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Geotechnical Properties of Soil for Design and Construction of Foundation from Elebele Town, Bayelsa State, Nigeria

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ABSTRACT: The geotechnical properties of soils influence the stability of construction materials and civil engineering structures. This study investigated the geotechnical properties of soil for design and construction of foundation from Elebele Town, Bayelsa State, Nigeria using standard techniques. Results obtained show that the Atterberg limit results reveal that the liquid limit ranges from 64.3% to 96.5%, the plastic limit ranges from 28.9% to 45.6% while the plasticity index values range from 33.7% to 51.3%. The cohesive soils (clays) are highly plastic (CH) in the Unified Soil Classification System (USCS) designation. The natural moisture content ranges from 57.5% to 87.9%. The particle size distribution analysis reveals that the sand is fine to medium to coarse grained and in a medium dense state of compaction and based on its coefficient of uniformity and gradation classifies as poorly graded (SP) by the USCS designation. The moisture content of the sand ranges from 10.2% to 13.5% while the bulk unit weight ranges from 18.8KN/m^3 to 20.3 KN/m^3. The angle of shearing resistance ranges from 27^0 to 34^0. The result of the undrained shear strength of the clay ranges from 15Kpa and 18Kpa. The clay is very soft to soft and exhibit medium to high moisture content. The strength test result indicates a material of low undrained shear strength, the coefficient of consolidation, Cv of the clay soil samples varies between 1.41m^2/year and 2.49 m^2/year. The coefficient of volume compressibility, Mv, for the same materials varies between 0.667 m^2/MN and 6.338 m^2/MN, generally indicating clay layers of high to very high compressibility. Raft foundation is best suited for this weak, soft foundation materials.

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The oldest building material known to us is soil. Geotechnical investigation of the soil is important before carrying out construction of any structure on the earth surface as the load of the structure is eventually transfer to the soil beneath and for the stability of the structure, it is necessary for the soil to withstand this load exerted by the structure. The foundation is the portion of a structure that transmits the loads from the structure to the underlying foundation material. Occasionally, some of these civil engineering structures such as building, roads, etc. do not stand the taste of time possibly because of lack of due consideration of the importance of the study of the sub-surface layers of the soils thereby resulting to collapse of structures. Several cases of collapsed buildings and other civil engineering structures are likely to start with one or all the deformational failures such as cracking, subsidence, corrugation, collapsing and sliding or formational failure etc. of the sub-surface soil formations on which structures are built on. When the foundation of any structure is constructed on compressible soil, it leads to settlement. Knowledge of the rate at which the compression of the soil takes place is essential for design consideration. The properties of the soil such as plasticity, compressibility or strength of the soil directly affect the design in the construction. (Ekpelu et al, 2018; Didei et al, 2016). The shear strength of soils is of special relevance among geotechnical soil properties because it is one of the essential parameters for analysing and solving

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stability problems. (Calculating earth pressure, the bearing capacity of footings and foundations, slope stability or stability of embankments and earth dams, Karsten et al, 2006). Assessment of geotechnical properties of sub-soil at project site is necessary for generating relevant input data for design and construction of foundations for proposed structures. (Oke and Amadi, 2008; Oghenero et al, 2014; Ngah and Nwankwoala, 2013; Nwankwoala et al, 2014) have stated that proper soil investigation, design and construction of civil engineering structures prevent an adverse environmental impact or structural failure or post construction problems. Hence, the objective of this study is to investigate the geotechnical properties of soil for design and construction of foundation from Elebele Town, Bayelsa State, Nigeria using standard techniques.

MATERIALS AND METHODS

Description of the Study Area: The study area is found within longitude 6^{o} 10^{1} E and 6^{o} 16^{1} E and latitude 4^{o} 30^{1} N and 4^{o} 39^{l} N (Fig. 1). The study area is in the Niger Delta rain forest vegetation and basically accessible by a good road network and river system. The study area is Elebele town in Ogbia local government area. The inhabitants are mainly fishermen and farmers. The Ogbia people speak the Ogbia language, a unique ljaw dialect and have close kinship and language ties with the Okoroma people of Nembe local government of Bayelsa, the Odual people of Abua/Odual local government of Rivers State as well as the Ogbogolo people of Ahoada-West local government area in Rivers State. The terrain is flat, low, sloping very gently seawards (usually does not exceed 20m above sea level) and is drained and crisscrossed by network of distributaries characterized by the freshwater ecology of the upper reaches of the River Nun within the Niger Delta. The location falls within the Niger Delta (Miocene-Recent) which occurs at southern part of Nigeria bordering the Atlantic Ocean. Stratigraphically, the Niger Delta comprises of the lower marine unit, the Akata Formation, the middle continental unit, the Agbada Formation and the upper continental sequence, the Benin Formation. However, the study area falls within the Benin Formation which is characterized by clay, sand and sandstones that are coarse grained (commonly very granular) to very fine grained.(Reyment, 1965, Short and Stauble, 1967). The main deposit encountered at the site is organic peaty clays and sands. The area is associated with freshwater swamps, backswamps and meander belts of flat to sub-horizontal elevation. There is severe drainage problem with seasonal and temporary flooding due to heavy rainfall and rise in groundwater table.

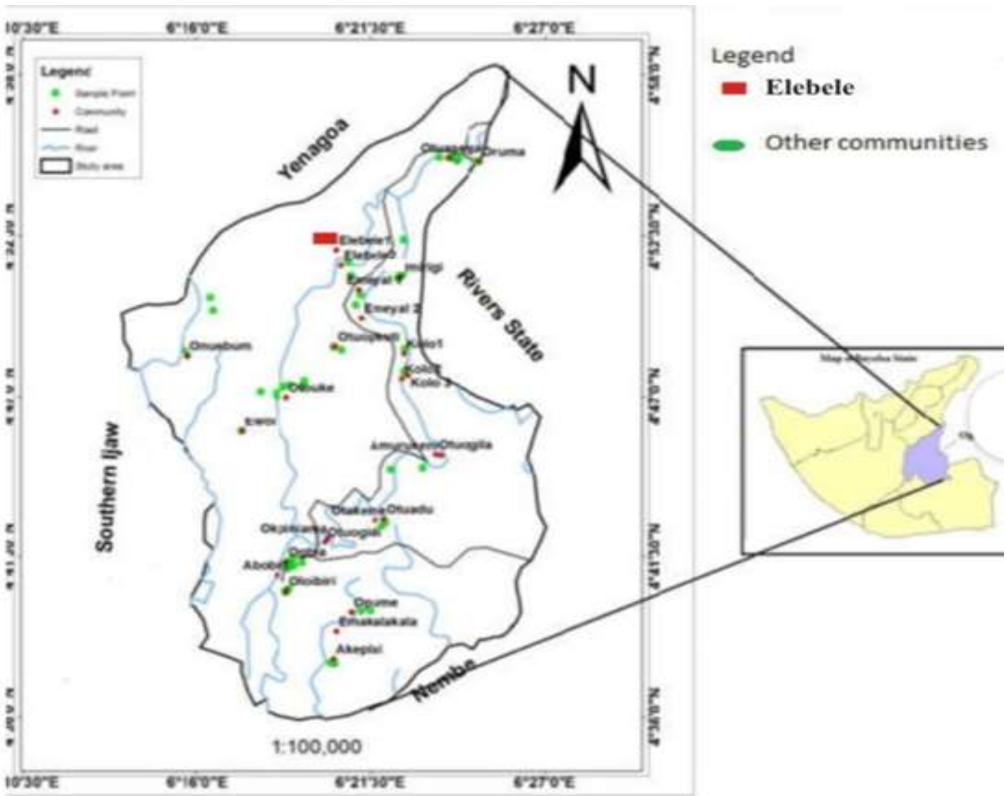

Fig. 1 Map of Ogbia local government area showing the study location.

Sample Collection: The investigation comprised mainly the drilling of two (2) number geotechnical boreholes in Elebele town, with soil sampling, measurement of water table and conducting standard penetration tests. The boreholes were drilled using the percussion boring rig. The disturbed samples were taken at regular intervals and at change in soil type. The samples were used for a detailed and systematic description of the soil in each stratum in terms of its visual and tactile properties and for laboratory tests. The soil sampling was carried out in accordance with BS1377, with a minimum requirement set out in ASTM. Field measurements of groundwater showed that groundwater levels stood at between 1.0m and 3.0m. The water levels in boreholes are subject to seasonal fluctuations.

Laboratory investigation: A series of classification, strength and compressibility tests were carried out in the laboratory. These tests were performed in accordance with British and ASTM standards. Detail of the different tests are given below.

Moisture content: Moisture content test was carried out in accordance with BS1377, on samples recovered from the boreholes. The moisture content was determined by drying selected moist/wet soil materials for at least 18 hours to a constant mass in a 110^{o}c 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 moisture content of the material.

Atterberg Limits: Atterberg limits were determined on soil specimens with a particle size 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 the brittle states (plastic limit, W_P) of fine-grained soils. The liquid limit is the water content at which a part of soil placed 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 test was carried out. Distilled water was added during soil mixing to achieve the required consistency. Plastic limit is the water content at which a soil can no longer be deformed by rolling into 3mm diameter threads without crumbling. The difference between the liquid limit and the plastic limit is the plasticity index, I_P.

Particle Size Analysis: Particle size analysis were performed by means of sieving. Sieving was carried out for particles that would be retained on a 0.075mm sieve, dry sieving was carried out by passing the soil sample over a set of standard sieve sizes and then shakes the entire units for few minutes with sieve shaker (machine). Particle size is presented on a logarithmic scale so that two soils having the same degree of uniformity are represented by curves of the same shape regardless of their positions on the particle size distribution plot. The general slope of the distribution curve may be described by the coefficient of uniformity Cu, where $Cu=D_{60}/D_{10}$ and the coefficient of curvature Cc, where $Cc= (D_{30})^2/ D_{60}.D_{10}$. D_{60}, D_{30} and D_{10} are effective particle sizes indicating that 60%, 30% and 10% respectively of the particles (by weight) are smaller than the given effective size. Reference test standard, BS1377, Part2, 1990.

Unit Weight: The unit weights were determined from measurement of mass and volume of the soil. The unit weight (KN/m^3) refers to the unit weight of the soil at the sampled water content, the dry unit was determined from the mass of oven-dried soil and the initial volume. . Reference test standard, BS1377, Part2, 1990.

Unconsolidated undrained Triaxial: Unconsolidated undrained triaxial compression tests were performed on cohesive samples, relatively undisturbed samples obtained from the open boreholes, with the objective of determining their undrained strength parameters, in accordance with BS1377, Part2, 1990

Direct Shear Test: The soil specimen is loaded into the shear box which split into two halves along a horizontal plane at its middle. The box is square with 60mm sides and 50mm high. It is made up of brass metal. It is placed inside a larger box-container and mounted on the loading frame. A proving ring is fitted to the upper halve of the box to measure the shear force. The proving ring which butts against a fixed support records the shear force as the box moves and the shear displacement is measured with a dial gauge fitted to the container. Another dial gauge fitted to the top of the pressure pad measures the change in the thickness of the specimen. . Reference test standard, BS1377, Part1-2016.

Oedometer Consolidation: Laboratory consolidation tests were carried out on cohesive soil specimens, relatively undisturbed sample with object of determining the compressibility properties of the soils, in accordance with BS 1377. The plot of void ratio (e) against effective pressure (P) for the samples tested presented in tables 1 and figure 6 together with calculated values of the coefficients of consolidation, (Cv) and coefficient of compressibility (Mv). Test results show that the samples are of predominantly high compressibility.

Soil Stratigraphy: The strata shows that the site is predominantly clay both in boreholes BH1 and BH2 (Fig. 2A and 2B). In BH1, the strata reveal a formation of peaty clay from the ground surface to 3.0m depth. The clay is soft in consistency and grey in colour. Beneath the clay to the depth of 5.0m, loose fine sand is encountered. The sand is silty and grey in colour. Beneath the sand to the final 15.0m depth of the investigation, peaty clay is again observed. The clay is also soft in consistency and grey in colour. In BH2, peaty clay is observed from ground surface to a depth of 6.50m. Underneath the peaty clay, fine sand is encountered to a depth of 7.50m. Between 7.50m and 10.50m, another layer of peaty clay is observed. Below 10.50m to the depth of 12.5m, fine sand is encountered. The sand is loose to medium dense in compaction and grey in colour. Beneath the sand stratum to the final 30.0m depth of the investigation, peaty clay is again encountered. The clay is soft in consistency and grey in colour.

RESULTS AND DISCUSSION

Soft Clays: The engineering properties and behaviour of clay is of significant because of the dominant influence of the fines. The shear strength exhibited by the cohesive soil drops significantly when in contact with water. The engineering properties of soil samples obtained from the laboratory analysis are presented in Tables 1 to 5. The borehole logs are presented as Fig. 2A and 2B, the typical particle size distribution curve is shown in Fig.3. The Mohr circle failure envelope is presented in Fig. 4; the direct shear test plot is shown in Fig. 5, while the consolidation curve is shown in Fig. 6.

Medium dense sand: The sand is fine to medium grained, poorly graded, medium dense and greyish to brown in colour. The layers are almost of uniform gradation. The ranges of variations in relevant engineering parameters of the sand are shown in table 5.

Table 1 Geotechnical properties of soil samples

Soil type	Soil parameters	Min.	Max.	Mean
Clay	Moisture Content (%)	57.5	87.9	72.7
	Bulk unit weight (KN/m^3)	14.2	15.0	14.6
	Effective unit weight (KN/m^3)	6.4	6.6	6.5
	Undrained shear strength (Kpa)	15	18	16.5
	Cohesion, C (KN/m^2)	16	24	20
	Angle of shearing resistance (Degree)	3	6	4.5
	Liquid limit (%)	64.3	96.5	80.4
	Plastic limit (%)	28.9	45.6	37.3
	Plasticity Index (%)	33.7	51.3	42.5
	Classification USCS	**CH**	**CH**	**CH**
	Coefficient of consolidation (m^2/Yr.)	1.41	2.49	1.95
	Coefficient of compressible (m^2/MN)	0.667	6.338	3.50
	Poisson's ratio	0.40	0.43	0.42
	Coefficient of earth pressure at rest, Ko	0.81	0.90	0.86

Table 2 Results of the Atterberg limit test

Location/ Borehole No.	Depth of sample (m)	Moisture content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity index (%)	Liquidity index	Coefficient of Earth pressure at Rest, Ko	Casagrande classification
Elebele	1.5	87.9	96.5	45.2	51.3	0.83	0.87	CH
1	7.0	67.5	76.4	28.9	47.5	0.81	0.81	CH
	9.0	66.5	78.2	29.2	49.0	0.76	0.84	CH
	14.0	75.1	85.6	44.3	41.3	0.75	0.90	CH
2	1.0	73.6	76.4	38.7	37.7	0.92	0.81	CH
	4.0	87.6	94.2	45.6	48.6	0.86	0.87	CH
	9.0	79.8	87.5	41.0	46.5	0.83	0.90	CH
	13.0	67.4	76.2	38.6	37.6	0.77	0.81	CH
	16.0	76.5	84.6	40.8	43.8	0.82	0.84	CH
	19.0	64.5	75.6	38.5	37.1	0.70	0.87	CH
	21.0	65.0	76.4	38.7	37.7	0.70	0.84	CH
	24.0	57.5	64.3	28.9	35.4	0.81	0.87	CH
	28.0	67.1	73.2	39.5	33.7	0.82	0.90	CH

Table 3 Results of particle size distribution and drained direct shear test

Bore hole No.	Depth of sample (m)	Moisture content (%)	Bulk Unit Wt .KN/m^3	Angle of shearing Resistance (ϕ) Degree	Effective particle size D_{10} (mm)	D30 (mm)	Mean particle size D50	D60 (mm)	Coeff. of uniformity Cu=D60/D10	Cc	US CS
1	4.0	13.5	18.8	27	0.088	0.152	0.178	0.198	2.250	1.326	SP
2	7.0	12.1	19.5	29	0.033	0.072	0.100	0.105	3.182	1.496	SP
	11.0	10.2	20.1	32	0.102	0.154	0.165	0.184	1.804	1.264	SP
	12.0	10.1	20.3	34	0.052	0.100	0.154	0.165	3.173	1.166	SP

Table 4 Results of the Undrained Triaxial compression tests

BH No.	Depth (m)	Moisture content (%)	Bulk Unit Wt KN/m^3	Dry Unit Wt. KN/m^3	Undrained Cohesion Cu KN/m^2	Angle of Shearing Resist. (ϕ) Degree	Shear Modul. MN/m^2	Poisson's Ratio
	1.5	87.9	14.2	7.6	19	4	5.6	0.40
1	7.0	67.5	14.8	8.8	21	6	8.7	0.40
	9.0	66.5	14.5	8.7	23	5	9.7	0.41
	14.0	75.1	15.0	8.6	24	3	6.7	0.41
2	1.0	73.5	14.7	8.5	18	6	6.7	0.43
	4.0	87.6	14.6	7.8	16	4	9.5	0.42
	9.0	79.8	14.7	8.2	17	3	8.7	0.43
	13.0	67.4	14.8	8.8	20	6	7.8	0.40
	16.0	76.5	14.6	8.3	18	5	8.2	0.40
	19.0	64.5	14.7	8.9	20	4	8.5	0.41
	21.0	65.0	14.5	8.8	22	5	7.9	0.41
	24.0	57.5	14.8	9.4	20	4	8.0	0.41
	28.0	67.1	14.9	8.9	21	3	8.7	0.40

Table 5 Characteristics values for sand samples

Soil type	Soil Parameters	Min.	Max.	Mean
Sand	Moisture content (%)	10.2	13.5	11.9
	Bulk unit weight (KN/ m^3)	18.8	20.3	19.6
	Effective unit weight (KN/ m^3)	8.31	9.09	8.7
	Poisson's ratio	0.35	0.40	0.38
	Angle of shearing resistance (Degree)	27	34	30.5
	Effective particle size, D_{10}mm	0.033	0.102	0.068
	Effective particle size, D_{30}mm	0.072	0.154	0.113
	Mean particle size, D_{50}mm	0.100	0.178	0.139
	Effective particle size, D_{60}mm	0.105	0.198	0.152
	Coefficient of uniformity Cu= D_{60}/D_{10}	3.182	1.941	2.562
	Coefficient of curvature Cc = $(D_{30})^2/ D_{60}.D_{10}$	1.496	1.306	1.401
	Classification USCS	SP	SP	SP
	Standard Penetration Test (SPT) Resistance N value	8	15	11.5

The moisture content affects the engineering performance of clay deposits. The ability to expand when it absorbs water and shrink when it loses moisture.

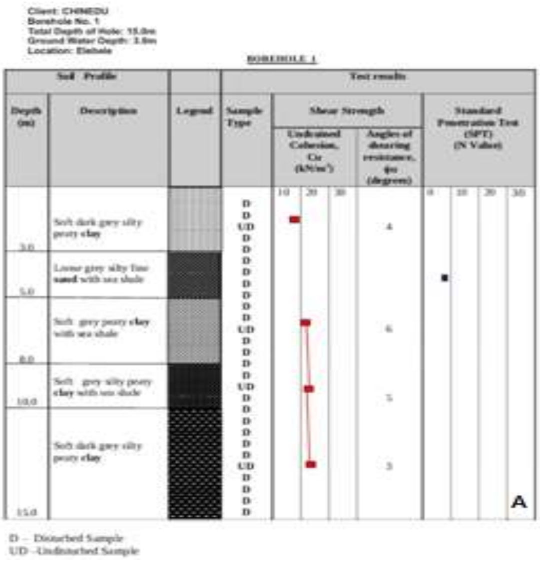

Fig. 2 (A). Borehole log for BH1

Moreso, the moisture content values range between 57.5 to 87.9%, this is relatively high because of the wet season period of sampling. Atterberg limit results reveal that the liquid limit ranges from 64.3- 96.5%, the plastic limit ranges from 28.9- 45.6% while the plasticity index ranges from 33.7- 51.3%, indicating that the clays are highly plastic (CH) on the bases of unified soil classification system (USCS).

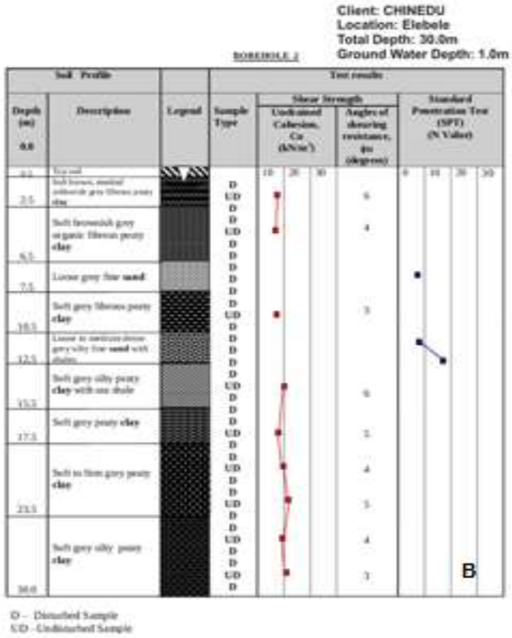

Fig 2 **B** Borehole log for BH2

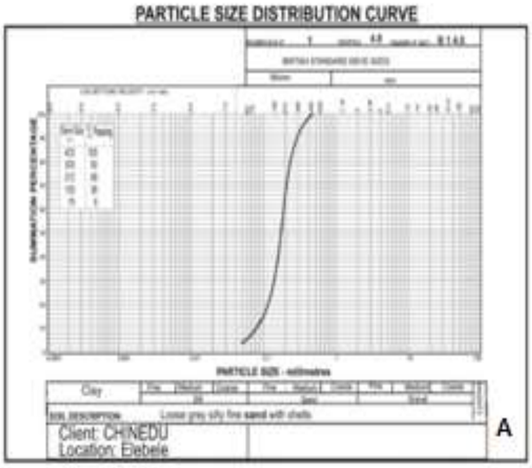

Fig.3 Particle size distribution curve BH1 @ 4.0m

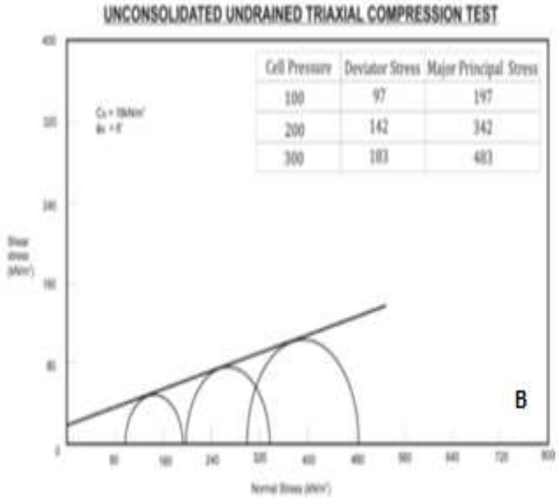

Fig.4 Mohr circle for BH2 @ 1.0m

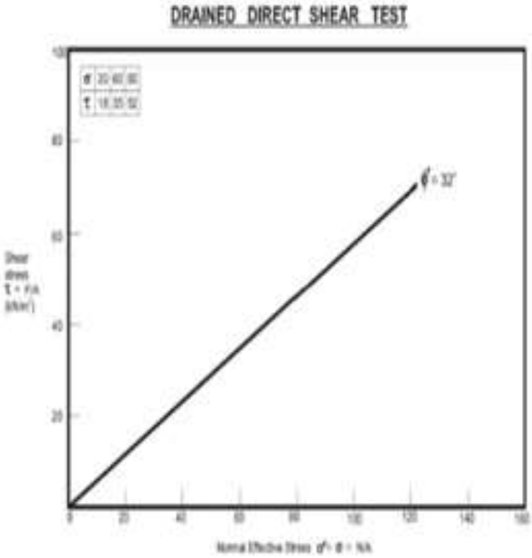

Fig.5 Direct shear test forBH2 @ 11.0m

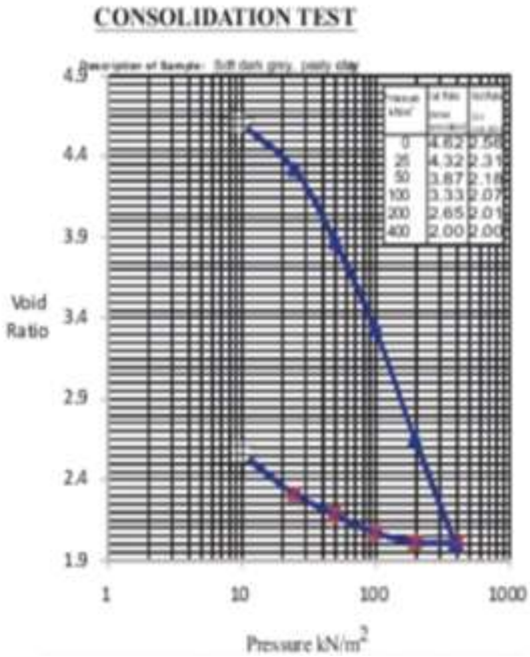

Fig. 6 Consolidation curve for BH1 @ 1.5m

The particle size distribution reveals that the cohesionless soil samples are predominantly fine to medium, medium dense poorly graded sand (SP). The cohesive soils are highly organic clays and peats that are very soft and very highly compressible as the values of coefficient of volume compressibility (Mv) varies between 0.667 and 6.338m^2/MN, exceeded the <0.05 which is classified as very low compressibility (Carter, 1983).

Conclusion: The study has provided improved and detailed understanding of the geotechnical properties and characteristics of the underlying soils across the studied area. The very low water gradient in the Niger Delta, coupled with the flat topography, the soil properties and high rainfall of the wet season, it is important to check this engineering problem by constructing good drainage network. Finally, the raft foundation is the most suitable as it provides support in highly compressible, low strength foundation materials.

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