International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 13 Issue 6 ǁ June 2025 ǁ PP. 150-158

Geotechnical Evaluation of Settlement Properties for Foundation Purposes, Aluu, Rivers State, Nigeria.

Nnurum, Ekaette Uzoma [1], Amaechi, Marvellous Obomate[2]
Udoh, Gabriel Cletus [3], *Oghonyon, Rorome[4].
[1,2,4] Department of Geology, University of Port Harcourt, Nigeria
[3] Department of Geology, Akwa Ibom State University, Ikot Akpaden, Nigeria
**Corresponding Author's email: oghonyonrorome@gmail.com*

Abstract
This study evaluates the settlement characteristics of soils in Aluu, Rivers State, Nigeria, to determine their suitability for foundation purposes. Soil samples were collected from three locations which are Umuochi (Location 1, BH1), Umuoko (Location 2, BH2) and Omuokiri (Location 3, BH3). The soil samples were analyzed in the laboratory to assess properties influencing compressibility, swelling potential, and settlement behavior. The lithostratigraphy revealed a profile of fine sandy clay to medium clayey sand within the top 2 meters. Laboratory results indicated moisture content ranging from 17% to 35%, a liquid limit of 31% to 64%, a plastic limit of 18% to 24%, and a plasticity index of 8.2% to 33.5%. Specific gravity values ranged between 2.49 and 2.84, with a bulk density of approximately 1.890 g/cm³. The proportions of silt and clay at Omuochi are 1.3%, sand is 88%. The proportions of clay at Umuoko ranges from 1% to 6.2%, sand ranges from 88% to 99%. The proportions of Silt and Clay at Omuokiri ranges from 1.9% to 2.6%, sand ranges from 89% to 95%. The liquid limit in Omuochi is 56% and Plasticity Index ranges from 25% to 28%. At Umuoko, the liquid limit ranges from 31% to 58% and Plasticity Index ranges from 8.2% to 33.5%. At Omuokiri, the liquid limit ranges from 33% to 64% and Plasticity Index ranges from 15% to 24% showing low to high compressible clay. Settlement testing indicated a settlement rate of 31 mm, with predicted settlement times of 3.3 years for 50% settlement (T_{50}) and 15.3 years for 90% settlement (T_{90}). These findings suggest moderate to high settlement potential, highlighting the need for careful foundation design and soil improvement techniques to enhance stability. This study provides essential geotechnical data to guide foundation planning in Aluu, contributing to safer and more reliable building practices in the region.

Keywords: Geotechnical, Consolidation, Settlement, Foundation, Lithology.

Date of Submission: 01-06-2025 Date of acceptance: 10-06-2025

I. Introduction

Stability and longevity in any structure depend largely on the foundation soils and their behavioral patterns (Nnurum et al. 2025). Natural geotechnical settlement is influential in the determination of foundation bearing capacity in bearing structural loads without excessive or differential settlement. As soils compress and shift as they settle under load, structures lose stability, particularly in the case of non-uniform settlement (differential settlement). Sub-soil geotechnical informations are necessary in designing effectively to construct civil engineering structures to avoid negative environmental impacts or failure in the structure/prevention against post-construction failures ((Oghenero et al, 2014; Ngah & Nwankwoala, 2013; Nwankwoala & Amadi, 2013; Amadi et al., 2012). The occurrence is highly prevalent in the case of Aluu, Rivers State, Nigeria, where soils vary in composition and water table is variable, thereby complicating the foundation designing and construction process. As the soils differ in compositions, i.e., clay, silt, sand, the settlement patterns differ as well, as functions of their compressibility, permeability, as well as their moisture compositions (Nnurum, et al., 2021). Such factors as the one highlighted above are considered by engineers at the foundation designing stage to avoid failure in the structure, crack formation in the structure, or even collapse. The town of Aluu in Rivers State, Nigeria, is growing with many residential and commercial structures under construction. The geology in the area is sedimentary compositions characteristic in keeping with the Niger Delta environment where the variable composition in soils with high water tables as well as flooding during seasons deteriorates foundation stability. The tropical nature in the environment exposed to experience water-sensitive soils as well as clay with the possibility to expand further complicates the settlement in the soils, particularly during as well as after rainfall. This is due to the fact that the settlement behavior of the soils plays an important role in the safe and economical foundation design in the region.

The purpose of the research is to determine the settlement behavior of soils in the area to obtain required data to be used in the foundation in the area. By assessing the settlement behavior and soil carrying capacity, the research aims to advise foundation engineers and builders with the most suitable foundations to be used as well as the methods to be used in the improvement of the soil to avoid settlement hazards.

II. Study Area

Research location for the current work is Aluu, located in the Obio-Akpor Local Government in the Rivers State in the south part of Nigeria. Also in the geologically significant Niger Delta area, with the coordinated position being N4055’8.84840”, N4055’47.05070”, N4055’36.81630”. Aluu possesses special geotechnical as well as environmental conditions which render it an apt location to determine the settlement characteristics of soil in foundation. This section gives the location details of Aluu in full. Aluu is about 15 km in the northwestern direction of Port Harcourt, the state capital, and as such is easily reachable from the state capital. The proximity of Aluu to Port Harcourt has resulted in an escalating housing development as well as business in the village since population growth as well as urbanization drive the need for houses as well as infrastructural growth. The existence in the village of one of the campuses of the University of Port Harcourt has further contributed to the significance of the need for the village development. The existing knowledge about the Niger Delta geology is premised on the work of the following authors (Reyment, 1965; Short & Stauble, 1967; Murat, 1970; Merki, 1970, TKs Abam; 2016, Nnurum et al., 2024) as well as Akpokodje (1979, 1986, 1987, 1989).

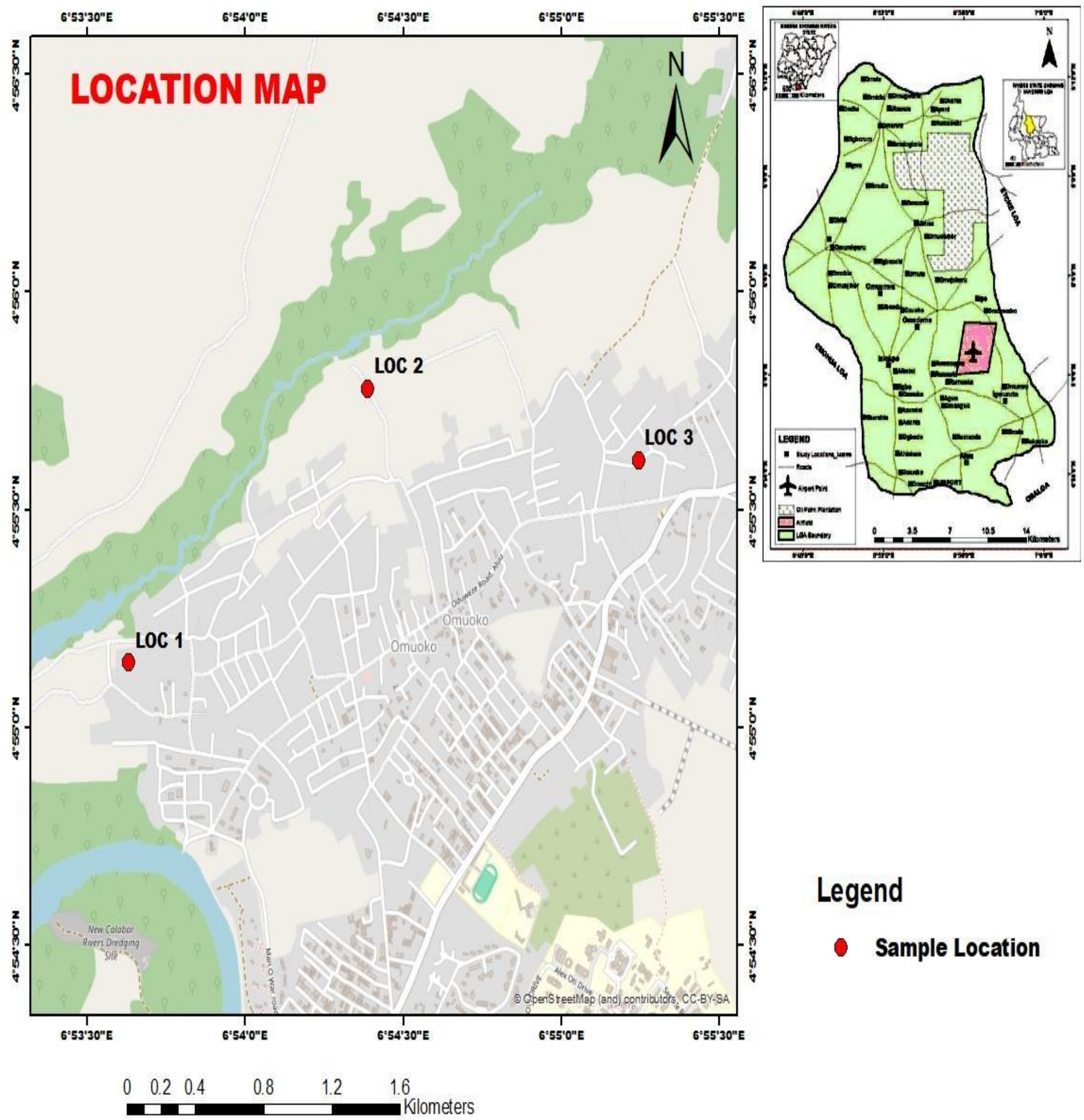

Figure 1 : Location map

III. Materials and Method

Materials and equipment employed in the research of the behavior of soil settlement play a crucial role in the efficient gathering and analysis of the data. They assist in the identification of the determination of the soil properties, field test, and laboratory test. The main material employed in the study is the soil samples which were obtained at intervals from the research site. Equipment used included the Hand Auger, Casagrande Apparatus, Consolidometer (Oedometer), empty containers, specific bottle, measuring cylinder, pipette, permeameter, an electric shaker, the triaxial cylinder, Laboratory Oven, and Weighing Balance. The samples were obtained from the site at the Aluu Community with the geographic location as presented in Table 1. The field test was conducted via the drilling of three (3) borings and the boring was drilled to the depth of 2m. Sampling was carried out using the hand auger as provided in the British standard code for the site investigation, and the sampling was conducted at intervals of every 0.5m. Samples were placed in sample bags and each one of the bags was labeled based on the position.

Table 1: Coordinates of borehole points

LOCATION	LATITUDES (°)	LONGITUDES (°)
BH1 (Umuochi)	4.919125	6.893858
BH2 (Umuoko)	4.929636	6.906448
BH3 (Omuokiri)	4.926893	6.920748

3.1 Statistical Analysis

Series of laboratory tests have been carried out on the samples that were brought from the field. These laboratory tests were performed strictly in agreement with the British Standards (BS 1377 of 1990).

$$\text{Moisture content} = \frac{\text{Mass of water (Mw)}}{\text{Mass of dry soil (Ms)}} \times \frac{100}{1} \quad (1.1)$$

$$\text{Plastic Index} = \text{Liquid Limit} - \text{Plastic Limit} \quad (1.2)$$

$$\textit{Specific Gravity (Gs)} = \frac{\text{Mass of soil particles}}{\text{Mass of equal volume of water}} \quad (1.3)$$

From the curve D_{10}, D_{30}, D_{60} was derived and the Coefficient of uniformity (Cu) was calculated using the formula

$$Cu = \frac{D_{60}}{D_{10}} \quad (1.4)$$

Coefficient of concavity was also calculated using

$$Cc = \frac{D_{30}^2}{D_{60} \times D_{10}} \quad (1.5)$$

Permeability is calculated using Hazens formula

The rate and amount of settlement were finally calculated using the formula

$$\text{Total settlement} = Cc\ (1+eo) \times \text{Log}\ (P) \quad (1.6)$$

Cc = Compression index

H = Thickness of compressible layer

e_o = Initial void ratio

ρ_o = Initial weight of soil

ρ = weight imposed by the superstructure

$$\text{Consolidation settlement} = Mv\ 0.55\ qn \times 1.5\ B \quad (1.7)$$

Mv = Coefficient of volume compressibility

qn = Net foundation pressure

B = Breath of Foundation

$$T_{years} = \frac{T.d^2}{CV} \quad (1.8)$$

d = Thickness

Cv = Coefficient of consolidation

T = constant

From the consolidation graph the following were obtained

- CV (Coefficient of consolidation)
- K (Permeability of the sample)
- MV (Coefficient of volume decreases)

Finally, the graph of void ratio against log of pressure was plotted and the compression index for the soil was obtained.

IV. Results and Discussion

This section presents the results of all the fields and laboratory tests carried out in this research work. All tests were carried out in accordance with BS1377 (1990)

4.1 Lithologic Description

Information was gathered from the field and the laboratory tests to determine the typical stratigraphical profile of the project site. The lithologic description was made possible using samples from the study area, with three (3) boreholes (Figure 1, 2 & 3). The main lithology within the study area is clayey sand underlain by sandy clay.

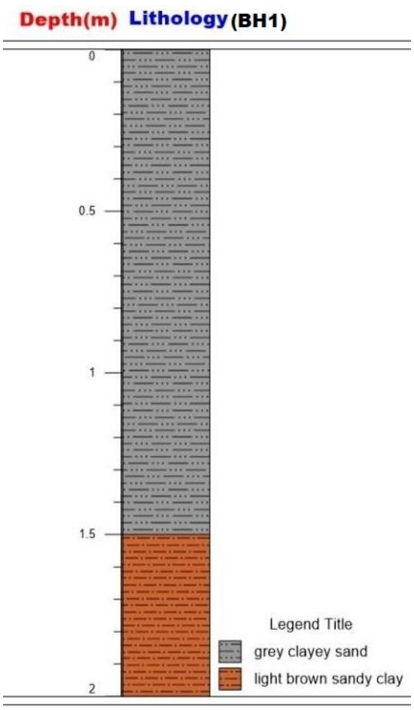

Fig 1: Soil Litholog for BH1

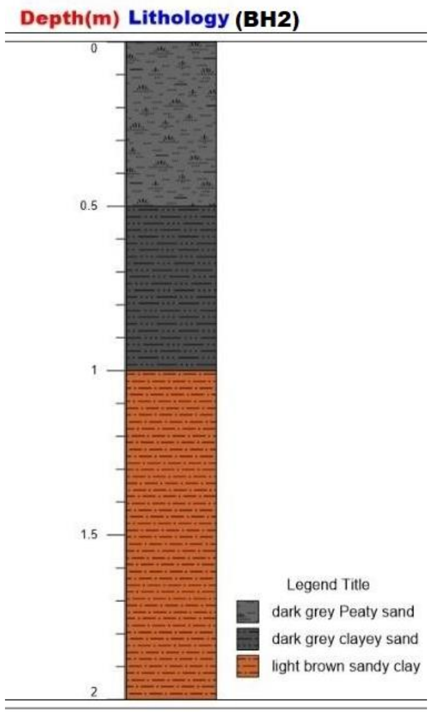

Fig 2: Soil Lotholog for BH2

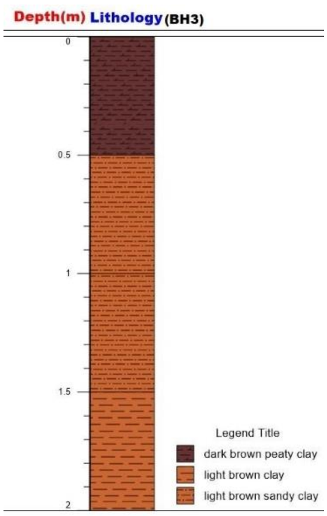

Fig 3: Soil Lotholog for BH3

4.2 Natural Moisture Content

In the study area, the natural moisture content of the soil was determined using equation 1.1. Moisture content varies from depth to depth at the different locations, this is due to its closeness to the stream (Udoh et al, 2023). At Omuochi, the moisture content ranges from 23% to 35%. At Umuoko, it ranges from 17% to 25%. At Omuokiri, it ranges from 21% to 32%. According to ASTM D2216-10 standard moisture content is low (>12%), medium (12-20%), high (>20%). The summary of the moisture content is shown in Fig 4.

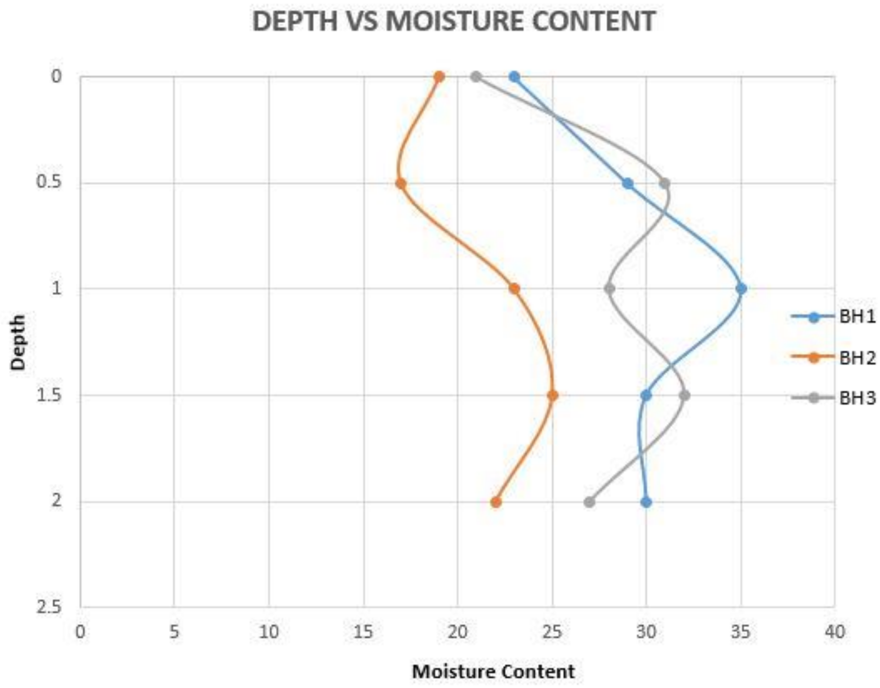

Fig 4: Natural Moisture Content

4.3 Atterberg Limit

The Atterberg Limit tests was used to distinguish between the different types of silt and clays, it is calculated using equation 1.2. The liquid limit in Omuochi is 56% and Plasticity Index ranges from 25% to 28%. At Umuoko, the liquid limit ranges from 31% to 58% and Plasticity Index ranges from 8.2% to 33.5%. At Omuokiri, the liquid limit ranges from 33% to 64% and Plasticity Index ranges from 15% to 24% showing low to high compressible clay. The Liquid limit test is shown in Fig. 5, and from Fig. 6 the soil above the A-line in plasticity chart confirms the presence of clay soil under the Unified Soil Classification System (USCS).

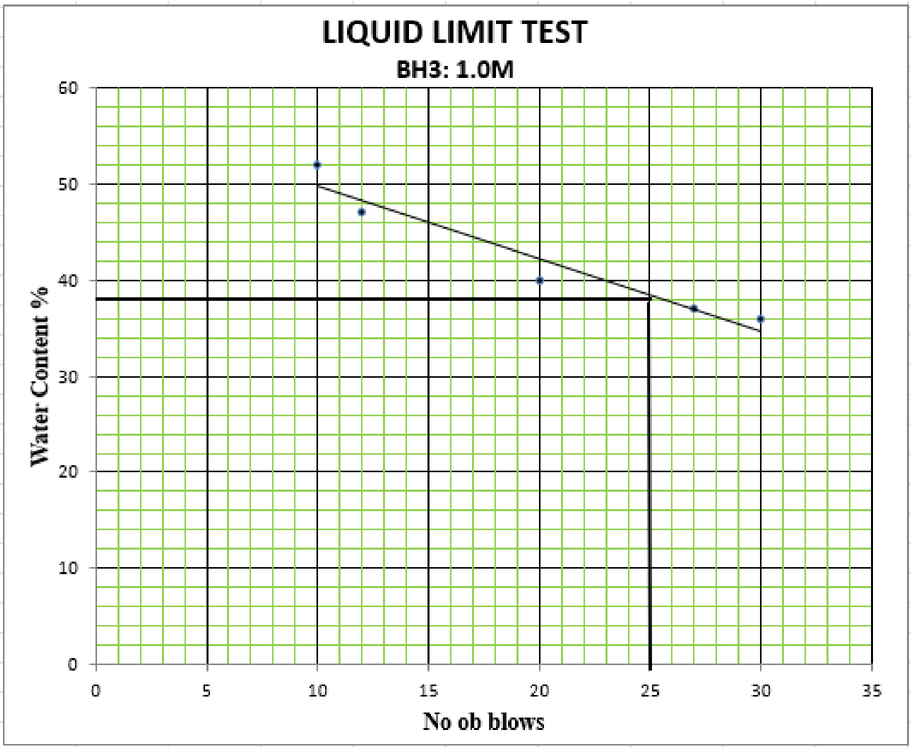

Fig 5: Graph Showing the Liquid Limit Test

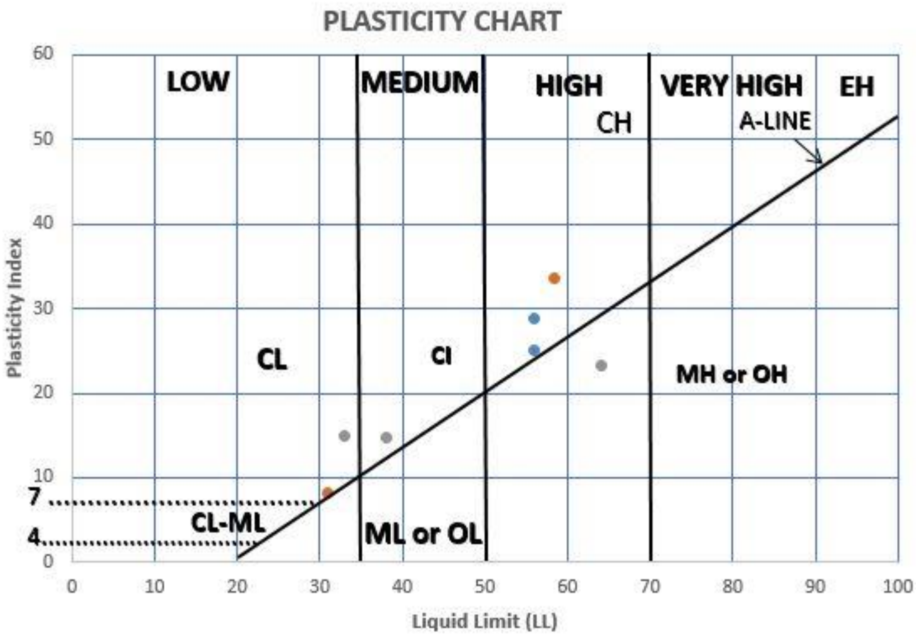

Fig 6: Plasticity Chart

4.4 Particle Size Distribution

Geotechnical properties of non-cohesive soils are mainly controlled by the Particle Size Distribution while those of the cohesive soils are controlled by the clay minerals present in the soil. The proportions of silt and clay at Omuochi are 1.3%, sand is 88%. The proportions of clay at Umuoko ranges from 1% to 6.2%, sand ranges from 88% to 99%. The proportions of Silt and Clay at Omuokiri ranges from 1.9% to 2.6%, sand ranges from 89% to 95%. Generally, the percentage of sands and fines varies at different location but within the given range stated here, and permeability was also derived. Some locations like Umuoko have well graded soils with Cu greater than 6, while others are poorly graded sands. Poorly graded sands often cause high immediate settlement due to large pore spaces, whlie Well-graded soils are better for construction because they compact easily with fewer voids

(Nnurum et al, 2021). The Cu and Cc were derived using equation 1.4 & 1.5, the result of typical particle size distribution tests is also shown in Fig 7 and summarized in Table 2.

PARTICLE SIZE DISTRIBUTION (SIEVING)(ASTM C33)					
SAMPLE	BH 2: 1.0M				
Weight of dry Sample	212.2				
SIEVE SIZE(mm)	SIEVE MASS(g)	Mass of sieve and soil sample (g)	Mass of soil = Mass Retained (g)	Mass passing (9)	%PASSING
2	528.5	542.9	14.4	197.8	93
1	474.1	494.8	20.7	177.1	83
0.5	442.7	490.5	47.8	129.3	61
0.25	463.6	529.2	86.8	82.5	39
0.15	447.9	482.4	34.5	48	23
0.075	490	515.3	26.3	22.7	11

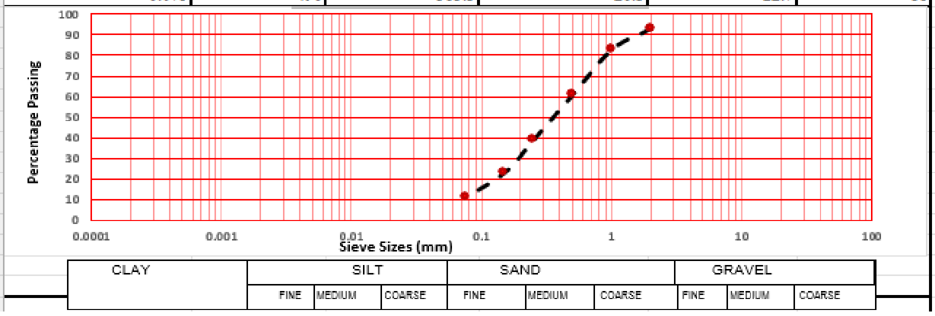

Fig 7: Graph Showing the Sieve Analysis

Table 2: Showing Particle Size Distribution analysis

LOCATION	BOREHOLE	DEPTH	D_{10}	D_{30}	D_{60}	Cu	Cc	K
Umuochi	BH1	TOP SOIL	-	0.25	0.5	-	-	-
Umuoko	BH2	TOP SOIL	0.009	0.2	0.35	38.9	12.7	0.0081
		1M	-	0.2	0.5	-	-	-
		2M	0.12	0.25	0.6	5	0.87	1.44
Omuokiri	BH3	TOP SOIL	0.12	0.25	0.45	3.8	1.2	1.44
		1M	0.1	0.2	0.4	1	4	1
		2M	-	0.28	0.9	-	-	-

4.5 Specific Gravity of Soil

The specific gravity was used to know the ratio of the unit weight of the soil to the unit weight of water. The specific gravity of soils at Umuochi ranges from 2.65 to 2.69 showing the location is mainly of the soil type sand, Umuoko ranges from 2.49 to 2.80, shows the soil type sand, Silt, clay present, at Umuokiri ranges from 2.67 to 2.84 shows the Silty clay and clay with little or no sand. It was derived using equation 1.3.

4.6 Consolidation result

The allowable bearing when calculated using total immediate and final consolidation settlement, shearing loads, and any lateral consolidation, pressure for shallow clay foundations typically produces values that are accurate enough (Meyerhof, 1965). From the data gotten from the consolidation test, graphs were plotted for BH3 (Omuokiri) 0.5Meter. From the graphs the rate and amount of settlement were calculated using the formular in equation 1.6, 1.7 and 1.8. The total settlement is 31 mm, with settlement rates indicating that 50% of the total settlement (T_{50}) will occur in approximately 3.3 years, and 90% (T_{90}) will be reached in about 15.3 years. This means that in Aluu, it will take around 3 years for half of the building's settlement to take place, and roughly 15 years for 90% of it to occur. This values are clearly shown in Table 3. In computing Cv, the "square root of time fitting method" (Taylor, 1948) was adopted. According to Ola (1983) and reaffirmed in Nigerian Building and Road Research Institute (NBRRI, 2010) guidelines, standard consolidation times for typical clayey soils in Nigeria are usually shorter, with most of the primary consolidation expected to occur within the first 5 to 10 years. Additionally, the BS 1377: Part 5 (1990) standard for geotechnical laboratory testing outlines that for cohesive soils, expected settlement durations are generally within similar timeframes under standard loading conditions, supporting these comparative benchmarks. The elevated T_{50} and T_{90} values imply prolonged consolidation and settlement, likely due to low-permeability or high-compressibility soils. This could lead to continued ground movement over the service life of structures, posing risks of differential settlement and long-term structural distress. This study's insights into soil behaviour under load provide essential data for engineers and builders to optimize construction practices and ensure foundation stability in the Aluu area.

Table 3: Result of consolidation test

GEOTECHNICAL PARAMETERS	OMUOKIRI (BH3/0.5M)
Pressure range (KPa)	40 - 320
Compression index (CV)	0.2211
Coefficient of volume compressibility (MV)	2.682×10^{-4}
Coefficient of consolidation (Cc)	0.257
Initial void ratio (e_o)	0.8831
Immediate Settlement (MM)	11
Longterm Settlement (MM)	20
Final Settlement (MM)	31
T_{50} (Years)	3.3
T_{90} (Years)	15.3

V. Conclusion

The lithostratigraphy revealed a profile of fine sandy clay to medium clayey sand within the top 2 meters. The proportions of silt and clay at Omuochi are 1.3%, sand is 88%. The proportions of clay at Umuoko ranges from 1% to 6.2%, sand ranges from 88% to 99%. The proportions of Silt and Clay at Omuokiri ranges from 1.9% to 2.6%, sand ranges from 89% to 95%. The liquid limit in Omuochi is 56% and Plasticity Index ranges from 25% to 28%. At Umuoko, the liquid limit ranges from 31% to 58% and Plasticity Index ranges from 8.2% to 33.5%. At Omuokiri, the liquid limit ranges from 33% to 64% and Plasticity Index ranges from 15% to 24% showing low to high compressible clay. The soil analysis in Aluu indicates variable compressibility and swelling potential, affecting its foundation suitability. The lithostratigraphic profile, Atterberg limits, and settlement tests reveal that soil in the area presents moderate to high settlement risks, requiring careful foundation design and soil stabilization techniques. The settlement timeline, indicated by T_{50} and T_{90} values of 3.3 years and 15.3 years respectively, suggests that the soil in the area consolidates at a slow rate over time. When compared to standard expectations—where T_{50} values typically range between 1 to 2 years and T_{90} between 5 to 10 years for cohesive soils under normal loading conditions—these values are notably high.

VI. Recommendation

To ensure foundation stability and long-term structural integrity in Aluu, Rivers State, deep foundations such as piles or piers are recommended over shallow foundations due to the observed settlement rate of 31 mm and prolonged settlement periods (T_{50} and T_{90} values of 3.3 and 15.3 years respectively). These deep foundations help transfer structural loads to more stable subsurface layers, by passing the compressible upper soils. Alternatively, raft foundations combined with preloading or vertical drains may be considered if shallow solutions are required and proper settlement mitigation strategies are implemented. Additionally, given the wide range of soil plasticity and compressibility—evidenced by liquid limits between 31% and 64%, and plasticity indices from 8.2 to 39—soil improvement techniques should be implemented. In line with National Lime Association guidelines, stabilization is particularly necessary where the plasticity index exceeds 12. Methods such as lime or cement stabilization, preloading, and compaction can significantly enhance soil strength and bearing capacity. Furthermore, in locations where highly plastic soils are encountered, further ground improvement measures such as the use of geosynthetics, sand drains, or vertical drains should be considered to reduce compressibility and improve soil stability. Collectively, these recommendations will support safer and more reliable construction practices in the region.

References

[1]. Abam, T. K. S. (2016). Engineering geology of the Niger Delta. *Journal of Earth Sciences and Geotechnical Engineering*, *6*(3), 65-89.

[2]. Afolabi, O. A., & Gambo, M. (2019). An Evaluation of Soil Settlement Behavior in Coastal areas of Nigeria. International *Journal of Geotechnical Engineering*, 9(3), 231–245. https://doi.org/10.1080/19386362.2019.1657004

[3]. Akpokodje EG (1986). The geotechnical properties of lateritic and non-lateritic soils of southeastern Nigeria and their evaluation for road construction. *Bulletin of the International Association of Engineering Geology*. 33:115-121.

[4]. Akpokodje EG (1987). The engineering-geological characteristics and classification of the major superficial soils of the Niger Delta. *Engineering Geology*. 23(3-4):193-211.

[5]. Amadi, A.N; Eze, C.J; Igwe, C.O; Okunlola, I.A and Okoye, N.O (2012). Architect's and geologist's view on the causes of building failures in Nigeria. Modern Applied Science, Vol.6 (6): 31 – 38.

[6]. British Standard Methods of Test for soils for Civil Engineering Purposes. B.S 1377: Part 2, 1990. Published by the British Standards Institution, pp 8 – 200.

[7]. British Standards Institution (1990). *BS 1377-5:1990 Methods of Test for Soils for Civil Engineering Purposes – Compressibility, Permeability and Durability Tests*. London: BSI.

[8]. Ekeocha, N. E., Oguzie, I. E., & Nwaigwe, K. (2018). Challenges of Foundation Settlement in the Niger Delta and Sustainable Mitigation Strategies. *International Journal of Civil Engineering and Technology*, 9(3), 749-760.

[9]. Igwe, O., & Okogbue, C. O. (2018). Assessment of Settlement Characteristics of Soils for Foundation Engineering in the Southeastern Niger Delta. Geotechnical and Geological Engineering, 26(4), 1131–1143.

[10]. Merki JP. (1970) Structural geology of the Cenozoic Niger Delta. African Geology. University of Ibadan Press, 1970:251-268.

[11]. Meyerhof GG. (1965) Shallow foundations. Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers. 91(2):21-31.

[12]. NBRRI (2010). *Geotechnical Guidelines for Infrastructure Development in Nigeria*. Nigerian Building and Road Research Institute.

[13]. Nnurum, E. U., Olaka, V., & Oghonyon, R. (2025). Geotechnical Properties of Soils in Parts of Eleme, South-Southern Nigeria and its Suitability for Building Foundation. 10(5): 3771-3781, *International Journal of Innovative Science and Research Technology (IJISRT)*, https://doi.org/10.38124/ijisrt/25may2065.

[14]. Nnurum, E. U., Ugwueze, C. U., Tse, A. C., & Udom, G. J. (2021) Soil Gradation Distribution across Port Harcourt, South-eastern Nigeria. *International Journal of Research in Engineering and Science (IJRES).* 9(11): 25-33.

[15]. Nnurum, E. U., Tse, A. C., Ugwueze, C. U., & Chiazor, F. I. (2024). Multicriteria evaluations for sand production potentials: a case study from a producing oil field in the Niger Delta Basin (Nigeria). Scientia Africana, 23(3), 341-354.

[16]. Nnurum, E. U., Ugwueze, C. U., Tse, A. C., & Udom, G. J. (2021). Spatial distribution of Soil Permeability across Port Harcourt Area, Southeastern Nigeria. *Journal of Scientific and Engineering Research,* 8 (10), 84 - 93

[17]. Nwankwoala, H.O and Amadi, A.N (2013). Geotechnical Investigation of Sub-soil and Rock Characteristics in parts of Shiroro-Muya-Chanchaga Area of Niger State, Nigeria. International Journal of Earth Sciences and Engineering, Vol.6(1):8 – 17.

[18]. Nwankwoala, H.O and Warmate, T (2014). Geotechnical Assessment of Foundation Conditions of a Site in Ubima, Ikwerre Local Government Area, Rivers State, Nigeria. International Journal of Engineering Research and Development (IJERD) 9(8): 50 – 63.

[19]. Obiora, D. N., & Amah, E. A. (2021). Geotechnical Investigation of Compressible Soils in the Niger Delta for foundation design. Engineering Geology, 278(3), 104180. https://doi.org/10.1016/j.enggeo.2021.104180

[20]. Oghenero, A.E; Akpokodje, E.G and Tse, A.C (2014). Geotechnical Properties of Subsurface Soils in Warri, Western Niger Delta, Nigeria. Journal of Earth Sciences and Geotechnical Engineering, 4(1): 89 – 102

[21]. Okeke, C. N., Agwu, O. K., & Ezema, N. G. (2016). Settlement evaluation of soil for foundation design in deltaic regions. *Journal of Engineering and Applied Sciences*, 11(9), 6051-6057.

[22]. Okonta, R. A., & Abam, T. K. S. (2022). Plasticity and Compaction Characteristics of Soil in Relation to Foundation Settlement in the Niger Delta region. *Journal of Soil Mechanics and Foundation Engineering*, 14(1), 103–115.

[23]. Ola, S. A. (1983). *Geotechnical properties and behaviour of some Nigerian soils*. Quarterly Journal of Engineering Geology and Hydrogeology, 16(2), 131–144.

[24]. Oluyemi, G. D., & Olusola, A. A. (2011). Groundwater Influences on Foundation Settlement in Tropical Deltaic Regions. *Water Resources Journal*, 22(3), 45-52.

[25]. Reyment RA. (1965) Aspects of the geology of Nigeria: The stratigraphy of the Cretaceous and Cenozoic deposits. Ibadan University Press, 145.

[26]. Short KC, Stäuble AJ. (1967) Outline of geology of the Niger Delta. AAPG Bulletin. 51(5):761-779.

[27]. Taylor DW (1948). Fundamentals of Soil Mechanics. John Wiley & Sons, New York

[28]. Udoh, G. C., Udom, G. J., & Nnurum, E. U. (2023). Suitability of soils for Foundation Design, Uruan, South Southern Nigeria. International Journal of Multidisciplinary research and growth evaluation 4(4), 962-972.

[29]. Udom, G. J., & Esu, E. O. (2017). Impact of Geotechnical Soil Properties on Construction practices in the Niger Delta region. *Nigerian Journal of Technology*, 36(2), 201–210.

[30]. Usman, A., & Ayinla, R. (2015). Soil Stabilization Techniques for Managing Foundation Settlement in Coastal Areas of Nigeria. *Geotechnical Research*, 8(3), 149–162.