Geotechnical Characterization and Shear Strength Evaluation of Subsurface Soils for Foundation Design in Gbarian, Yenagoa, Niger Delta, Nigeria

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Abstract:
Reliable geotechnical investigation is crucial for designing safe and stable foundations in coastal and deltaic environments, where subsurface soils are often highly variable, compressible, and weak near the surface. This study provides a detailed geotechnical assessment of the subsurface conditions at a proposed three-storey building site in Gbarian Clan, Yenagoa, within the Niger Delta region of Nigeria. Two boreholes extending to 25 m were drilled, and both disturbed and undisturbed samples were obtained for laboratory analysis following BS 1377 and ASTM Procedures. The testing program included direct shear tests for granular soils and unconfined compressive strength (UCS) tests for cohesive soils.

The results show that the upper 3–6 m consists mainly of soft to firm clay with undrained shear strengths (Su) ranging from 15–35 kPa. These clays display moderate to high compressibility and low bearing capacity, conditions that could lead to significant settlement under applied loads. Below approximately 9 m, the soil profile transitions to dense to very dense sands, characterized by high friction angles (φ = 40.7°–45.9°), indicating strong, competent bearing layers with minimal compressibility. UCS values for the clay samples range from 30.15–69.53 kPa, reflecting an increase in strength with depth due to the effects of overburden pressure.

Bearing capacity evaluations based on Terzaghi's equations show that shallow foundations founded within the dense sand layers would be structurally adequate, while the softer upper clay horizons may require ground improvement or the adoption of deep foundation systems. Overall, the findings are consistent with known Niger Delta geology and provide essential data for determining appropriate foundation solutions for the project site

Keywords: Geotechnical investigation, Niger Delta soils, Shear strength, Unconfined compressive strength (UCS), Direct shear test, Bearing capacity, Foundation design, Deltaic stratigraphy, soft clay, and Dense sand

1.0 Introduction

Site-specific geotechnical investigations are crucial for assessing subsurface conditions, determining engineering soil properties, and informing foundation design to minimize risks such as settlement, bearing failure, and differential movement. Coastal and deltaic environments like the Niger Delta pose additional geotechnical challenges due to the prevalence of soft clays, compressible silts, and irregular stratification (Ezenwaka et al., 2014).

Shallow foundations in such weak soils often undergo excessivesettlement,making detailed site investigation indispensable.

This geotechnical investigation was undertaken for J'Marvy Merchandises as part of the proposed development of a three-storey building in Gbarian Clan, Yenagoa LGA, Bayelsa State, Nigeria. In accordance with the National Building Code (NBC, 2006) issued by the Housing and Urban Development Ministry, soil investigations are a mandatory requirement before the construction of multi-storey or other engineered structures. The code specifies that site characterization must be carried out using test pits and/or boreholes, with a minimum of two test pits per site drilled to at least 2 m depth, or to bedrock if encountered at a shallower level.

The key objectives of this geotechnical investigation include:

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- Drilling **two boreholes** to depths of up to **25 m** to identify bearing strata.
- Collecting disturbed and undisturbed samples for strength and compressibility testing.
- Providing laboratory data—including unconfined compressive strength (UCS), consolidation, and direct shear results—to guide foundation type selection and design parameters.

The findings from this study will provide essential geotechnical information for the safe and reliable foundation design of the proposed building.

2.0 Geological Setting

2.1 National Geological Framework

The geology of Nigeria consists of three major litho-petrological units:

1. The **Precambrian Basement Complex**, comprising migmatite–gneiss complexes, schist belts, and older granites.
2. The **Younger Granites**, represented by Jurassic ring-complex intrusions.
3. The **Sedimentary Basins**, ranging from the Cretaceous to the Tertiary periods, including the extensive **Niger Delta Basin**.

2.2 Local Geology

The project site is located within the Niger Delta Complex and is underlain by recent alluvial, fluvio-deltaic, and mangrove-swamp deposits. These sediments typically consist of alternating layers of clay, silt, and sand, which are often highly compressible with low near- surface bearing capacity (Teme & Nwankwoala, 2023). Boreholes **BH01 and BH02** were drilled to depths of up to 25 m to capture the variability in subsurface conditions. Reconnaissance observations and a review of existing geological information confirm that the encountered materials are characteristic of the region's deltaic depositional environment.

3.0 Literature Review

Geotechnical site investigation provides critical data for evaluating subsurface conditions, soil strength, deformation characteristics, and overall suitability for engineering structures (Clayton et al., 1995). Shear strength is one of the most fundamental engineering properties used to evaluate the stability and load-carrying capacity of soils. According to Terzaghi and Peck (1967), the shear strength of soil is governed primarily by **cohesion (c)** and **angle of internal friction (φ)**, which together determine its ability to resist shear stresses imposed by structural loads. For granular soils such as sands, **frictional resistance (φ)** is the dominant shear parameter, while apparent or true cohesion is generally negligible (Budhu, 2011). Direct shear tests, conducted in accordance with **BS 1377:1990 Part 7**, remain the most widely accepted laboratory method for evaluating shear strength of sands and silty sands.

In saturated cohesionless soils, increases in density, particle interlocking, and confinement lead to significant increases in φ (Das & Sobhan, 2014). Dense and very dense sands commonly exhibit φ-values between 34° and 45°, depending on gradation, particle shape, and in-situ compaction. The high φ-values obtained in direct shear testing are often associated with improved foundation performance and reduced settlement, especially under shallow footings (Holtz, Kovacs & Sheahan, 2011).

Unconfined compressive strength (UCS), on the other hand, is commonly applied to fine- grained cohesive soils to obtain the undrained strength (Su = qu/2). Undrained shear strength governs the short-term behavior of foundations in saturated clays, indicating stiffness, compressibility, and load-bearing capacity (Das & Sobhan, 2013). Su values between 25–75 kPa are typical for soft to medium clays in deltaic environments (Lambe & Whitman, 1969). The Niger Delta region, characterized by alternating soft clays, silts, organic layers, and loose-to-dense sands, presents significant geotechnical variability, which influences foundation performance (Short & Stauble, 1967; Oyedele & Okoh, 2011., Oyegun & Adeyemo, 2012). Hence, site-specific laboratory testing is essential for reliable engineering design.

Several investigations in the Niger Delta have shown that shallow clay deposits generally exhibit low to moderate UCS values, while deeper sections commonly contain dense sand layers that serve as reliable bearing strata for deep foundation systems (Adebayo & Olofinyo, 2017; Akpokodje, 1987).

The soils at **Gbarian, Yenagoa**, align with these regional observations, presenting a profile of dense to very dense sands at depths >9 m and moderate-strength silty clays in the upper layers, where dense sands at deeper horizons provide competent layers for spread footings or piles, while the upper clayey horizons may require improvement depending on loading conditions. Literature consistently emphasizes that accurate interpretation of shear strength profiles is critical for designing safe and economical foundations in such coastal terrains. The implications for foundation design depend on the strength, density, and compressibility of these strata.

4.0 Methodology

4.1 Field Investigation

Two boreholes were drilled using the rotary wash boring method (water circulation) to depths sufficient to encounter competent bearing strata, reaching up to 25 m. The drilling process employed drill rods, circulating drilling water or mud, casing where necessary for unstable formations, and removal of cuttings through annular flow to a mud tank or settling pit. Soil samples were obtained at predetermined depths—3, 6, 9, 14, 18, and 21 m—and prepared for laboratory testing.

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4.2 Sample Collection and Laboratory Testing

During drilling, disturbed and undisturbed samples were retrieved. Laboratory tests were conducted in accordance with ASTM/BS standards:

- Direct shear test (for non-cohesive soils) – BS 1377: Part 7
- Unconfined compressive strength (UCS) test (for cohesive soils) – BS 1377: Part 7
- Consolidation test (for cohesive soils) – ASTM D 4235

4.3 .Bearing Capacity Estimation:

Test results were then used to derive strength and compressibility parameters, assess bearing capacity and settlement potential, and provide foundation recommendations.
Empirical correlations using UCS and direct shear parameters, with a factor of safety of 3 applied in line with typical engineering practice (Das, 2013). Ultimate bearing capacity for shallow strip footings on undrained clay was estimated using Terzaghi's bearing capacity formula (Terzaghi, Peck & Mesri, 1996).

Undrained Shear Strength (S_u):

Unconfined compressive strength tests **(q_u)** divided by 2 give an approximate Undrained Shear Strength (S_u).

$S_u = q_u / 2$ equ (1)

Terzaghi undrained strip footing formula for ultimate capacity (q_{ult}) For cohesive (undrained) soil, Terzaghi (for a strip footing) gives:

equ (2)

	q_{ult}	=	$N_c \cdot S_u$
where	N_c	=	5.14.

Allowable (working) bearing pressure (q_{allow}):

Common conservative factor-of-safety for working allowable pressures is **FS = 3** (typical for serviceability/working design on foundations):

$q_{allow} = q_{ult} / FS$ equ (3)

5.0 Results and Discussion

5.1 Direct Shear Test (apparent cohesion c, and angle of shearing resistance φ):

For borehole (BH01) at 9.0 m: Apparent Cohesion is 2.2 kPa (effectively negligible, as expected for sands), with Angle of Shearing resistance (φ) = 41.8°**,** at 18.0 m: Apparent Cohesion c = 2.2 kPa, with Angle of Shearing resistance (φ) = 43.2°, respectively. Soil description **(Table 1a & 1b).**
For borehole (BH02) at 14.0 m: Apparent Cohesion is 1.1 kPa (effectively negligible, as expected for sands), with Angle of Shearing resistance (φ) = 40.7°**,** at 21.0 m: Apparent Cohesion c = 0.0 kPa, with Angle of Shearing resistance (φ) = 45.9°, respectively. Soil description **(Table 2a & 2b).**

Interpretation:

These φ-values are very high and represent a powerful**,** very dense sand layer, well-suited for high bearing capacity foundations or pile support. The increase from 41.8° to 43.2° for BH01 and 45.9° at 21 m for BH02 indicates greater compaction, particle interlocking, and overburden confinement, showing progressive densification of the soil profile. This horizon presents an excellent bearing layer with minimal settlement potential.

Engineering significance:

- Such high friction angles imply high bearing capacity, low compressibility, and good resistance to shear failure.
- These sand layers can comfortably support shallow or deep foundations depending on the overlying weaker soils.

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Table 1a: DETERMINATION OF SHEAR STRENGTH BY DIRECT SHEAR (in the small shear box apparatus). Set of stage test – tested in accordance with BS 1377:1990: Part 7: Clause 4 (procedure 4.5.4) TEST REPORT – SUMMARY			
Project Location: Gbarian Clan, Yenagoa. Project Reference: Sample Depth: 9m Borehole number: BH01 Sample Type: Compacted cohesionless Sample number: Specimen Orientation: Horizontal Sample Description: FINE SAND WITH SILT, LIGHT YELLOWISH BROWN, DENSE, POORLY GRADED. (N=39)			
Particle Density (Mg/m^3): 2.00 (Assumed). Specimens tested submerged			
INITIAL CONDITIONS	**SPECIMEN 1**	**SPECIMEN 2**	**SPECIMEN 3**
Specimen Depth (m)	**9.00**	**9.00**	**9.00**
Height (mm)	**20.0**	**20.0**	**20.0**
Diameter (mm)	**60.0**	**60.0**	**60.0**
Area (mm^2)	**2827.4**	**2827.4**	**2827.4**
Moisture content (measured)(%)	**213**	**279**	**235**
Moisture content (trimmings)(%)	**24**	**24**	**24**
Bulk density (Mg/m^3)	**2.00**	**2.00**	**2.00**
Dry density (Mg/m^3)	**0.64**	**0.53**	**0.60**
Void Ratio	**2.129**	**2.793**	**2.348**
Degree of Saturation (%)	**200**	**200**	**200**
Voids ratio at the end of consolidation	**2.129**	**2.793**	**2.348**
SHAERING			
Rate of displacement(mm/min)	**0.300000**	**0.300000**	**0.300000**
CONDITION AT PEAK SHEAR STRESS			
Normal Stress (KPa)	**69**	**139**	**208**
Shear Stress (KPa)	**64**	**130**	**167**
Horizontal displacement (mm)	**2.97**	**3.25**	**3.68**
Vertical displacement (mm)	**0.221**	**0.230**	**0.230**
Apparent Cohesion (KPa)		**2.2**	
Angle of Shearing resistance (^{0})		**41.8**	

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Table 1b: DETERMINATION OF SHEAR STRENGTH BY DIRECT SHEAR (in the small shear box apparatus). Set of stage test – tested in accordance with BS 1377:1990: Part 7: Clause 4 (procedure 4.5.4) TEST REPORT – SUMMARY			
Project Location: Gbarian Clan, Yenagoa. Project Reference: Sample Depth: 18.0m Borehole number: BH01 Sample Type: Compacted cohesionless Sample number: Specimen Orientation: Horizontal Sample Description: FINE SAND WITH SILT, OLIVE YELLOW, VERY DENSE, POORLY GRADED. (N>50)			
Particle Density (Mg/m^3): 2.00 (Assumed). Specimens tested submerged			
INITIAL CONDITIONS	**SPECIMEN 1**	**SPECIMEN 2**	**SPECIMEN 3**
Specimen Depth (m)	**18.0**	**18.0**	**18.0**
Height (mm)	**20.0**	**20.0**	**20.0**
Diameter (mm)	**60.0**	**60.0**	**60.0**
Area (mm^2)	**2827.4**	**2827.4**	**2827.4**
Moisture content (measured)(%)	**222**	**273**	**199**
Moisture content (trimmings)(%)	**13**	**13**	**13**
Bulk density (Mg/m^3)	**2.00**	**2.00**	**2.00**
Dry density (Mg/m^3)	**0.62**	**0.54**	**0.67**
Void Ratio	**2.216**	**2.731**	**1.986**
Degree of Saturation (%)	**200**	**200**	**200**
Voids ratio at the end of consolidation	**2.216**	**2.864**	**2.016**
SHAERING			
Rate of displacement(mm/min)	**0.300000**	**0.300000**	**0.300000**
CONDITION AT PEAK SHEAR STRESS			
Normal Stress (KPa)	**69**	**139**	**208**
Shear Stress (KPa)	**78**	**133**	**197**
Horizontal displacement (mm)	**2.09**	**2.68**	**2.86**
Vertical displacement (mm)	**0.214**	**0.223**	**0.119**
Apparent Cohesion (KPa)		**2.2**	
Angle of Shearing resistance (^{0})		**43.2**	

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Table 2a: DETERMINATION OF SHEAR STRENGTH BY DIRECT SHEAR (in the small shear box apparatus) **Set of stage test – tested in accordance with BS 1377:1990: Part 7: Clause 4 (procedure 4.5.4)** **TEST REPORT – SUMMARY**			
Project Location: Gbarian Clan, Yenagoa. **Project Reference:** **Sample Depth: 14.0m** **Borehole number: BH02** **Sample Type: Compacted cohesionless** **Sample number:** **Specimen Orientation: Horizontal Sample** **Description: FINE SAND WITH TRACES OF SILT, LIGHT YELLOWISH BROWN, DENSE, POORLY GRADED. (N=28)**			
Particle Density (Mg/m^3): 2.00 (Assumed). **Specimens tested submerged**			
INITIAL CONDITIONS	**SPECIMEN 1**	**SPECIMEN 2**	**SPECIMEN 3**
Specimen Depth (m)	**14.00**	**14.00**	**14.00**
Height (mm)	**20.00**	**20.00**	**20.00**
Diameter (mm)	**60.00**	**60.00**	**60.00**
Area (mm^2)	**2827.4**	**2827.4**	**2827.4**
Moisture content (measured)(%)	**193**	**163**	**172**
Moisture content (trimmings)(%)	**20**	**20**	**20**
Bulk density (Mg/m^3)	**2.00**	**2.00**	**2.00**
Dry density (Mg/m^3)	**0.68**	**0.76**	**0.73**
Void Ratio	**1.927**	**1.631**	**1.724**
Degree of Saturation (%)	**200**	**200**	**200**
Voids ratio at the end of consolidation	**1.927**	**1.631**	**1.762**
SHAERING			
Rate of displacement(mm/min)	**0.300000**	**0.300000**	**0.300000**
CONDITION AT PEAK SHEAR STRESS			
Normal Stress (KPa)	**69**	**139**	**208**
Shear Stress (KPa)	**70**	**116**	**180**
Horizontal displacement (mm)	**2.07**	**3.04**	**3.61**
Vertical displacement (mm)	**0.123**	**0.202**	**0.138**
Apparent Cohesion (KPa)		**1.1**	
Angle of Shearing resistance (^{0})		**40.7**	

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Table 2b: DETERMINATION OF SHEAR STRENGTH BY DIRECT SHEAR (in the small shear box apparatus) Set of stage test – tested in accordance with BS 1377:1990: Part 7: Clause 4 (procedure 4.5.4) TEST REPORT – SUMMARY			
Project Location: Gbarian Clan, Yenagoa. Project Reference: Sample Depth: 21.0m Borehole number: BH02 Sample Type: Compacted cohesionless Sample number: Specimen Orientation: Horizontal Sample Description: FINE SAND WITH TRACES OF SILT, LIGHT YELLOWISH BROWN, DENSE, POORLY GRADED. (N=32)			
Particle Density (Mg/m^3): 2.00 (Assumed). Specimens tested submerged			
INITIAL CONDITIONS	SPECIMEN 1	SPECIMEN 2	SPECIMEN 3
Specimen Depth (m)	21.00	21.00	21.00
Height (mm)	20.00	20.00	20.00
Diameter (mm)	60.00	60.00	60.00
Area (mm^2)	2827.4	2827.4	2827.4
Moisture content (measured)(%)	221	196	178
Moisture content (trimmings)(%)	14	14	14
Bulk density (Mg/m^3)	2.00	2.00	2.00
Dry density (Mg/m^3)	0.62	0.67	0.72
Void Ratio	2.213	1.964	1.779
Degree of Saturation (%)	200	200	200
Voids ratio at the end of consolidation	2.220	1.982	1.779
SHAERING			
Rate of displacement(mm/min)	0.300000	0.300000	0.300000
CONDITION AT PEAK SHEAR STRESS			
Normal Stress (KPa)	69	139	208
Shear Stress (KPa)	77	144	198
Horizontal displacement (mm)	2.58	3.37	3.04
Vertical displacement (mm)	0.182	0.200	0.141
Apparent Cohesion (KPa)		0.0	
Angle of Shearing resistance (^{0})		45.9	

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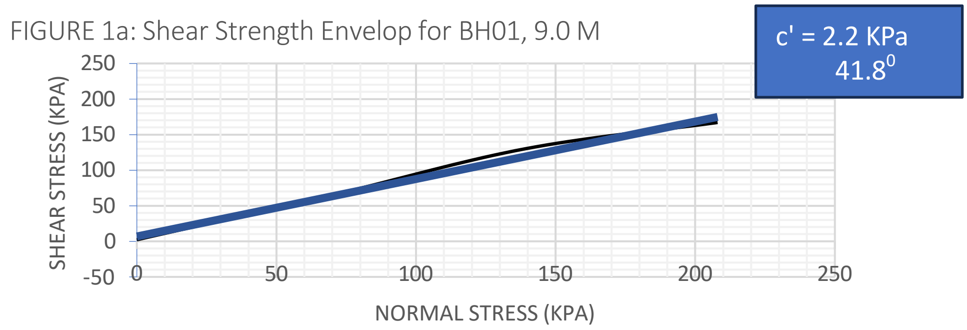

FIGURE 1a: Shear Strength Envelop for BH01, 9.0 M

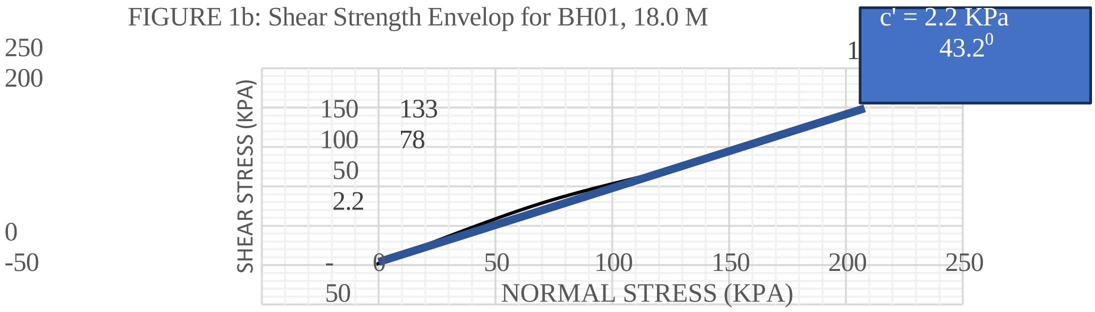

FIGURE 1b: Shear Strength Envelop for BH01, 18.0 M

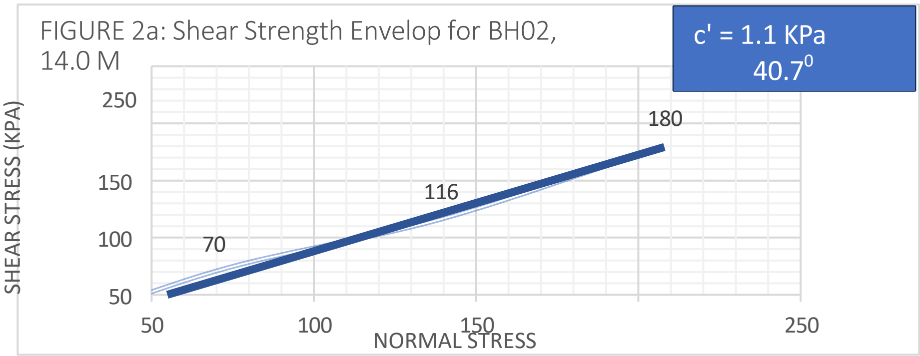

FIGURE 2a: Shear Strength Envelop for BH02, 14.0 M

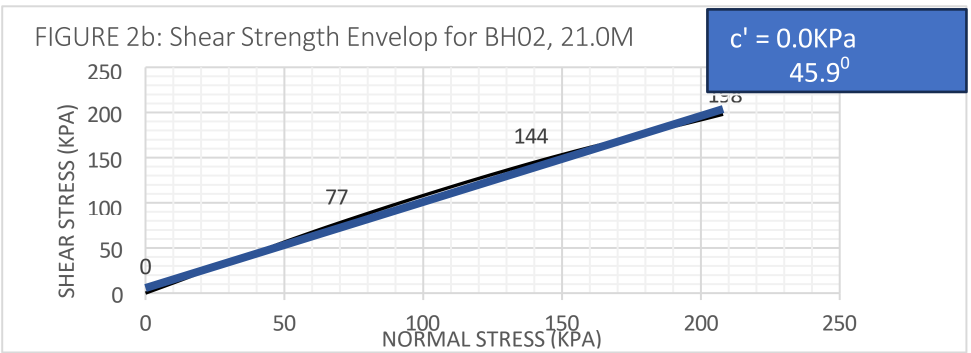

FIGURE 2b: Shear Strength Envelop for BH02, 21.0M

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5.2 Unconfined Compressive Strength (q_u):

For BH01: At 3.0 m depth, **q_u** = 59.06–62 kPa, undrained shear strength, S_u = 29.53 kPa, moisture content = 22.3%, Density ≈ 2.04 t/m³, axial strain at failure = 0.0525 (5.25%). (Table 3a)

That is, Consistency and Strength;

S_u = 29.53 kPa → Soft tofirm clay (standard classification: — Soft: S_u < 25 kPa; Firm: 25–50 kPa)

This indicates clay that is compressible and offers only moderate bearing support.

Stress–strain behavior; shows that failure occurred at 5.25% strain → clay is ductile, showing plastic deformation before failure. The gradual stress drop after peak shows strain-softening, typical of soft clays (figure 3a).

Moisture & Density:

Moisture content (22.3%) is moderate, suggesting the soil is not fully saturated.

Higher density (2.04 t/m³) for clay at this depth often means overburden pressure has caused some consolidation.

For BH01: At 6.0 m depth, **q_u** = 69.53 kPa, undrained shear strength, S_u = 34.765 kPa, moisture content = 43.2%, Density = 1.77 t/m³, axial strain at failure = 0.0275 (2.75%). (Table 3b)

That is, consistency;

S_u = 34.765 kPa ≈ 35 kPa → Firm clay, stronger than at 3 m, and there is considerably increase in strength with depth, commonly due to greater effective stress.

Stress–strain behavior, shows lower strain at failure (2.75%) indicates the clay is stiffer and less ductile at this depth.

Moisture and Density:

Moisture content increases significantly (43.2%), yet strength is higher—indicating: deeper layer is normally consolidated but stronger, possibly finer clay fraction

Lower density (1.77 t/m³) suggests a more saturated, less compact clay.

Engineering implications for BH01 are that clay at 3 m may experience moderate settlement under loads, while clay at 6 m has better shear strength and can support higher loads than the 3 m layer. This layer is suitable for end-bearing piles because of its moderate to firm shear strength; however, some settlement may still occur due to the compressible nature of the clay.

For BH02: At 3.0 m depth, **q_u** = 30.15 kPa, undrained shear strength, S_u = 15 kPa, moisture content = 31.1%, Density = 1.81 t/m³, axial strain at failure = 0.0325 (3.25%). (Table 3c).

That is, consistency;
S_u ≈ 15 kPa → Soft clay, considerably weaker than BH01 at the same depth, and is a highly compressible, low-stiffness layer.

Stress–strain behavior: The peak stress is low with early failure → indicating very low load- carrying capacity.

For BH02: At 6.0 m depth, **q_u** = 45.88 kPa, undrained shear strength, S_u = 22.94 ≈ 23 kPa, moisture content = 33.8%, Density = 1.91 t/m³, axial strain at failure = 0.0375 (3.75%), (Table 3b).

That is, consistency
S_u ≈ 23 kPa → Soft–firm clay but still weaker than BH01 at this depth. The strength increases with depth, from 30.15 → 45.88 kPa between 3 m and 6 m. This trend aligns with natural consolidation from overburden stresses.

The implications for BH02 are that, at 3.0 m depth, there is a high risk of differential settlement for shallow foundations, and it is not suitable for pad or strip footing without soil improvement (e.g., replacement, stabilization). A raft foundation may be possible for light structures, but caution is needed in wet seasons, as shear strength may reduce further. The 6 m layer is better but still not very strong, shallow foundations may not be suitable unless loads are very light. Pile foundations may need to extend deeper than 6 m to reach competent strata.

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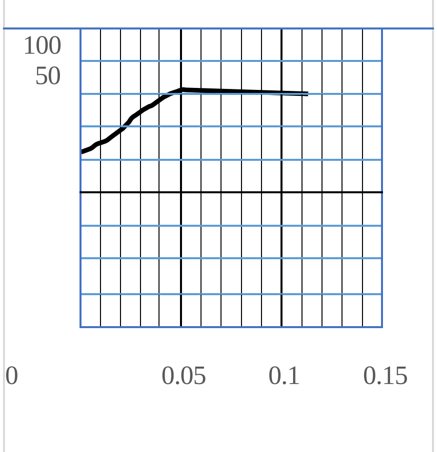
TABLE 3a: UNCONFINED COMPRESSION TEST							
Sample No:				**B/Hole No:**	BH01		
Location:	Gbarian Clan, Yenagoa			**Depth:**	3.0M		
Date:				**Type of material:**	**CLAY (SAMPLE A)**		
BS 1377 – 7:1990:7.2							
Specimen Details		**Initially**	**After Test**				
Diameter D (mm)	38.00		**Wet Mass g**	72.89			
Area A0 (mm^2)	1134.57		**Dry Mass g**	62.47			
Length L0 (mm)	80.00		**w. of container g**	15.70			
Volume V (cm^3)	90765.7		**Water g**	10.42			
Mass (g)	185.24		**Dry mass g**	46.77			
Density (t/m^3)	2.04		**Moisture content %**	22.3			
A_1 = 0.01	A_2 = 4.16						
Machine No:	061000047		**Rate of deformation**			**mm/ min**	
Force device No:	0.01		4.16		**Mean calibration**	**N/division**	**Stress factor KPa/division**
Deformation gauge reading (D1)	**Compression of specimen ΔL = (A_1× D1) Mm**	**Strain ε = ΔL/ L_0**	**Force gauge reading (D2)**	**ε × 100**	**Axial Force P = (A_2×D2) N**	**Corrected area A = $A_0/(1-ε)$ mm^2**	**Axial Stress δ1=(1000 P/A) KPa**
0	**0.0**	**0**	**0**	**0**	**0**	**0**	**0**
20	**0.2**	**0.0025**	**0.5**	**0.25**	**2.08**	**1137.4**	**1.83**
40	**0.4**	**0.0050**	**1.0**	**0.50**	**4.16**	**1140.3**	**3.65**
60	**0.6**	**0.0075**	**2.0**	**0.75**	**8.32**	**1143.1**	**7.28**
80	**0.8**	**0.0100**	**3.0**	**1.00**	**10.40**	**1146.0**	**9.07**
100	**1.0**	**0.0125**	**4.0**	**1.25**	**12.48**	**1148.9**	**10.86**
120	**1.2**	**0.0150**	**5.0**	**1.50**	**16.64**	**1151.8**	**14.45**
140	**1.4**	**0.0175**	**6.0**	**1.75**	**20.80**	**1154.8**	**18.01**
160	**1.6**	**0.0200**	**7.0**	**2.00**	**24.96**	**1157.7**	**21.56**
180	**1.8**	**0.0225**	**9.0**	**2.25**	**29.12**	**1160.7**	**25.09**
200	**2.0**	**0.0250**	**10.0**	**2.50**	**37.44**	**1163.7**	**32.17**
220	**2.2**	**0.0275**	**11.0**	**2.75**	**41.60**	**1166.7**	**35.66**
240	**2.4**	**0.0300**	**12.0**	**3.00**	**45.76**	**1169.7**	**39.12**
260	**2.6**	**0.0325**	**12.5**	**3.25**	**49.92**	**1172.7**	**42.57**
280	**2.8**	**0.0350**	**13.5**	**3.50**	**52.00**	**1175.7**	**44.23**
300	**3.0**	**0.0375**	**14.5**	**3.75**	**56.16**	**1178.8**	**47.64**



DOI: https://doi.org/10.5281/zenodo.17935381

320	**3.2**	**0.0400**	**15.5**	**4.00**	**60.32**	**1181.8**	**51.04**
340	**3.4**	**0.0425**	**16.0**	**4.25**	**64.48**	**1184.9**	**54.42**
360	**3.6**	**0.0450**	**16.5**	**4.50**	**66.56**	**1188.0**	**56.03**
380	**3.8**	**0.0475**	**17.0**	**4.75**	**68.64**	**1191.2**	**57.62**
400	**4.0**	**0.0500**	**17.0**	**5.00**	**70.72**	**1194.3**	**59.22**
420	**4.2**	**0.0525**	**17.0**	**5.25**	**70.72**	**1197.4**	**59.06**
440	**4.4**	**0.0550**	**17.0**	**5.50**	**70.72**	**1200.6**	**58.90**
460	**4.6**	**0.0575**	**17.0**	**5.75**	**70.72**	**1203.8**	**58.75**
480	**4.8**	**0.0600**	**17.0**	**6.00**	**70.72**	**1207.0**	**58.59**
500	**5.0**	**0.0625**	**17.0**	**6.25**	**70.72**	**1210.2**	**58.44**
520	**5.2**	**0.0650**	**17.0**	**6.50**	**70.72**	**1213.4**	**58.28**
540	**5.4**	**0.0675**	**17.0**	**6.75**	**70.72**	**1216.7**	**58.12**
560	**5.6**	**0.0700**	**17.0**	**7.00**	**70.72**	**1220.0**	**57.97**
580	**5.8**	**0.0725**	**17.0**	**7.25**	**70.72**	**1223.3**	**57.81**
600	**6.0**	**0.0750**	**17.0**	**7.50**	**70.72**	**1226.6**	**57.66**
620	**6.2**	**0.0775**	**17.0**	**7.75**	**70.72**	**1229.9**	**57.50**
640	**6.4**	**0.0800**	**17.0**	**8.00**	**70.72**	**1233.2**	**57.35**
660	**6.6**	**0.0825**	**17.0**	**8.25**	**70.72**	**1236.6**	**57.19**
680	**6.8**	**0.0850**	**17.0**	**8.50**	**70.72**	**1240.0**	**57.03**
700	**7.0**	**0.0875**	**17.0**	**8.75**	**70.72**	**1243.4**	**56.88**
720	**7.2**	**0.0900**	**17.0**	**9.00**	**70.72**	**1246.8**	**56.72**
740	**7.4**	**0.0925**	**17.0**	**9.25**	**70.72**	**1250.2**	**56.57**
760	**7.6**	**0.0950**	**17.0**	**9.50**	**70.72**	**1253.7**	**56.41**
780	**7.8**	**0.0975**	**17.0**	**9.75**	**70.72**	**1257.1**	**56.25**
800	**8.0**	**0.1000**	**17.0**	**10.00**	**70.72**	**1260.6**	**56.10**
820	**8.2**	**0.1025**	**17.0**	**10.25**	**70.72**	**1264.1**	**55.94**
840	**8.4**	**0.1050**	**17.0**	**10.50**	**70.72**	**1267.7**	**55.79**
860	**8.6**	**0.1075**	**17.0**	**10.75**	**70.72**	**1271.2**	**55.63**
880	**8.8**	**0.1100**	**17.0**	**11.00**	**70.72**	**1274.8**	**55.48**
900	**9.0**	**0.1125**	**17.0**	**11.25**	**70.72**	**1278.4**	**55.32**
920	**9.2**	**0.1150**	**17.0**	**11.50**	**70.72**	**1282.0**	**55.16**
940	**9.4**	**0.1175**	**17.0**	**11.75**	**70.72**	**1285.6**	**55.01**
960	**9.6**	**0.1200**	**17.0**	**12.00**	**70.72**	**1289.3**	**54.85**
					MAXIMUM AXIAL STRESS		**59.06 KPa**
					AXIAL STRAIN AT FAILURE		**0.0525**

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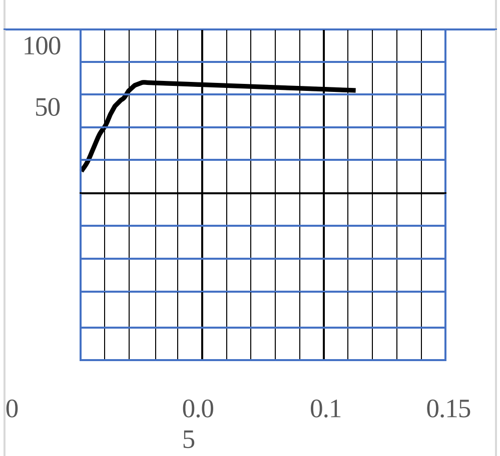
TABLE 3b: UNCONFINED COMPRESSION TEST			
Sample No:		**B/Hole No:**	BH01,
Location:	Gbarian Clan, Yenagoa	**Depth:**	6.0m
Date:		**Type of material:**	**CLAY (SAMPLE A)**
BS 1377 – 7:1990:7.2			

Specimen Details		**Initially**	**After Test**	
Diameter D (mm)	38.00		**Wet Mass g**	43.12
Area A0 (mm^2)	1134.57		**Dry Mass**	34.89
Length L0 (mm)	80.00		**w. of container g**	15.84
Volume V (cm^3)	90765.7		**Water g**	8.23
Mass (g)	160		**Dry mass g**	19.05
Density (mg/m^3)	1.77		**Moisture content %**	43.2
A_1 = 0.01	A_2 = 4.16			



Machine No:	061000047		**Rate of deformation**	mm/ min			
Force device No:	0.01		4.16		**Mean calibration**	**N/division**	**Stress factor KPa/division**

Deformation gauge reading (D1)	**Compression of specimen ΔL = (A_1× D1) Mm**	**Strain ε = ΔL/ L_0**	**Force gauge reading** (D2)	**ε × 100**	**Axial Force P = (A_2×D2) N**	**Corrected area A = A_0/(1-ε) mm^2**	**Axial Stress δ1=(1000 P/A) KPa**
0	**0.0**	**0**	**0**	**0**	**0**	**0**	**0**
20	**0.2**	**0.0025**	**2.0**	**0.25**	**8.32**	**1137.4**	**7.31**
40	**0.4**	**0.0050**	**5.0**	**0.50**	**20.80**	**1140.3**	**18.24**
60	**0.6**	**0.0075**	**8.0**	**0.75**	**33.28**	**1143.1**	**29.11**
80	**0.8**	**0.0100**	**10.0**	**1.00**	**41.60**	**1146.0**	**36.30**
100	**1.0**	**0.0125**	**13.0**	**1.25**	**54.08**	**1148.9**	**47.07**
120	**1.2**	**0.0150**	**15.0**	**1.50**	**62.40**	**1151.8**	**54.17**
140	**1.4**	**0.0175**	**16.0**	**1.75**	**66.56**	**1154.8**	**57.64**
160	**1.6**	**0.0200**	**18.0**	**2.00**	**74.88**	**1157.7**	**64.68**
180	**1.8**	**0.0225**	**19.0**	**2.25**	**79.04**	**1160.0**	**68.10**
200	**2.0**	**0.0250**	**19.5**	**2.50**	**81.12**	**1163.7**	**69.71**
220	**2.2**	**0.0275**	**19.5**	**2.75**	**81.12**	**1166.7**	**69.53**
240	**2.4**	**0.0300**	**19.5**	**3.00**	**81.12**	**1169.7**	**69.35**
260	**2.6**	**0.0325**	**19.5**	**3.25**	**81.12**	**1172.7**	**69.17**
280	**2.8**	**0.0350**	**19.5**	**3.50**	**81.12**	**1175.7**	**69.00**
300	**3.0**	**0.0375**	**19.5**	**3.75**	**81.12**	**1178.8**	**68.82**
320	**3.2**	**0.0400**	**19.5**	**4.00**	**81.12**	**1181.8**	**68.64**
340	**3.4**	**0.0425**	**19.5**	**4.25**	**81.12**	**1184.9**	**68.46**
360	**3.6**	**0.0450**	**19.5**	**4.50**	**81.12**	**1188.0**	**68.28**
380	**3.8**	**0.0475**	**19.5**	**4.75**	**81.12**	**1191.2**	**68.10**
400	**4.0**	**0.0500**	**19.5**	**5.00**	**81.12**	**1194.3**	**67.92**
420	**4.2**	**0.0525**	**19.5**	**5.25**	**81.12**	**1197.4**	**67.74**

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440	**4.4**	**0.0550**	**19.5**	**5.50**	**81.12**	**1200.6**	**67.57**
460	**4.6**	**0.0575**	**19.5**	**5.75**	**81.12**	**1203.8**	**67.39**
480	**4.8**	**0.0600**	**19.5**	**6.00**	**81.12**	**1207.0**	**67.21**
500	**5.0**	**0.0625**	**19.5**	**6.25**	**81.12**	**1210.2**	**67.03**
520	**5.2**	**0.0650**	**19.5**	**6.50**	**81.12**	**1213.4**	**66.85**
540	**5.4**	**0.0675**	**19.5**	**6.75**	**81.12**	**1216.7**	**66.67**
560	**5.6**	**0.0700**	**19.5**	**7.00**	**81.12**	**1220.0**	**66.49**
580	**5.8**	**0.0725**	**19.5**	**7.25**	**81.12**	**1223.3**	**66.31**
600	**6.0**	**0.0750**	**19.5**	**7.50**	**81.12**	**1226.6**	**66.14**
620	**6.2**	**0.0775**	**19.5**	**7.75**	**81.12**	**1229.9**	**65.96**
640	**6.4**	**0.0800**	**19.5**	**8.00**	**81.12**	**1233.2**	**65.78**
660	**6.6**	**0.0825**	**19.5**	**8.25**	**81.12**	**1236.6**	**65.60**
680	**6.8**	**0.0850**	**19.5**	**8.50**	**81.12**	**1240.0**	**65.42**
700	**7.0**	**0.0875**	**19.5**	**8.75**	**81.12**	**1243.4**	**65.24**
720	**7.2**	**0.0900**	**19.5**	**9.00**	**81.12**	**1246.8**	**65.06**
740	**7.4**	**0.0925**	**19.5**	**9.25**	**81.12**	**1250.2**	**64.88**
760	**7.6**	**0.0950**	**19.5**	**9.50**	**81.12**	**1253.7**	**64.71**
780	**7.8**	**0.0975**	**19.5**	**9.75**	**81.12**	**1257.1**	**64.53**
800	**8.0**	**0.1000**	**19.5**	**10.00**	**81.12**	**1260.6**	**64.35**
820	**8.2**	**0.1025**	**19.5**	**10.25**	**81.12**	**1264.1**	**64.17**
840	**8.4**	**0.1050**	**19.5**	**10.50**	**81.12**	**1267.7**	**63.99**
860	**8.6**	**0.1075**	**19.5**	**10.75**	**81.12**	**1271.2**	**63.81**
880	**8.8**	**0.1100**	**19.5**	**11.00**	**81.12**	**1274.8**	**63.63**
900	**9.0**	**0.1125**	**19.5**	**11.25**	**81.12**	**1278.4**	**63.45**
920	**9.2**	**0.1150**	**19.5**	**11.50**	**81.12**	**1282.0**	**63.28**
940	**9.4**	**0.1175**	**19.5**	**11.75**	**81.12**	**1285.6**	**63.10**
960	**9.6**	**0.1200**	**19.5**	**12.00**	**81.12**	**1289.3**	**62.92**
					MAXIMUM AXIAL STRESS		**69.53 KPa**
					AXIAL STRAIN AT FAILURE		**0.0275**

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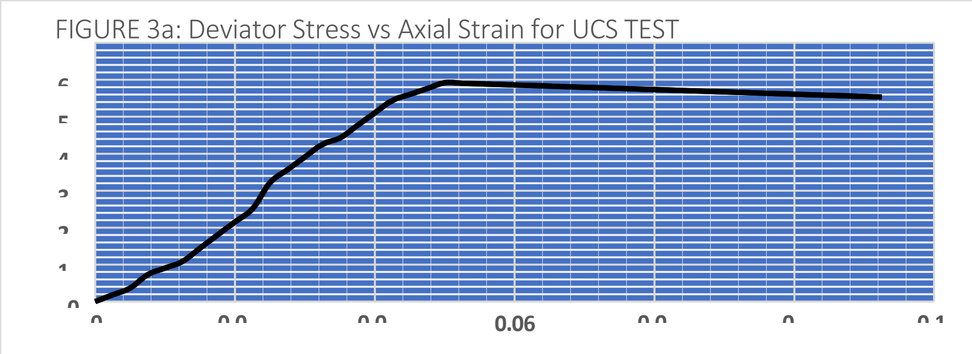

FIGURE 3a: Deviator Stress vs Axial Strain for UCS TEST

AXIAL STRESS OR DEVIATOR STRESS Δ KPA

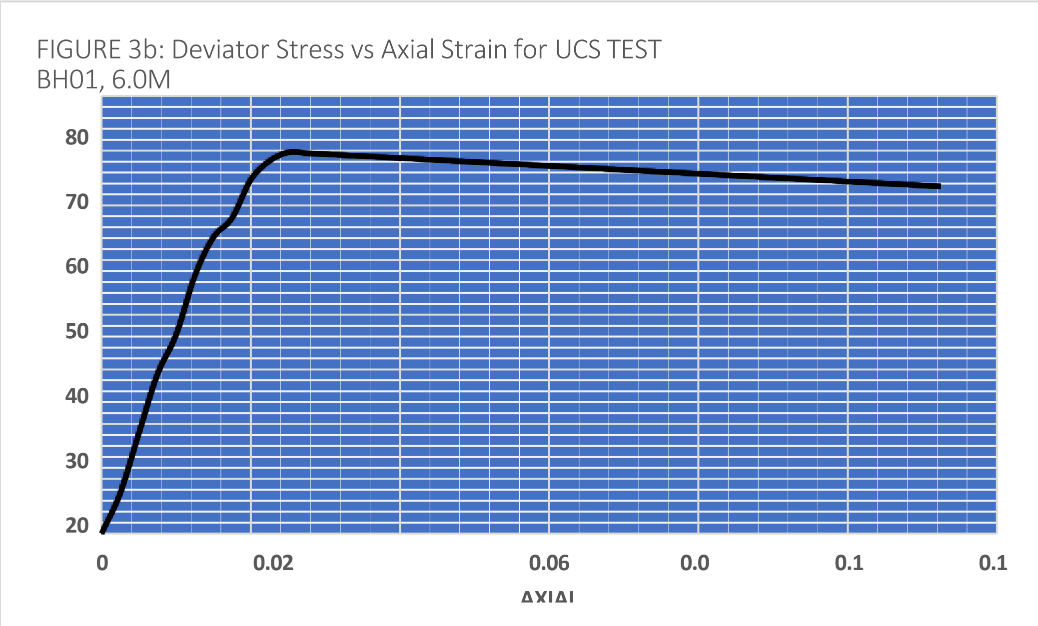

FIGURE 3b: Deviator Stress vs Axial Strain for UCS TEST BH01, 6.0M

AXIAL STRESS OR DEVIATOR STRESS Δ KPA

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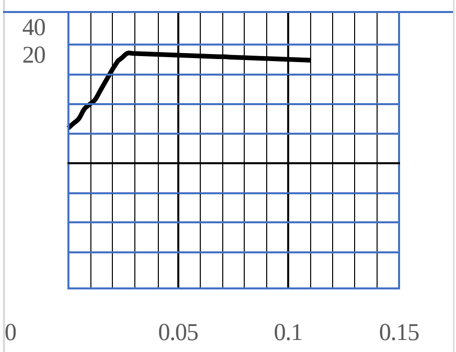
TABLE 4a: UNCONFINED COMPRESSION TEST

Sample No:		**B/Hole No:**	BH 02
Location:	Gbarian Clan, Yenagoa	**Depth:**	3.0 M
Date:		**Type of material:**	**CLAY (SAMPLE A)**

BS 1377 – 7:1990:7.2

Specimen Details		**Initially**	**After Test**	
Diameter D (mm)	38.00		**Wet Mass g**	66.04
Area A_0 (mm^2)	1134.57		**Dry Mass g**	54.11
Length L_0 (mm)	80.00		**w. of container g**	15.71
Volume V (cm^3)	90765.7		**Water g**	11.93
Mass (g)	164.64		**Dry mass g**	38.40
Density (t/m^3)	1.81		**Moisture content %**	31.1
A_1 = 0.01	A_2 = 4.16			



Machine No:	061000047		**Rate of deformation**			**mm/min**	
Force device No:	0.01		4.16		**Mean calibration**	**N/division**	**Stress factor KPa/division**
Deformation gauge reading (D1)	**Compression of specimen ΔL = (A_1× D1) mm**	**Strain ε = ΔL/ L_0**	**Force gauge reading (D2)**	**ε × 100**	**Axial Force P = (A_2×D2) N**	**Corrected area A = A_0/(1-ε) mm^2**	**Axial Stress δ1=(1000P /A) KPa**
0	**0.0**	**0**	**0**	**0**	**0**	**0**	**0**
20	**0.2**	**0.0025**	**0.5**	**0.25**	**2.08**	**1137.4**	**1.83**
40	**0.4**	**0.0050**	**1.0**	**0.50**	**4.16**	**1140.3**	**3.65**
60	**0.6**	**0.0075**	**1.5**	**0.75**	**6.24**	**1143.1**	**5.46**
80	**0.8**	**0.0100**	**2.5**	**1.00**	**10.40**	**1146.0**	**9.07**
100	**1.0**	**0.0125**	**3.0**	**1.25**	**12.48**	**1148.9**	**10.86**
120	**1.2**	**0.0150**	**3.5**	**1.50**	**18.72**	**1151.8**	**12.64**
140	**1.4**	**0.0175**	**4.5**	**1.75**	**22.88**	**1154.8**	**16.21**
160	**1.6**	**0.0200**	**5.5**	**2.00**	**27.04**	**1157.7**	**19.76**
180	**1.8**	**0.0225**	**6.5**	**2.25**	**31.20**	**1160.0**	**23.30**
200	**2.0**	**0.0250**	**7.5**	**2.50**	**33.28**	**1163.7**	**26.81**
220	**2.2**	**0.0275**	**8.0**	**2.75**	**35.36**	**1166.7**	**28.53**

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240	2.4	0.0300	8.5	3.00	35.36	1169.7	30.23
260	2.6	0.0325	8.5	3.25	35.36	1172.7	30.15
280	2.8	0.0350	8.5	3.50	35.36	1175.7	30.08
300	3.0	0.0375	8.5	3.75	35.36	1178.8	30.00
320	3.2	0.0400	8.5	4.00	35.36	1181.8	29.92
340	3.4	0.0425	8.5	4.25	35.36	1184.9	29.84
360	3.6	0.0450	8.5	4.50	35.36	1188.0	29.76
380	3.8	0.0475	8.5	4.75	35.36	1191.2	29.69
400	4.0	0.0500	8.5	5.00	35.36	1194.3	29.61
420	4.2	0.0525	8.5	5.25	35.36	1197.4	29.53
440	4.4	0.0550	8.5	5.50	35.36	1200.6	29.45
460	4.6	0.0575	8.5	5.75	35.36	1203.8	29.37
480	4.8	0.0600	8.5	6.00	35.36	1207.0	29.30
500	5.0	0.0625	8.5	6.25	35.36	1210.2	29.22
520	5.2	0.0650	8.5	6.50	35.36	1213.4	29.14
540	5.4	0.0675	8.5	6.75	35.36	1216.7	29.06
560	5.6	0.0700	8.5	7.00	35.36	1220.0	28.98
580	5.8	0.0725	8.5	7.25	35.36	1223.3	28.91
600	6.0	0.0750	8.5	7.50	35.36	1226.6	28.83
620	6.2	0.0775	8.5	7.75	35.36	1229.9	28.75
640	6.4	0.0800	8.5	8.00	35.36	1233.2	28.67
660	6.6	0.0825	8.5	8.25	35.36	1236.6	28.59
680	6.8	0.0850	8.5	8.50	35.36	1240.0	28.52
700	7.0	0.0875	8.5	8.75	35.36	1243.4	28.44
720	7.2	0.0900	8.5	9.00	35.36	1246.8	28.36
740	7.4	0.0925	8.5	9.25	35.36	1250.2	28.28
760	7.6	0.0950	8.5	9.50	35.36	1253.7	28.21
780	7.8	0.0975	8.5	9.75	35.36	1257.1	28.13
800	8.0	0.1000	8.5	10.00	35.36	1260.6	28.05
820	8.2	0.1025	8.5	10.25	35.36	1264.1	27.97
840	8.4	0.1050	8.5	10.50	35.36	1267.7	27.89
860	8.6	0.1075	8.5	10.75	35.36	1271.2	27.82
880	8.8	0.1100	8.5	11.00	35.36	1274.8	27.74
900	9.0	0.1125	8.5	11.25	35.36	1278.4	27.66
920	9.2	0.1150	8.5	11.50	35.36	1282.0	27.58
940	9.4	0.1175	8.5	11.75	35.36	1285.6	27.50
960	9.6	0.1200	8.5	12.00	35.36	1289.3	27.43
					MAXIMUM AXIAL STRESS		30.15 KPa
					AXIAL STRAIN AT FAILURE		0.0325

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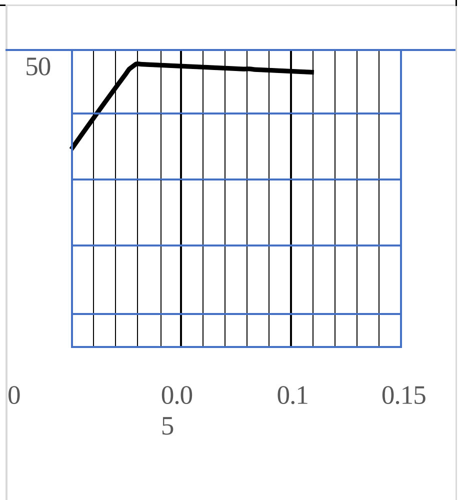
TABLE 4b: UNCONFINED COMPRESSION TEST

Sample No:		**B/Hole No:**	BH 02
Location:	Gbarian Clan, Yenagoa	**Depth:**	6.0M
Date:		**Type of material:**	**CLAY (SAMPLE A)**

BS 1377 – 7:1990:7.2

Specimen Details		**Initially**	**After Test**	
Diameter D (mm)	38.00		**Wet Mass g**	63.17
Area A_0 (mm^2)	1134.57		**Dry Mass g**	51.24
Length L_0 (mm)	80.00		**w. of container g**	15.91
Volume V (cm^3)	90765.7		**Water g**	11.93
Mass (g)	173.45		**Dry mass g**	35.33
Density (t/m^3)	1.91		**Moisture content %**	33.8
A_1 = 0.01	A_2 = 4.16			



Machine No:	061000047		**Rate of deformation**		**mm/ min**
Force device No:	0.01	4.16	**Mean calibration**	**N/division**	**Stress factor KPa/division**

Deformation gauge reading (D1)	**Compression of specimen ΔL = (A_1× D1) mm**	**Strain ε = ΔL/ L_0**	**Force gauge reading (D2)**	**ε × 100**	**Axial Force P = (A_2×D2) N**	**Corrected area A = A_0/(1-ε) mm^2**	**Axial Stress δ1=(1000 P/A) KPa**
0	**0.0**	**0**	**0**	**0**	**0**	**0**	**0**
20	**0.2**	**0.0025**	**0.5**	**0.25**	**2.08**	**1137.4**	**1.83**
40	**0.4**	**0.0050**	**1.5**	**0.50**	**6.24**	**1140.3**	**5.47**
60	**0.6**	**0.0075**	**2.5**	**0.75**	**10.40**	**1143.1**	**9.10**
80	**0.8**	**0.0100**	**3.5**	**1.00**	**14.56**	**1146.0**	**12.70**
100	**1.0**	**0.0125**	**4.5**	**1.25**	**18.72**	**1148.9**	**16.29**
120	**1.2**	**0.0150**	**5.5**	**1.50**	**22.88**	**1151.8**	**19.86**
140	**1.4**	**0.0175**	**6.5**	**1.75**	**27.04**	**1154.8**	**23.42**
160	**1.6**	**0.0200**	**7.5**	**2.00**	**31.20**	**1157.7**	**26.95**
180	**1.8**	**0.0225**	**8.5**	**2.25**	**35.36**	**1160.0**	**30.46**
200	**2.0**	**0.0250**	**9.5**	**2.50**	**39.52**	**1163.7**	**33.96**
220	**2.2**	**0.0275**	**10.5**	**2.75**	**43.68**	**1166.7**	**37.44**
240	**2.4**	**0.0300**	**11.5**	**3.00**	**47.84**	**1169.7**	**40.90**

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260	**2.6**	**0.0325**	**12.5**	**3.25**	**52.00**	**1172.7**	**44.34**
280	**2.8**	**0.0350**	**13.0**	**3.50**	**54.08**	**1175.7**	**46.00**
300	**3.0**	**0.0375**	**13.0**	**3.75**	**54.08**	**1178.8**	**45.88**
320	**3.2**	**0.0400**	**13.0**	**4.00**	**54.08**	**1181.8**	**45.76**
340	**3.4**	**0.0425**	**13.0**	**4.25**	**54.08**	**1184.9**	**45.64**
360	**3.6**	**0.0450**	**13.0**	**4.50**	**54.08**	**1188.0**	**45.52**
380	**3.8**	**0.0475**	**13.0**	**4.75**	**54.08**	**1191.2**	**45.40**
400	**4.0**	**0.0500**	**13.0**	**5.00**	**54.08**	**1194.3**	**45.28**
420	**4.2**	**0.0525**	**13.0**	**5.25**	**54.08**	**1197.4**	**45.16**
440	**4.4**	**0.0550**	**13.0**	**5.50**	**54.08**	**1200.6**	**45.04**
460	**4.6**	**0.0575**	**13.0**	**5.75**	**54.08**	**1203.8**	**44.92**
480	**4.8**	**0.0600**	**13.0**	**6.00**	**54.08**	**1207.0**	**44.81**
500	**5.0**	**0.0625**	**13.0**	**6.25**	**54.08**	**1210.2**	**44.69**
520	**5.2**	**0.0650**	**13.0**	**6.50**	**54.08**	**1213.4**	**44.57**
540	**5.4**	**0.0675**	**13.0**	**6.75**	**54.08**	**1216.7**	**44.45**
560	**5.6**	**0.0700**	**13.0**	**7.00**	**54.08**	**1220.0**	**44.33**
580	**5.8**	**0.0725**	**13.0**	**7.25**	**54.08**	**1223.3**	**44.21**
600	**6.0**	**0.0750**	**13.0**	**7.50**	**54.08**	**1226.6**	**44.09**
620	**6.2**	**0.0775**	**13.0**	**7.75**	**54.08**	**1229.9**	**43.97**
640	**6.4**	**0.0800**	**13.0**	**8.00**	**54.08**	**1233.2**	**43.85**
660	**6.6**	**0.0825**	**13.0**	**8.25**	**54.08**	**1236.6**	**43.73**
680	**6.8**	**0.0850**	**13.0**	**8.50**	**54.08**	**1240.0**	**43.61**
700	**7.0**	**0.0875**	**13.0**	**8.75**	**54.08**	**1243.4**	**43.69**
720	**7.2**	**0.0900**	**13.0**	**9.00**	**54.08**	**1246.8**	**43.38**
740	**7.4**	**0.0925**	**13.0**	**9.25**	**54.08**	**1250.2**	**43.26**
760	**7.6**	**0.0950**	**13.0**	**9.50**	**54.08**	**1253.7**	**43.14**
780	**7.8**	**0.0975**	**13.0**	**9.75**	**54.08**	**1257.1**	**43.02**
800	**8.0**	**0.1000**	**13.0**	**10.00**	**54.08**	**1260.6**	**42.90**
820	**8.2**	**0.1025**	**13.0**	**10.25**	**54.08**	**1264.1**	**42.78**
840	**8.4**	**0.1050**	**13.0**	**10.50**	**54.08**	**1267.7**	**42.66**
860	**8.6**	**0.1075**	**13.0**	**10.75**	**54.08**	**1271.2**	**42.54**
880	**8.8**	**0.1100**	**13.0**	**11.00**	**54.08**	**1274.8**	**42.42**
900	**9.0**	**0.1125**	**13.0**	**11.25**	**54.08**	**1278.4**	**42.30**
920	**9.2**	**0.1150**	**13.0**	**11.50**	**54.08**	**1282.0**	**42.18**
940	**9.4**	**0.1175**	**13.0**	**11.75**	**54.08**	**1285.6**	**42.06**
960	**9.6**	**0.1200**	**13.0**	**12.00**	**54.08**	**1289.3**	**41.95**
					MAXIMUM AXIAL STRESS		**45.88 KPa**
					AXIAL STRAIN AT FAILURE		**0.0375**

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FIGURE 4a: Deviator Stress vs Axial Strain for UCS TEST BH02, 3.0M

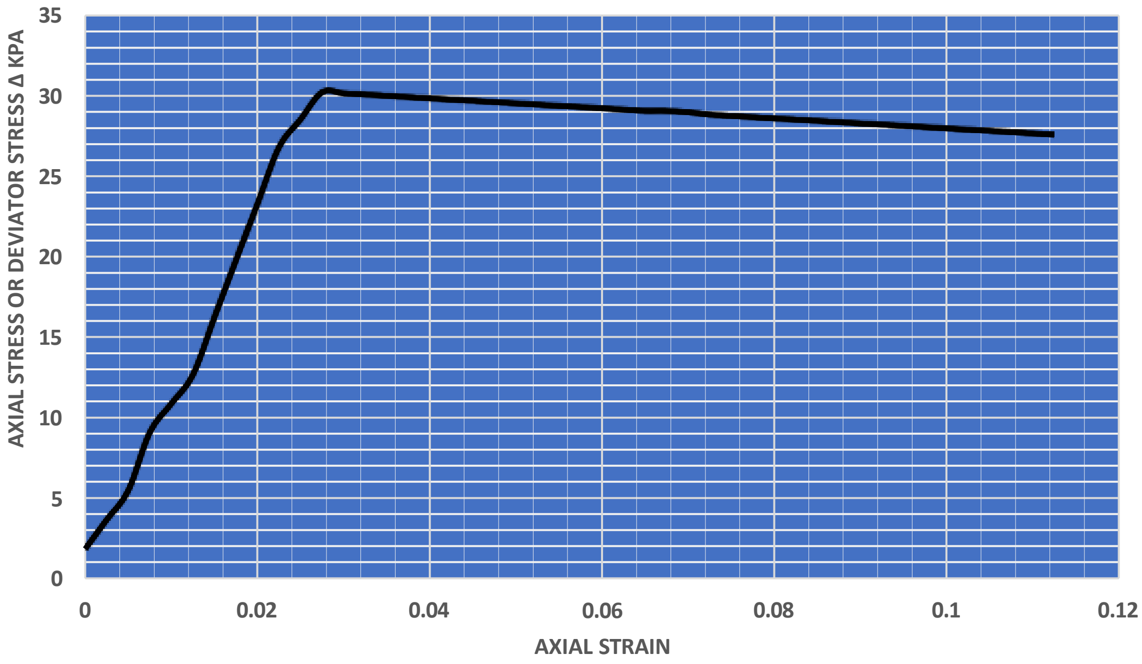
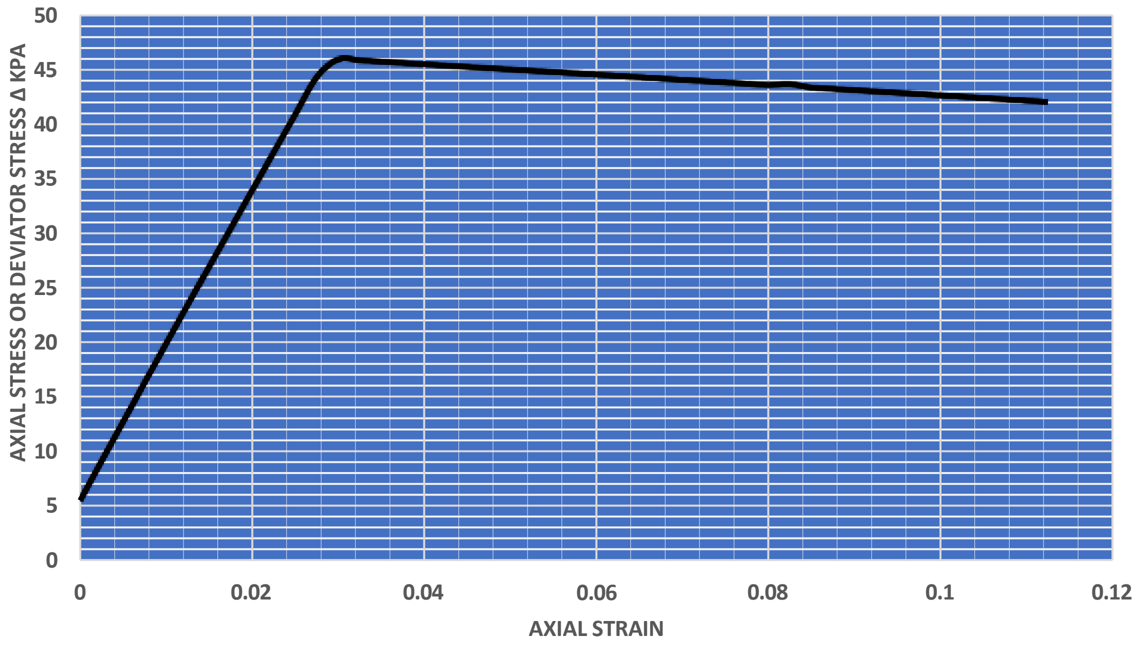


FIGURE 4b: Deviator Stress vs Axial Strain for UCS TEST BH02, 6.0M



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5.3 Consolidation Tests:

Consolidation tests were carried out on undisturbed samples at 3 m depth for BH01 and BH02. Test results show progressive decreases in void ratio with increasing effective stress for both BH01 and BH02. The e–logσ curves (already plotted in Table 5a and 5a) illustrate classical normal compression behavior.

For BH01 at 3 m depth: Normally Consolidated Soft Clay Key indicators:

- Initial void ratio, e_0 = 0.97
- Final void ratio at 1,629.75 kPa = 0.57
- The steep slope indicates high compressibility.
- Compressibility Index C_C = 0.197 → medium compressibility
- Recompression Index C_r = 0.048 → low swelling potential
- Preconsolidation Pressure P_C = 50 kPa → soil is normally consolidated
- Permeability k ≈ 10^{-9} – 10^{-10} cm/s → extremely low permeability
- Coefficient of Consolidation C_V ≈ 2×10^{-5} – 7×10^{-5} cm²/s → slow consolidation

Engineering Interpretation

The BH01 clay at 3 m is weak, soft, and highly compressible. Structures founded at this depth will undergo:

- Significant primary settlement
- Long consolidation periods
- Sensitivity to changes in loading
- Difficulty dissipating pore pressure

This layer is inadequate for shallow foundations.

For BH02 at 3 m depth: Over-consolidated Clay with Moderate Compressibility Key indicators:

- Initial void ratio, e_0 = 1.03
- Final void ratio = 0.75, indicating even higher compressibility than BH01.
- Compressibility Index C_C = 0.211 → medium compressibility (slightly higher than BH01)
- Recompression Index C_r = 0.028 → low elastic rebound
- Preconsolidation Pressure P_C = 95 kPa → soil is over-consolidated
- Permeability k ≈ 10^{-8} – 10^{-9} cm/s → low permeability
- Coefficient of Consolidation C_V ≈ 2×10^{-4} — 3×10^{-4} cm²/s → faster consolidation The higher void ratio in BH02 reflects a more waterlogged and weaker clay deposit.

Engineering Interpretation

BH02 clay is stiffer and undergoes faster settlement compared to BH01 due to higher pre-consolidation pressure. Although compressible, the soil will behave more predictably and settle less under load.

This depth may support light structures, but settlement checks remain necessary.

5.4 Integration of SPT and Consolidation Results

A comparison of SPT and consolidation behaviour reveals:

- Soft clays (upper 0–6 m) with low N-values and high Compressibility Index C_C confirm a highly compressible surface layer.
- Medium sands in the intermediate zone (N = 12–39) provide improved bearing characteristics but still exhibit moderate settlement risk.
- Dense to very dense sands below 12 m provide optimal end-bearing resistance, with settlement negligible under typical building loads.

Hence, the deeper sandy layer is suitable for end-bearing piles because of its moderate to firm shear strength; however, settlement may still occur in the upper clay due to its compressible nature.

5.5 Foundation Engineering Implications

5.5.1 Unsuitability of Shallow Foundations

Due to soft, normally consolidated clay at 3–6 m, shallow foundations would experience:

- Excessive settlement.
- Long consolidation times
- Risk of differential settlement
- Low bearing capacity

5.5.2 Suitability of Deep Foundations

The sand layers below 12 m show:

- High N-values (20–81)
- High stiffness and density
- Low compressibility
- Good drainage

Hence, pile foundations terminating in the dense sand are recommended.

5.5.3 Negative Skin Friction

Because the upper clays will consolidate over time, piles may experience downward drag forces. Engineering mitigation measures include:

- Use of PVC sleeve along pile shafts
- Increasing pile section diameter or reinforcement
- Considering drag load in capacity calculations

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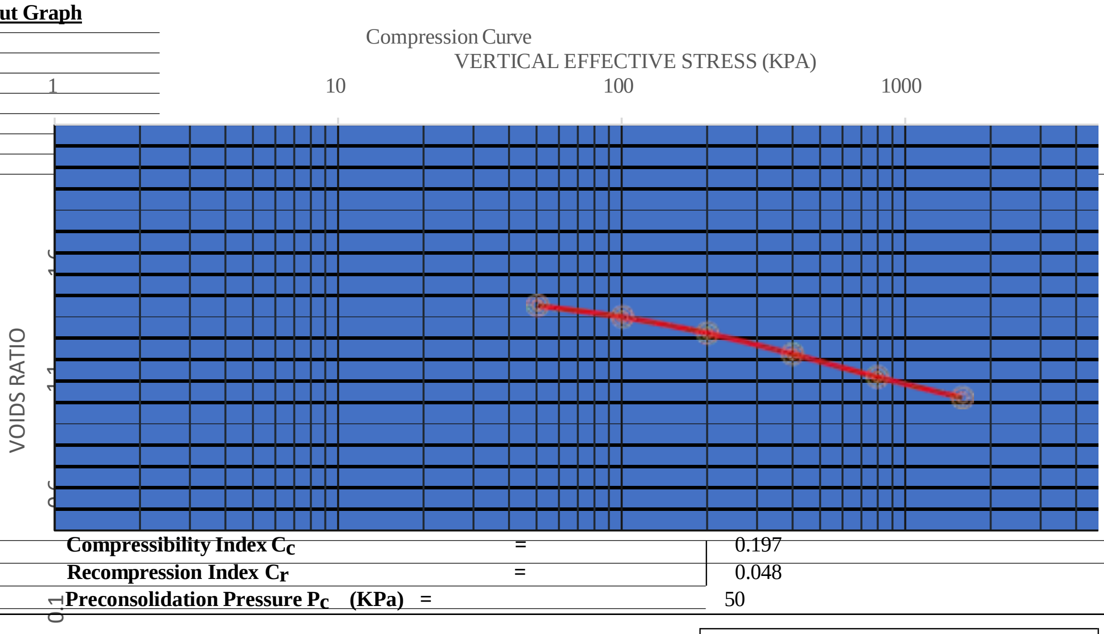
Table 5a: ONE-DIMENSIONAL COMPRESSION TEST – ASTM D2435

	PR0JECT INFORMATION
Name:	
Client:	**J'Marvy Merchandises**
Location:	**Gbarian Clan, Yenagoa**
	Test Details

Weight M (g)	**Thickness H (cm)**	**Moisture Content (%)**	**Wet**	**Dry**
		Before Test		
	2.00	**39.22**		

Vertical Load (KN)	**Effective Stress (KPa)**	**Voids Ratio**	**Coefficient of Consolidation C_V (cm^2/sec)**	**Permeability (cm/sec)**
		Test Results		
0.1	50.93	0.97	0.00003	4.5915E-09
0.2	101.86	0.92	0.00003	1.7306E-09
0.4	203.72	0.85	0.00002	6.2081E-10
0.8	407.44	0.76	0.00003	5.2713E-10
1.6	814.87	0.66	0.00004	3.2456E-10
3.2	1629.75	0.57	0.00007	2.9208E-10

Test Output Graph



Compressibility Index C_C	=	0.197
Recompression Index C_r	=	0.048
Preconsolidation Pressure P_C (KPa)	=	50

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Table 5b: ONE-DIMENSIONAL COMPRESSION TEST – ASTM D2435

PR0JECT INFORMATION		TEST INFORMATION	
Name: No:		**Sample Ref.**	BH 02, 3m
Client:	**J'Marvy Merchandises**	**Sample Condition:**	Undisturbed
Location:	Gbarian Clan, Yenagoa.		

Test Details

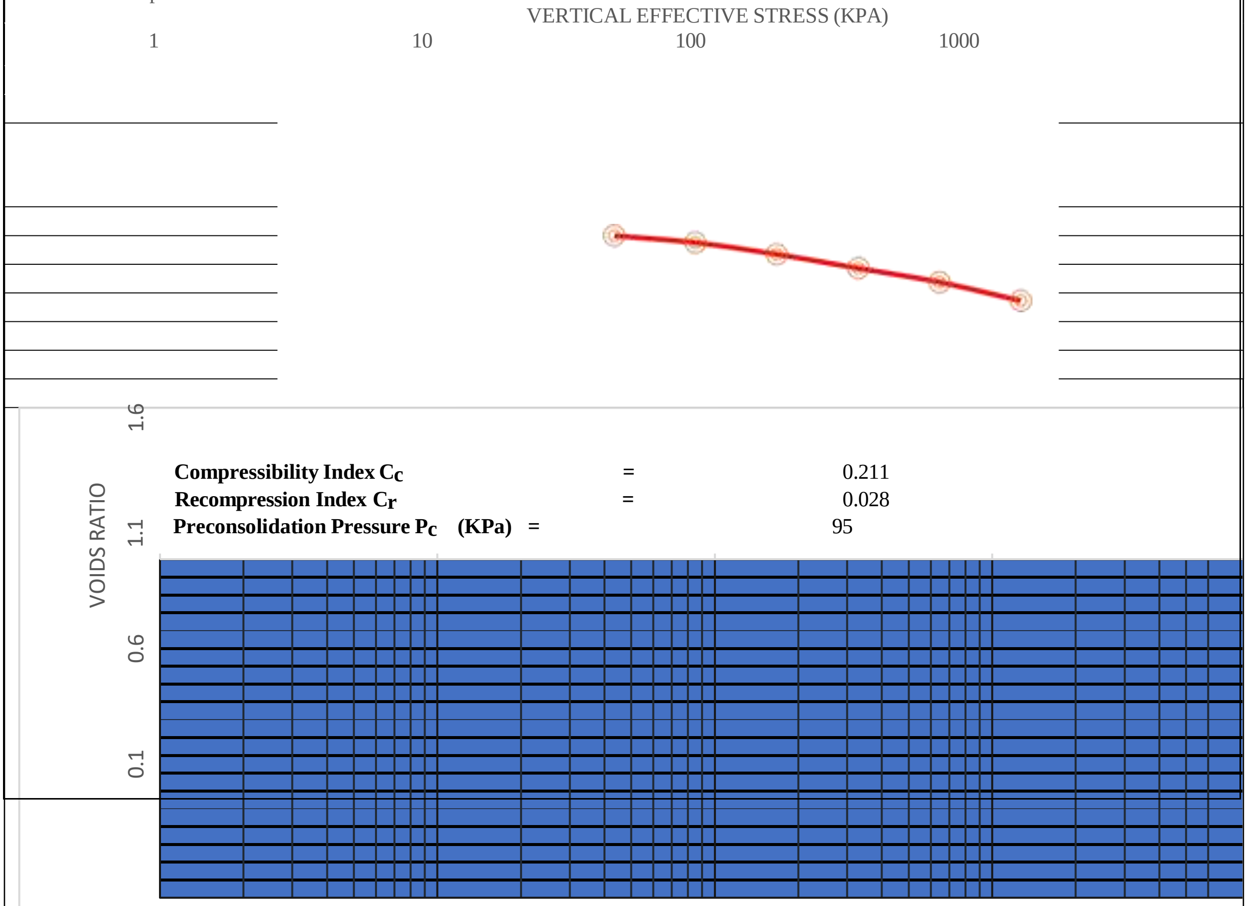
		Before Test			After Test		
Weight	**Thicknes s H e**	**Moistur Density Content**	**Wet Density**	**Dry e**	**Moistur Content**	**Wet Density**	**Dry Density M**
(g)	**(cm)**	**(%)**	**(g/cm^3)**	**(g/cm^3)**	**(%)**	**(g/cm^3)**	**(g/cm^3)**
100.06	2.00	39.22	2.55	1.83	36.26	2.49	1.83

Test Results

Vertical Load (KN)	**Effective Stress (KPa)**	**Voids Ratio**	**Coefficient of Consolidation C_V (cm^2/sec)**	**Permeability (cm/sec)**
0.1	50.93	1.03	0.00020	3.4758E-08
0.2	101.86	1.00	0.00020	1.2037E-08
0.4	203.72	0.95	0.00019	5.8037E-09
0.8	407.44	0.89	0.00022	3.4297E-09
1.6	814.87	0.83	0.00033	2.6213E-09
3.2	1629.75	0.75	0.00029	1.1744E-09

Test Output Graph

Compression Curve



Compressibility Index C_c = 0.211

Recompression Index C_r = 0.028

Preconsolidation Pressure P_c (KPa) = 95

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5.6 Derived Parameters and Allowable Bearing Pressure Estimates

BH01 at 3.0m depth:

- Undrained shear Strength (S_u) = 29.53 KPa.
- Ultimate bearing capacity (q_{ult}) = 151.8 KPa.
- Allowable bearing Pressure (q_{allow}) = 50.6 KPa. BH01 at 6.0 m:
- Undrained shear Strength (S_u) = 34.765 KPa.
- Ultimate bearing capacity (q_{ult}) = 178.7 KPa.
- Allowable bearing Pressure (q_{allow}) = 59.6 KPa. BH02 at 3.0 m:
- Undrained shear Strength (S_u) = 15.075 KPa.
- Ultimate bearing capacity (q_{ult}) = 77.5 KPa.
- Allowable bearing Pressure (q_{allow}) = 25.8 KPa. BH02 at 6.0 m:
- Undrained shear Strength (S_u) = 22.94 KPa.
- Ultimate bearing capacity (q_{ult}) = 117.9 KPa.
- Allowable bearing Pressure (q_{allow}) =39.3 KPa.

6.0.Recommendations

Foundations within the weak clay layer (0–6 m), should be avoided.

The UCS results indicate soft clays with low shear strength. Differential settlement may occur if shallow foundations are placed within the compressible layers

1. Found the structure on the dense/very dense sand layers at ≥9 m depth. Friction angles of 41–46° indicate significantly high bearing capacity.

Recommended foundation types: Driven piles, bored cast-in-situ piles, or deep strip or raft foundations (if clay thickness is removed or improved).

2. If shallow foundations must be used, ground improvement is necessary.

Suitable methods: Preloading/surcharging, Vibro-compaction, Dynamic compaction (where feasible), Stone columns, or Replacement with engineered fill.

3. Maintain adequate drainage around the structure to prevent softening of upper clay layers, ensure proper site grading, surface water control, and subsurface drainage.

6.0 Summary and Conclusion

The geotechnical investigation revealed a stratified profile consisting of soft–firm clay in the shallow depths (0–6 m) underlain by dense to very dense sands from 9 m downward. Direct shear tests recorded high friction angles (40.7–45.9°) across both boreholes, confirming strong load-bearing characteristics of the deeper sandy strata.

UCS values of 59–70 kPa for shallow clays indicate weak, compressible soils that are unsuitable for heavy structural loads. Consequently, placing foundation within this clay layer would pose settlement risks.

The deeper sandy strata (≥9 m), characterized by high φ values and dense packing, are suitable and recommended for bearing structural loads using deep foundations such as driven or bored piles.

Overall, the site is geotechnically favorable for construction, provided foundations bypass the weak upper clays and are anchored in the dense sand layers. Proper drainage and possible ground improvement will further enhance long-term stability.

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