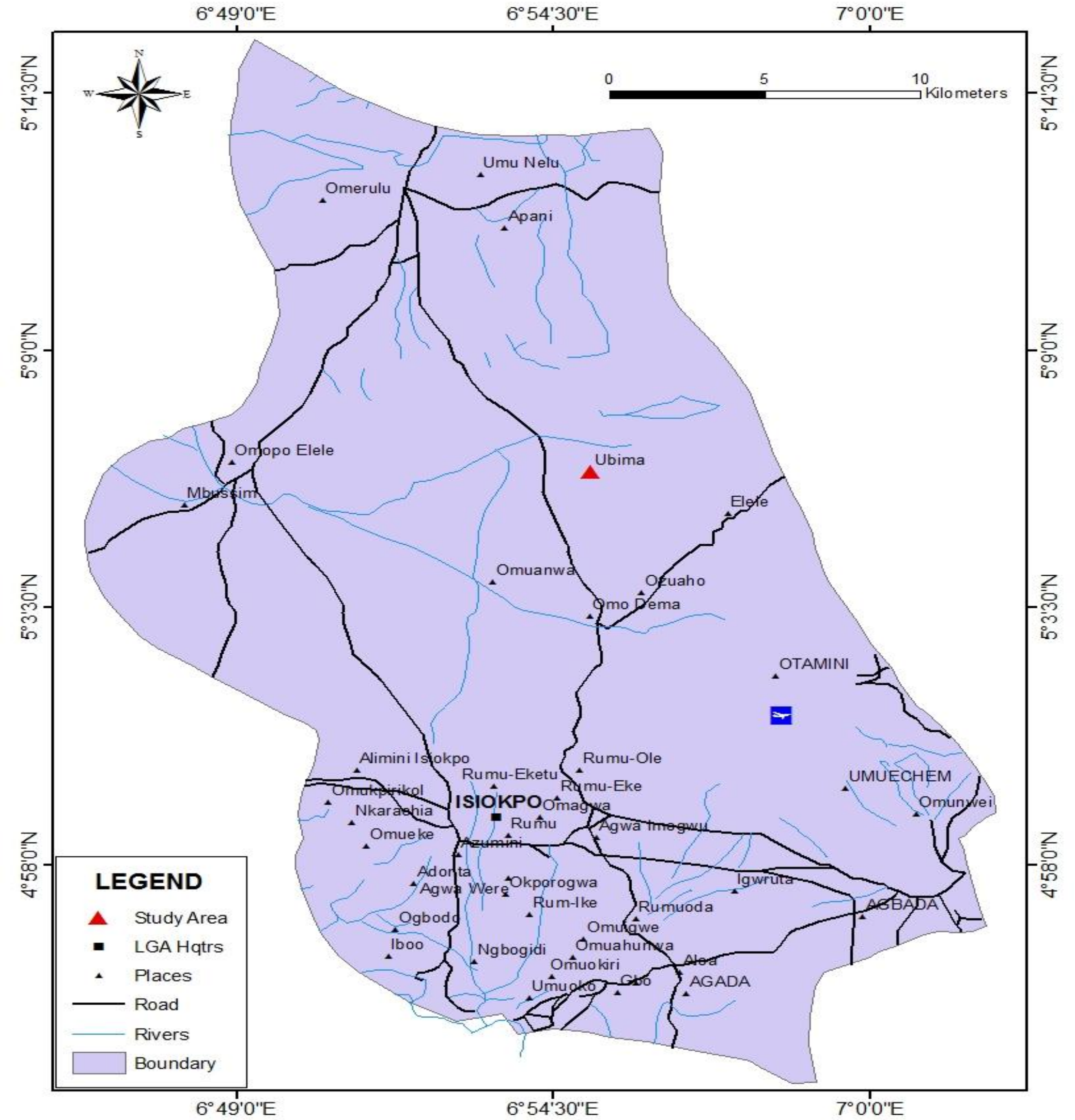

Fig. 1: Map of Ikwerre LGA Showing the Study Area - Ubima

II. METHODS OF STUDY

Cone Penetration Testing (CPT): Hydraulically operated, GMF type, static penetrometer of 100KN capacity was used in the cone resistance soundings. Mechanical mantle cone with friction jacket was used in the operation. Discontinuous sounding procedure was adopted in the test. The cone in its retracted position is first forced into the ground a distance of 10cm by the application of force to the outer sounding tubes. The cone was then pushed out a distance of about 4cm by the application of force to the inner rods only and the magnitude of the force required to achieve this, was measured on the pressure gauges and recorded and this is the cone resistance.

Soil Borings: Conventional boring method which consists of the use of the light shell and auger hand rig were used in the boring operation. During the boring operations, disturbed samples were regularly collected at depths of 0.75m intervals and also when change of soil type was noticed. Undisturbed cohesive soil samples will be retrieved from the boreholes with conventional open-tube sampler 100mm in diameter and 450mm in length. The open-tube sampler consists essentially of a lower end and upper end screwed into a drive head which is attached to the rods of the rig. The head has an overdrive space and incorporates a non-return valve to permit the escape of air or water as the samples enters the tube. The sampler was driven into the soil by dynamic means using a drop hammer. On withdrawal of the sampler, the non-return valve assists in retaining the sample in the tube. All samples recovered from the boreholes were examined, identified and roughly classified in the field.

Standard Penetration Tests (SPT) were performed every 1.5m advance through cohesionless soils. The main objective of this test is to assess the relative densities of the cohesionless soils penetrated. Also, a 50mm diameter split spoon sampler was driven 450mm into the soil with a 63.5kg hammer falling freely a distance of 760mm. The sampler was driven into the soil in two stages. The initial 150mm penetration of the sampler is the seating drive and the last 300mm penetration, the test drive. The number of blows required to effect the last 300mm penetration below the seating drive provide an indication of the relative density of the cohesionless soil stratum tested. This is also referred to as the N-value. The penetration resistance in blow counts with depths are indicated on borehole logs.

III. BEARING CAPACITY

The conventional method of foundation design is based on the concept of bearing capacity or allowable bearing pressure of the soil. The bearing capacity is defined as the load or pressure developed under the foundation without introducing damaging movements in the foundation and in the superstructure supported on the foundation (Peck *et al*, 1973). Damaging movements may result from foundation failure or excessive settlement. The two criteria used in the design of foundation are therefore (i) Determination of bearing capacity of soil and the selection of adequate factor of safety, usually not less than 2.5 (ii) Estimating the settlement under the expected load and comparison with the permissible settlement.

IV. CHOICE OF PARAMETERS

In clays, the ultimate bearing capacity of spread foundation is calculated using total stress parameters. This gives the end-of-construction case, which is the worst condition, and allows the design to be based on undrained shear strength tests. 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 50kPa and angle of internal friction of 1 are adopted for the bearing capacity analysis.

V. RESULTS AND DISCUSSION

The study revealed that the soil deposits within the depths explored are characterized by a near-surface deposit of firm to stiff sandy clay. Beneath is a medium dense sandy layer. The water table was at 11m below ground level. The thickness of this deposit, as confirmed by both the borings and the cone resistance soundings varies within 9m. The clay is mainly of moderate compressibilty with *Mv values > 0.15*m^2*/MN* and *Brownish* in colour, with average Cone Penetrometer Test (CPT) value of 10kg/cm^2. The allowable bearing capacity profile of the sub-surface shows moderate bearing capacity characteristics (1.5m: 132KN/m^2). Settlement predictions based on a loading of 150KN/m^2 indicated a settlement of 10mm. For design purposes, undrained cohesion of 50kPa, angle of internal friction of zero and saturated unit weight of 18kN/m^3 are suggested for this layer. Underlying the lower clay is a layer of predominantly well sorted, medium dense sand. About 11m of the sand deposit was proved. Practically, for design purpose, mean angle of internal friction of 31^o and cohesion zero are suggested for the sand layer. Fig. 2 and 3 shows the variation of settlement with foundation pressure while Fig. 4 & 5 shows the relationship of void ratio versus pressure. Fig.6, 7 & 8 shows the Mohr Circle of the Quick Undrained Triaxial Test results for BH -1, BH-2 and BH-3, respectively while Fig. 9 & 10 shows the plots showing Stress- Strain relationships. Fig. 11 shows the Cone Penetration Profiles (CPT) for BH-1, and BH-2, respectively. Fig. 13 & 14 shows the Borehole Logs for BH-1 & BH-2 while Fig. 15, 16 & 17 gives the Particle Size Distribution Curves for BH-1 @ 13m and BH-2 @ 15m, BH-2 @ 17m, respectively. Table 1 shows the allowable bearing capacities for shallow foundation while Table 2a, b shows Settlement parameters and Computed Rate of Settlements. Table 3a & Table 3b also shows the settlement parameters while Table 4 shows Triaxial @ BH -1, 1.5m, Table 5: Triaxial @ BH -1, 3m and Table 6: Triaxial BH -1, 6m, respectively.
The ranges of variations in the relevant index and engineering parameters of the clay are summarized below:

	Minimum Values
Natural moisture content (%)	19
Liquid limit (%)	37
Plastic limit (%)	17
Plasticity index (%)	20
unit weight (kN/m^3)	19
Undrained cohesion (kPa)	50
Angle of internal friction (^{o})	3

Also, the ranges of variations in the relevant engineering parameters of the sand are given below:

	Average
Effective particle size d_{10} (mm)	0.2
Mean particle size d_{50} (mm)	0.5
Coefficient of uniformity $Cu = \frac{d_{60}}{D_{60}}$	4.75
Coefficient of curvature $Cc = \frac{d^2_{30}}{D_{10}\text{-}d_{60}}$	0.644
SPT penetration resistance N values	20 (blows/0.3m)

Table 1: Allowable Bearing Capacities for shallow foundations (Water depth < foundation Depth)

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	50	388.572	360.078	320.1864	129.52	120.03	**106.73**
1	1.5	50	388.608	360.117	320.2296	129.54	120.04	**106.74**
1	2	50	388.644	360.156	320.2728	129.55	120.05	**106.76**
1	2.5	50	388.68	360.195	320.316	129.56	120.07	**106.77**
1	5	50	388.86	360.39	320.532	129.62	120.13	**106.84**
1	10	50	389.22	360.78	320.964	129.74	120.26	**106.99**
1.5	1	50	397.572	369.078	329.1864	132.52	123.03	**109.73**
1.5	1.5	50	397.608	369.117	329.2296	132.54	123.04	**109.74**
1.5	2	50	397.644	369.156	329.2728	132.55	123.05	**109.76**
1.5	2.5	50	397.68	369.195	329.316	132.56	123.07	**109.77**
1.5	5	50	397.86	369.39	329.532	132.62	123.13	**109.84**
1.5	10	50	398.22	369.78	329.964	132.74	123.26	**109.99**
2	1	50	406.572	378.078	338.1864	135.52	126.03	**112.73**
2	1.5	50	406.608	378.117	338.2296	135.54	126.04	**112.74**
2	2	50	406.644	378.156	338.2728	135.55	126.05	**112.76**
2	2.5	50	406.68	378.195	338.316	135.56	126.07	**112.77**
2	5	50	406.86	378.39	338.532	135.62	126.13	**112.84**
2	**10**	**50**	**407.22**	**378.78**	**338.964**	**135.74**	**126.26**	**112.99**

Table 2a: Settlement Parameters

Sandy clay (over- consilidated)	**BH-1, 6m,**
e_o	0.661
Preconsolidation Pressure	150KPa
Cc	0.03
Soil Compressibility based on CC and e_o	0.01
P_i (elastic)	1
Pc (Primary)	8.8

Table 2b: Computed Rate of Settlements

Rate of Settlements	Years
T50	0.02
T90	0.1

Table 3a: Settlement Parameters

Clay	BH-1, 1.5m(Over consolidated)
e_o	**0.661**
Pre-consolidation Pressure	**120KPa**
Cc	**0.04**
Soil Compressibility based on CC and e_o	**0.03**
P_i (elastic)	**1**
Pc (Primary)	**9**

Table 3b: Computed Rate of Settlements

Rate of Settlements	Years
T50	**0.02**
T90	**0.1**

Table 4: Triaxial @ BH -1, 1.5m

Minor Principal Stress	100KN/m^2	300KN/m^2
Deviator Stress	138KN/m^2	158KN/m^2
Major Principal Stress	238KN/m^2	458KN/m^2

Table 5: Triaxial @ BH -1, 3m

Minor Principal Stress	100KN/m^2	300KN/m^2
Deviator Stress	130KN/m^2	157KN/m^2
Major Principal Stress	230KN/m^2	457KN/m^2

Table 6: Triaxial BH -1, 6m

Minor Principal Stress	100KN/m^2	300KN/m^2
Deviator Stress	116KN/m^2	138KN/m^2
Major Principal Stress	216KN/m^2	438KN/m^2

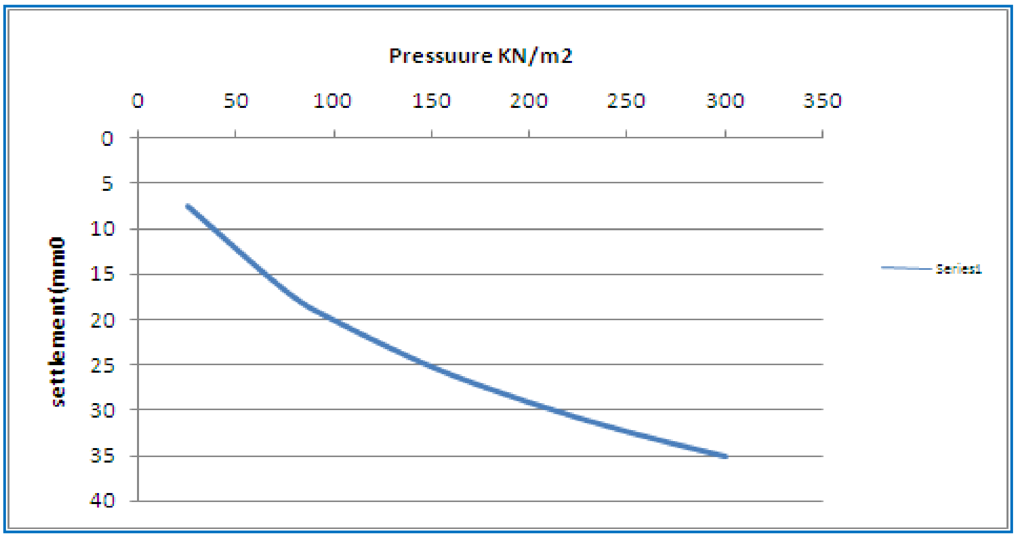

Fig. 2: Variation of Settlement with foundation Pressure

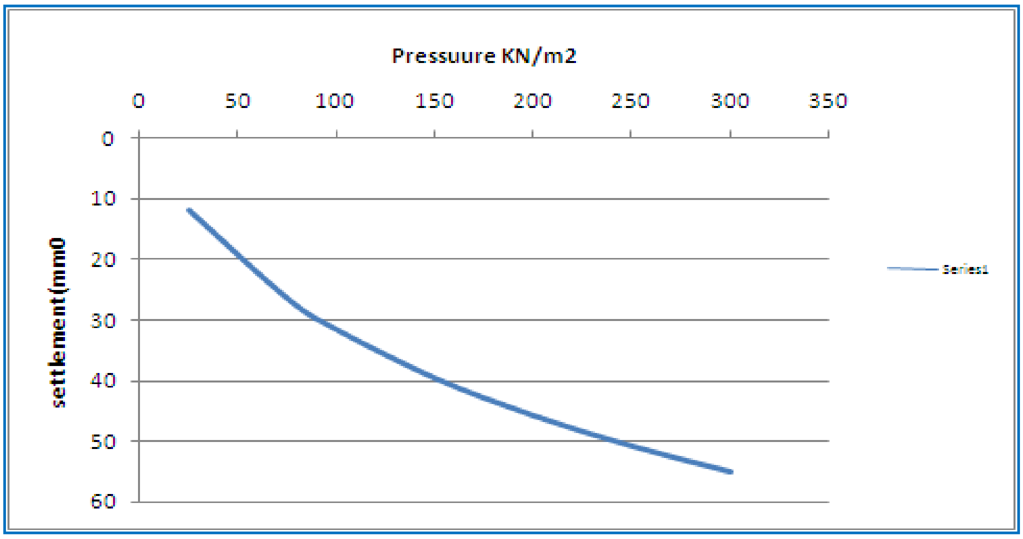

Fig. 3: Variation of Settlement with foundation Pressure

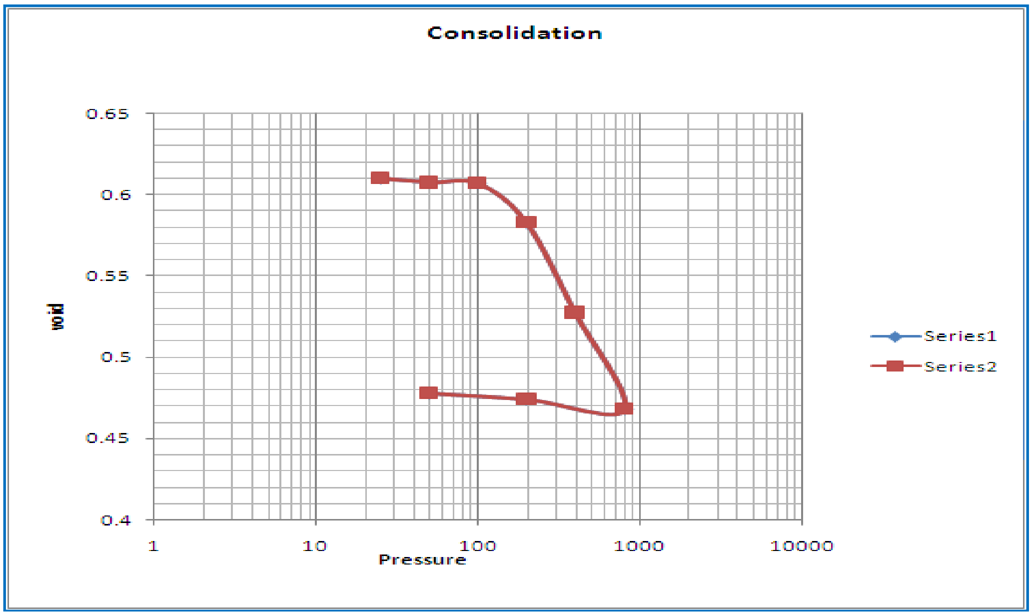

Fig.4: Graph of Void Ratio Versus Pressure

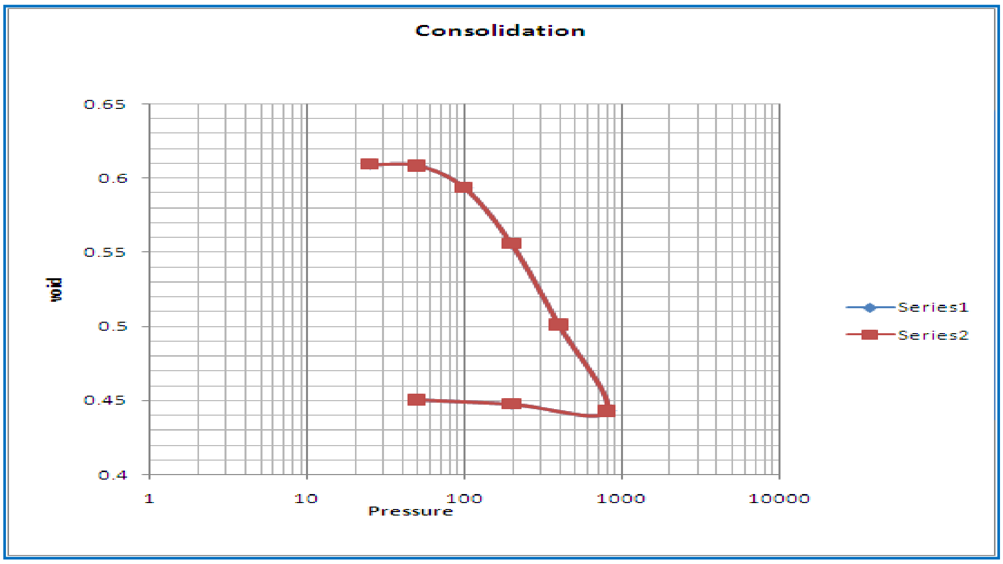

Fig. 5: Graph of Void Ratio Versus Pressure

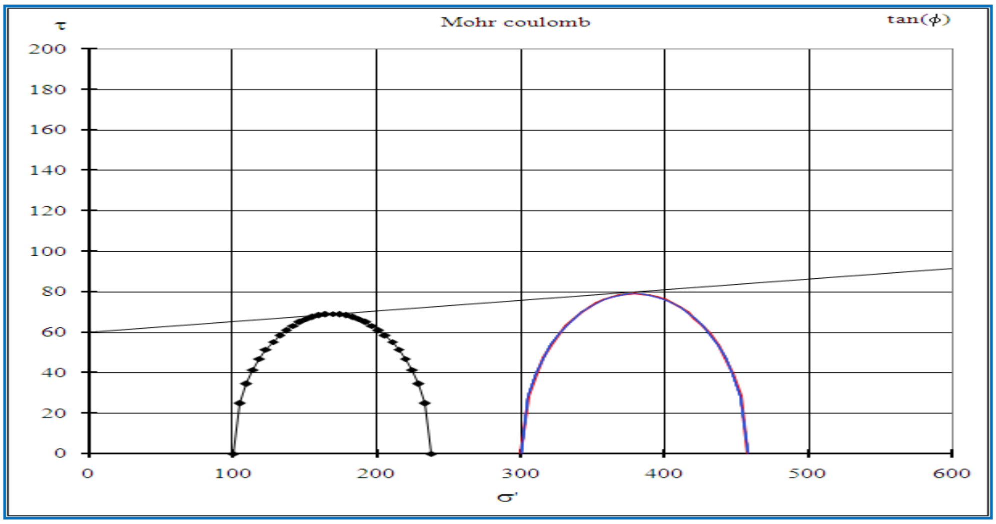

Fig. 6: Mohr Circle of the Quick Undrained Triaxial Test for BH -1

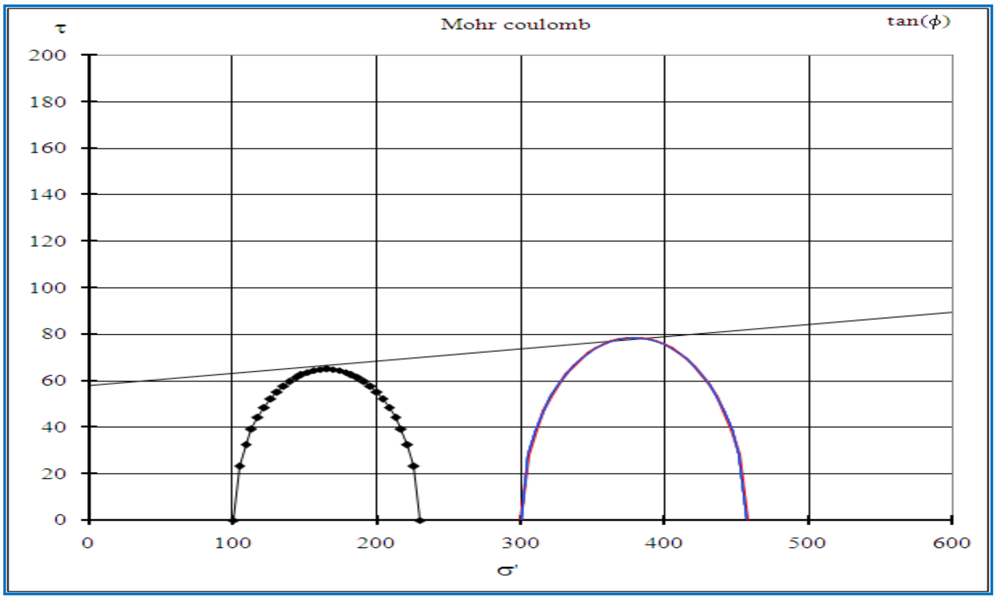

Fig. 7: Mohr Circle of the Quick Undrained Triaxial Test for BH -2

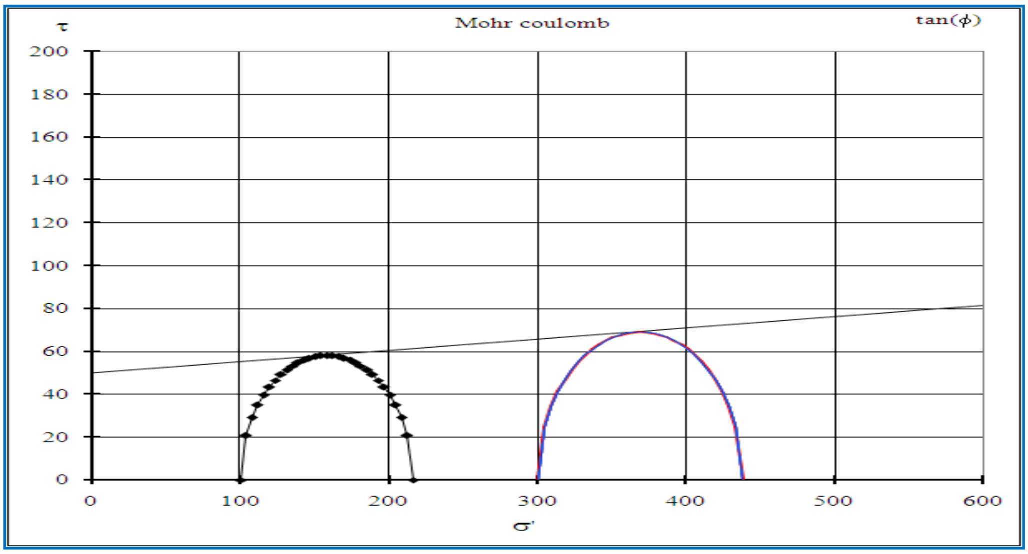

Fig. 8: Mohr Circle of the Quick Undrained Triaxial Test for BH -3

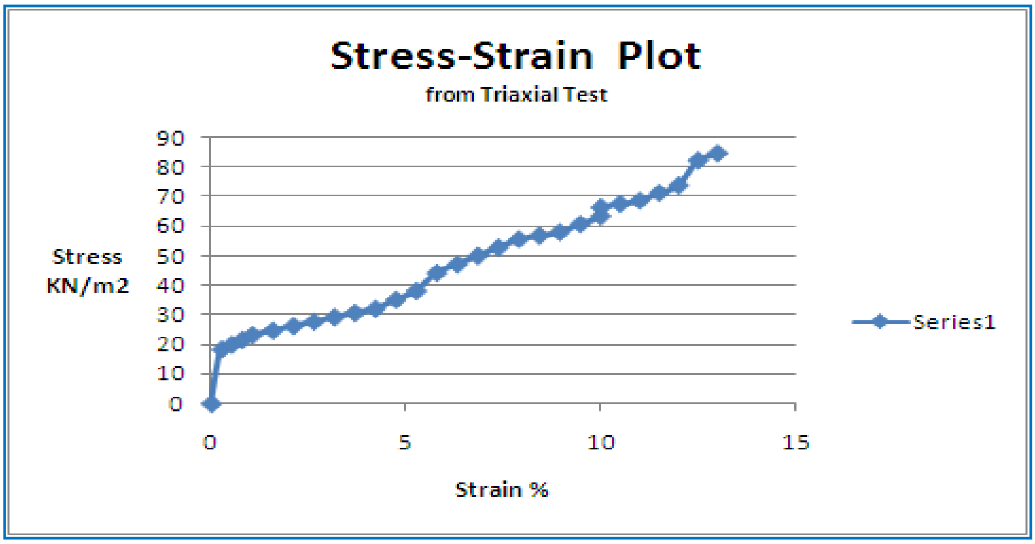

Fig. 9: Plots showing Stress- Strain Relationships

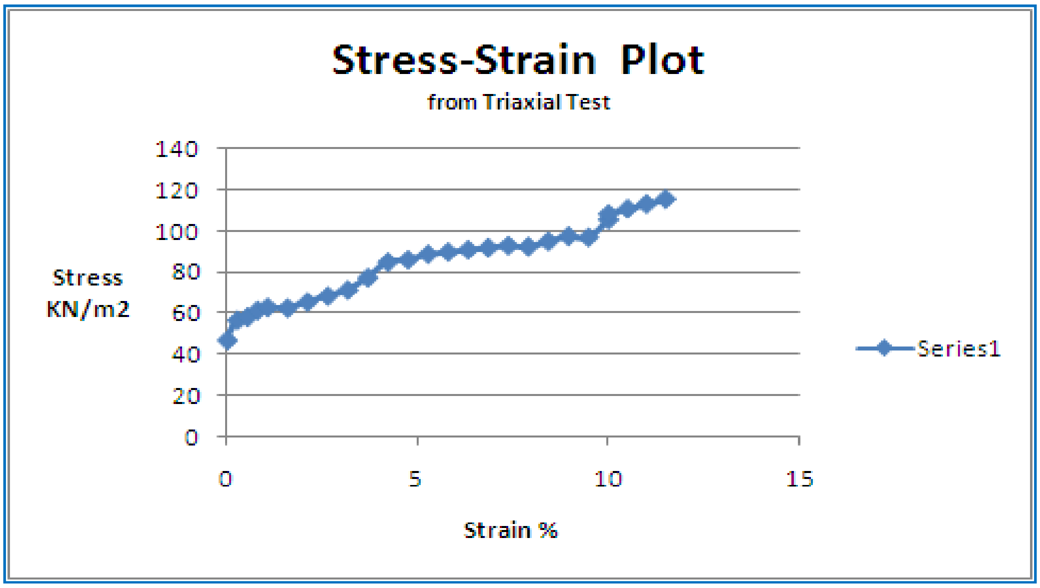

Fig. 10: Plots showing Stress- Strain Relationships

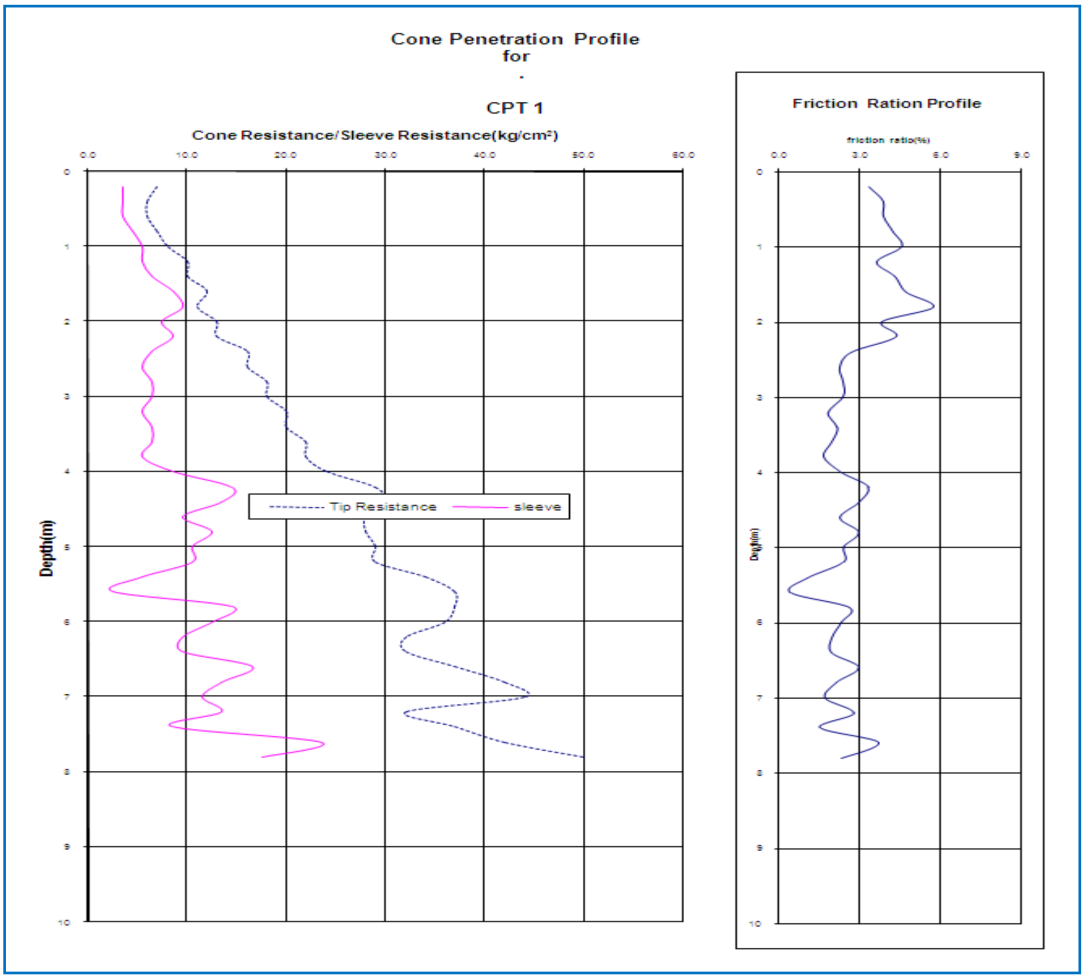

Fig. 11: Cone Penetration Profile (CPT for BH-1)

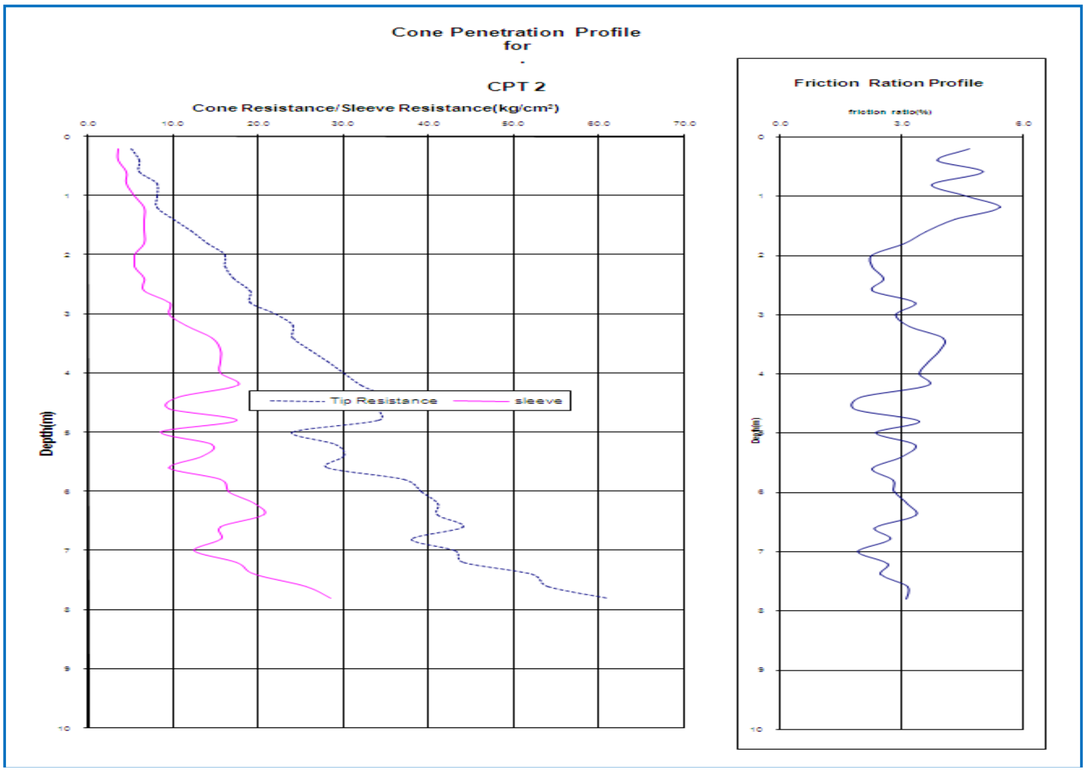

Fig. 12: Cone Penetration Profile (CPT for BH-2)

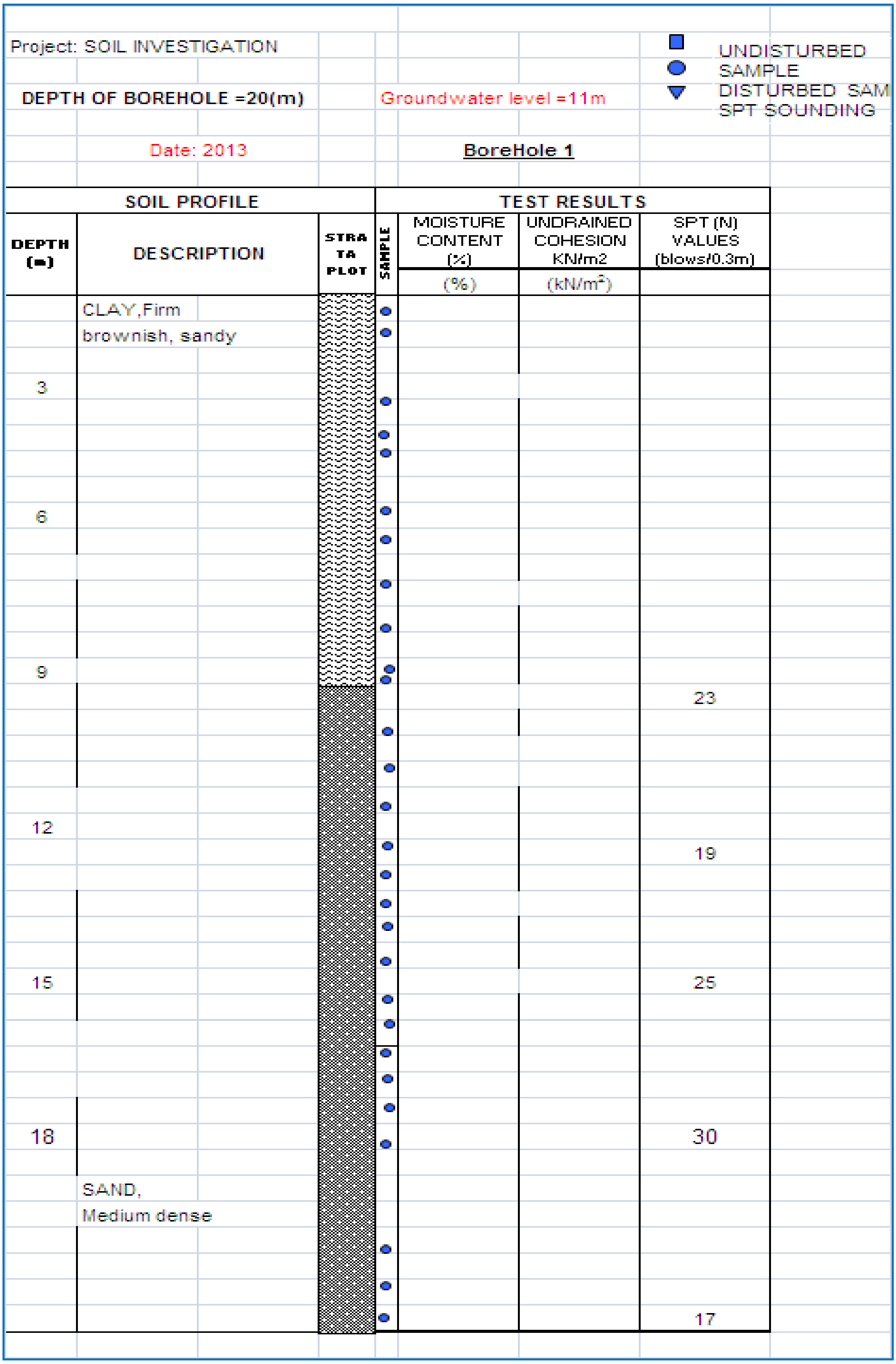

Fig. 13: Borehole Log for BH-1

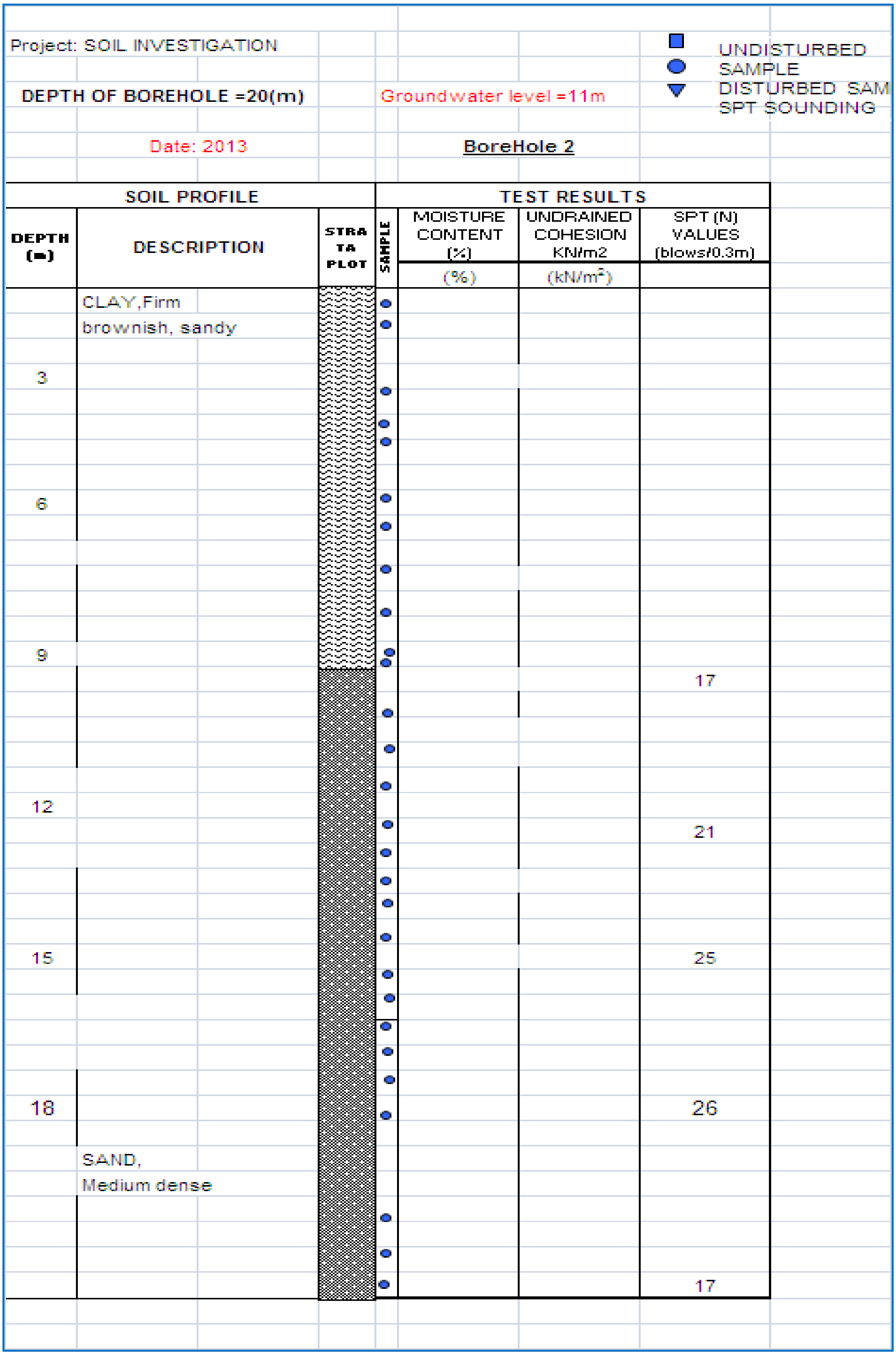

Fig. 14: Borehole Log for BH-2

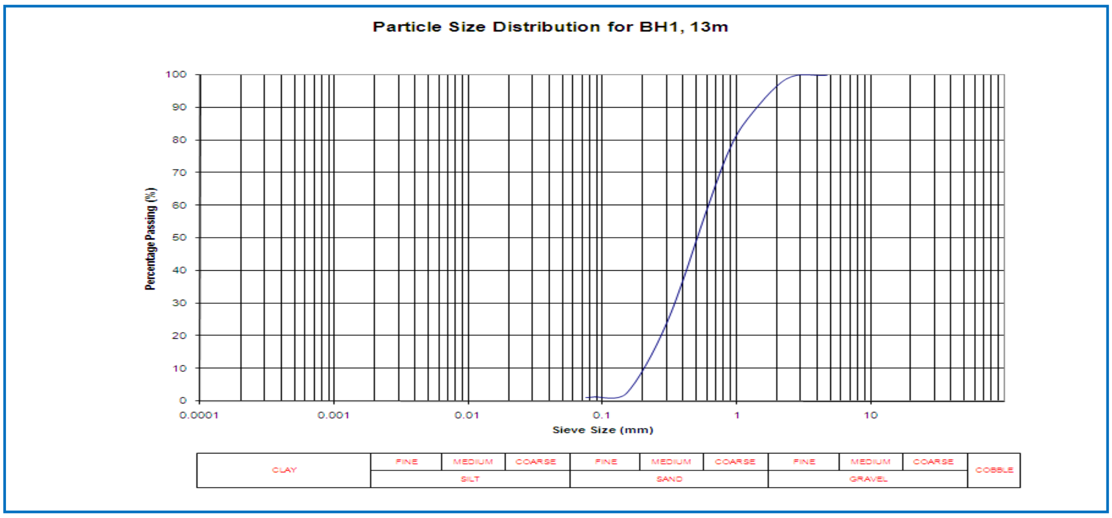

Fig. 15: Particle Size Distribution Curve for BH-1 @ 13m

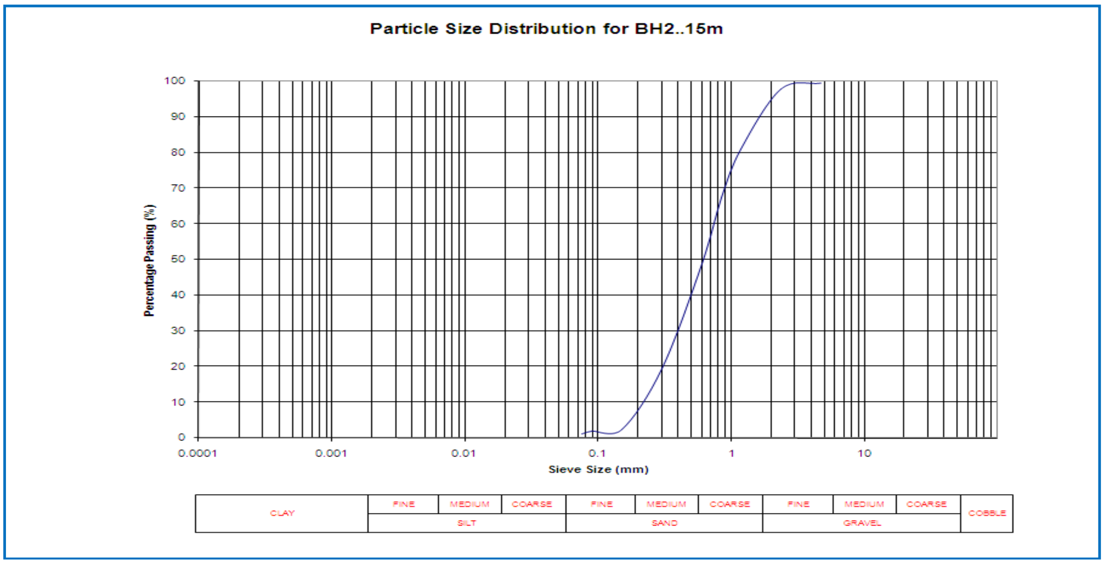

Fig. 16: Particle Size Distribution Curve for BH-2 @ 15m

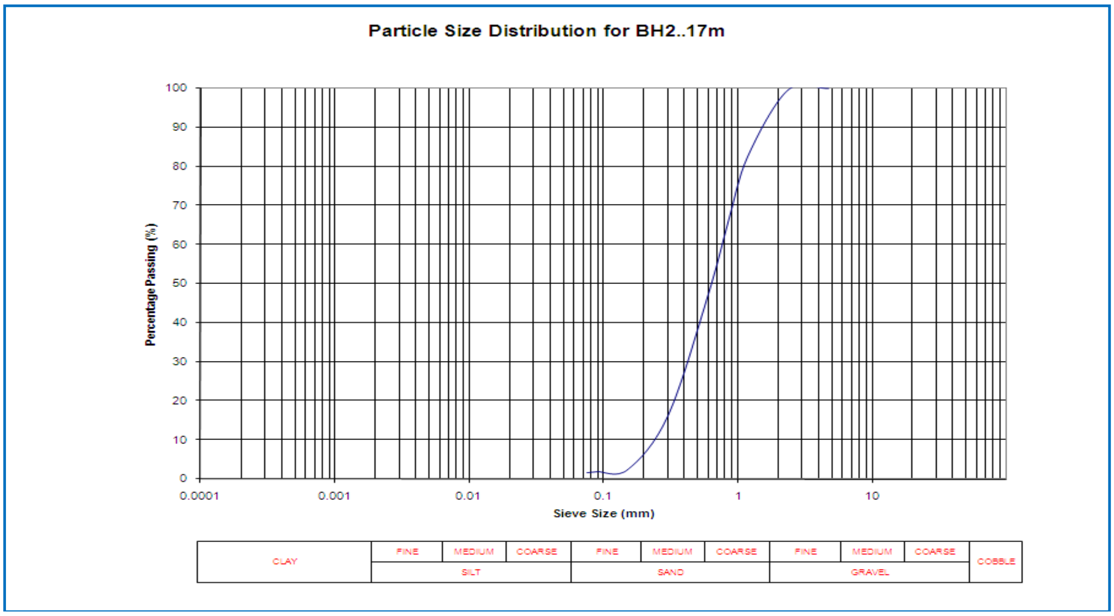

Fig. 17: Particle Size Distribution Curve for BH-2 @ 17m.

VI. CONCLUSIONS

This study therefore revealed that the soil deposits within the depths explored are characterized by a near-surface deposit of firm to stiff sandy clay. Beneath is a medium dense sandy layer. The water table was at 11m below ground level. The thickness of this deposit, as confirmed by both the borings and the cone resistance soundings varies within 9m. The clay is mainly of moderate compressibilty with *Mv values > 0.15*m^2*/MN* and *Brownish* in colour, with average CPT value of 10kg/cm^2. For design purposes, undrained cohesion of 50kPa, angle of internal friction of zero and saturated unit weight of 18kN/m^3 are suggested for this layer. Underlying the lower clay is a layer of predominantly well sorted, medium dense sand. About 11m of the sand deposits was proved. Practically, for design purpose, mean angle of internal friction of 31^o and cohesion zero are suggested for the sand layer.

This study shows that the topsoil is underlain by a firm to stiff clay with *Cu* of about 50KN/m2. Underneath this layer is Medium Dense Sandy Layer with Phi between 31^0 to 32^0. The allowable bearing capacity profile of the sub-surface shows moderate bearing Capacity characteristics (1.5m: 132KN/m^2). Settlement predictions based on a loading of 150KN/m^2 indicated a settlement of 10mm. Following the results of this study, the following foundation option(s) should be considered in the area (i) Shallow Foundation (ii) Placement of a Raft foundation for the heavier construction/facilities.

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