International Journal of Scientific Engineering and Science
Volume 9, Issue 6, pp. 29-34, 2025.
ISSN (Online): 2456-7361

Geotechnical Properties of Soils in Parts of Abia State, Nigeria, and Their Suitability as Subgrade Material

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Abstract— *Geotechnical investigation was done in some areas of Umuaku-Isuochi, Umunneochi Local Government Area of Abia State to identify, classify and determine the suitability of the soils as subgrade material. Three (3) geotechnical boreholes were drilled using hand auger to a depth of 2.0 meter at three (3) different locations Ozuohoro-Aguata Umudi (BH1), Umuaku-Central School (BH2) and Umuaku-Secondary School (BH3), top soils were collected and other samples were taken at 0.5 meter intervals. From detailed laboratory analysis carried out, the soil profile and classification were done and the soils at the three sites are predominantly clayey silty sand. The natural moisture content from the three (3) locations has average values of 7.3%, 8.4%, and 10.7%. These values are considerably low values and soils having low moisture content tend to have high shear strength, and this is a property of good subgrade material. The particle size distribution of the soils fall between 66.4-95.8% sand and 4.2 -34.9% fines, with average values of 76.0% and 23.9% respectively. From the Atterberg Limit Test, the Liquid Limit of the soils fall between 25.0-27.0% with average of 26.2% BH1, 22.2-31.1% with average of 26.3% for BH2 and 25.0-32.8 with average of 29.5% for BH3. These values are under 35% and according to Code of Practice for Site Investigation (BS5930, 1981) liquid limit values below 35% are of low plasticity. Hence the soil is of low plasticity which is a property of good subgrade material. The Plastic Limit ranges from 16.8-17.1% with average of 16.9% for BH2 and 15.6-28.7% with average of 19.6% for BH3. These values fall between the plastic ranges (16-35) of Code of Practice for Site Investigation (BS5930, 1981) thus soils in BH2 and BH3 are plastic. The soils in BH1 are non-plastic and this is a property of good subgrade material. The Plasticity Index fall between 12.2-13.9% with average of 13.1% for BH2 and 3.1-15.4% with average of 9.9% for BH3. These values fall between 0-15% in the according to Code of Practice for Site Investigation (BS5930, 1981), plasticity index within this range is of low swelling potential. Hence, the soils in these locations are of low swelling potential. Soils in BH1 has no plasticity index values thus they have little or no swelling potential. From the compaction test carried out in BH1, the maximum dry density (MDD) and optimum moisture content (OMC) are 2036.4kg/m3 and 10.9% respectively, it was inferred that the soils in this location are excellent to good subgrade material and they meet the subgrade standard.*

Keywords— *Geotechnical, Suitability, Plasticity, Moisture Content, Subgrade.*

I. INTRODUCTION

Geotechnical properties of soil play essential roles in the stability of civil engineering structures (buildings, roads, dams, highways, tunnels etc.) (Nnurum et al., 2025). To the structural engineer, earth materials (soil, rock) form a larger portion of construction materials, basically the foundation of structure (Akpokodje, 2001). The stability and sustainability of any structure lies majorly on the geology of the earth material which must be well identified and characterized by the geologists (Nnurum et al., 2025). Disregarding the role of geologists in the identification and characterization of these subsoil properties is a call for trouble. Structural failure especially roads and building are on the high increase in our nation today which has led to loss of lives, properties, wealth and environmental hazards. It has been reported that Nigeria, especially Lagos state has become the world's junk-yard of collapsed building worth millions of naira (Famoroti, 2005). If foundation of a structure is laid on compressible material, settlement will occur with time and eventually lead to collapse. It is saddening that structures which are made to provide shelter, convenience and comfort to humans turn around to be the cause of their death. The advice of a geotechnical firm should be strictly followed on the type of building and construction materials to be used to avoid structural failure (Ekaette et al., 2025). Extreme care should be taken during sampling and analysis of the soil sample in order to obtain best possible accurate result, as sampling error can result to construction error. The suitability of soils for a particular use should be based on its mechanical and index properties and not visual inspection or apparent similarity to other soils (Roy and Bhalla, 2017). Most road failure is majorly traced to use of non-suitable subgrade material. A highway subgrade is the supporting structure on which pavement, the life span of a road is a direct function of its subgrade material, the better compacted the subgrade is, the longer the road will last. It is also pertinent to note that cohesive soil which swell and shrink during wet and dry season respectively is not a good subgrade material. Compaction increases the shear strength, density and bearing capacity of soil and inversely reduces the permeability, porosity, void ratio and settlement.

II. LOCATION OF THE STUDY AREA

The study area (Umuaku-Isuochi) is located in Umunneochi Local Government Area of Abia State, the Southeastern part of Nigeria. Abia state entirely lies within latitudes 4˝48ˊN and 6˝02'N and longitudes 7˝09'E and 7˝09'E of the equator to Greenwich meridian. It was accessed by road. The study area lies within the Anambra basin, a major depocenter of clastic sediments in the southern portion of the Benue Trough (Nwajide, 20005).The Benue Trough is a rift basin in the

International Journal of Scientific Engineering and Science
Volume 9, Issue 6, pp. 29-34, 2025. ISSN (Online): 2456-7361

Central West Africa that exceeds NNE-SSE from about 800km in length and 150km in width (Obaje, 2009). Benue Trough is a major feature in Southeastern Nigeria developed from the rifting of South America and opening of South Atlantic Ocean ate site of triple junction (Burke et al. 1972, Peters 1978, Olade, 1975). Anambra basin is one of the energy-rich inland sedimentary basins in Nigeria. It is a nearly triangular shaped embayment covering about 300km^2 with a total sedimentary thickness of approximately 9km. It is frequently thought of as the youngest formation of the Benue Trough and is located west of the lower Benue Trough. The Niger Delta basin hinge line forms the southern boundary of the basin. It stretches northeastward into the Niger Valley, northward to the Jos highlands, and northeastward into Lafia. The eastern and western limits of the basin are defined by the Abakaliki Anticlinorium and Ibadan massif, respectively. The basin harbors the largest deposit of coal and lignite in Nigeria, which started in Enugu. It could be next to Niger Delta basin in hydrocarbon potential (Nnurum et al., 2024). The basin also holds an estimated gas potential in the region of 10 trillion cubic feet. The Ugwuoba gas fields near Onitsha contain some of the successfully explored gas wells in the basin. Over Fifty (50) billion barrel of crude oil reserves have been reported in some parts of the basin. The geologic formations of the Anambra basins include the Imo Shale, Ameki Ogwashi Asaba Formation, Nsukka Formation, Ajali Formation, Mamu Formation, and Nkporo Formation (Reyment, 1964 and 1965; Hoque, 1977; Ofoegbu, 1985; Agumanu, 1986). Fig 1 below clearly shows map of the study area.

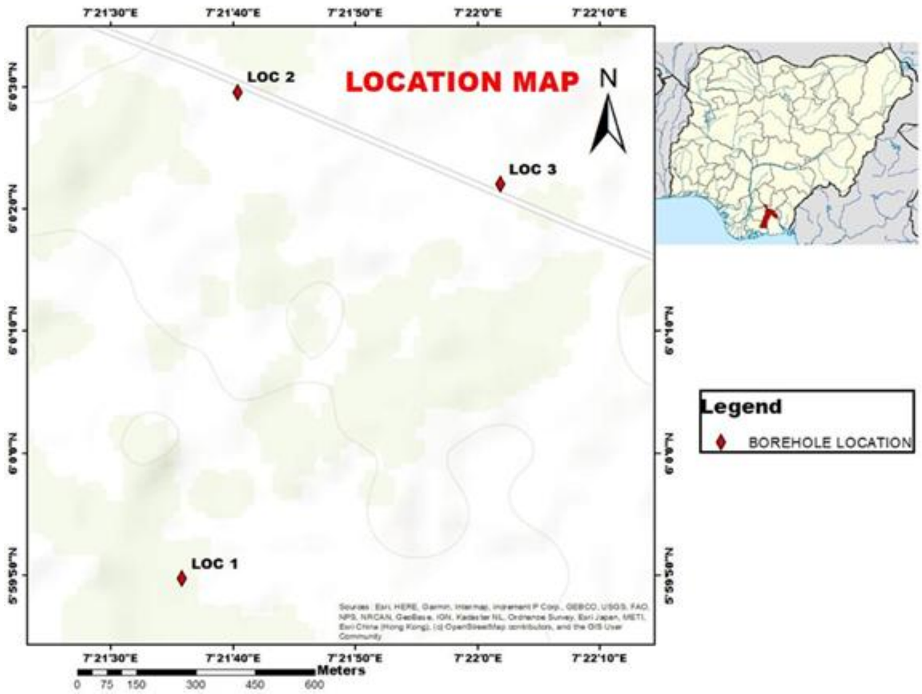

Fig. 1: Map of study area

III. Materials and Methods

Equipment used in the field investigation are;

Field equipment used were Hand Auger, G.P.S (Global Positioning System), Ziploc Bags, Masking Tape, Permanent Marker, Camera. Samples were taken from three (3) different locations which are Ozuohoro-Aguata Umudi (BH1), Umuaku-Central School (BH2) and Umuaku-Secondary School (BH3). Geotechnical boreholes were drilled by pushing and rotating the hand auger into the ground. Top soils were collected and other samples were taken at 0.5meter intervals. The samples were bagged in Ziploc bags and properly labeled. The bore hole terminated at 2.0m depth. Global Positioning System (GPS) coordinates and elevation values were recorded for each location. On site analysis (soil type, colour and textural descriptions) were carried out after which the samples were taken to the laboratory for further analysis.

3.1. Analysis

Laboratory analyses were done in accordance with British Standards BS1377 (1990). The following laboratory analyses were done to ascertain the geotechnical properties of the soils.

The Moisture Content of the soil was calculated thus

Moisture Content (M) = mass of water / mass of dry soil ×100 (1)

The bulk density was computed thus; (y wet) = Mass of wet soil / Volume of mould. (2)

Percentage passing = total mass passing / Total mass × 100 (3)

Plasticity Index was obtained thus

PI = LL – PL (4)

Where; PI = Plastic Limit, PL = Plastic Limit and LL = Liquid Limit

Compaction was calculated from the following formulas

MC = Mw/Ms × 100 (5)

MC = moisture content

Mw = mass of water and
Ms = mass of solid
Dry density (y dry) = y wet/1 + mc (6)

IV. Results and Discussion

The results of the tests carried out to determine the geotechnical properties of soils and their suitability as sub grade material are presented and discussed below.

4.1 Soil Description

The physical description shows that the soil within the study area is predominantly sand with silt and minute clay compositions (clayey silty sand). The textural characteristics range from fine to coarse. The reddish-brown coloration observed at some depth indicates weathering by oxidation, making the soil ferroginized. Detailed description of the various samples was carried out and it was discovered that the soil profile is predominantly clayey silty sand as shown in Fig 2.

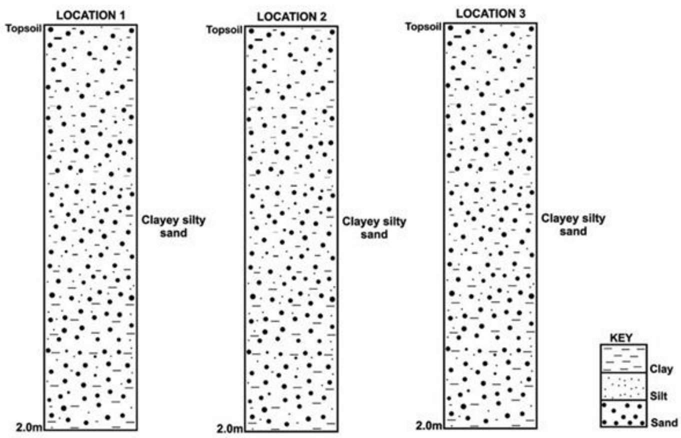

Fig. 2: Soil Profile/Litholog

4.2 Moisture Content Result

The natural moisture content of the soils at BH1 ranges from 5.1 to 8.2% with an average of 7.3%, 5.1 to 11.2% at BH2 with an average of 8.4%, and 8.1 to 12.7% at BH3 with an average of 10.7%, according to the findings. Due to its proximity to the stream, the moisture level differs from depth to depth across the various locations (Udoh et al, 2023). According to Emesiobi (2000), natural moisture content in soil may range from below 5 -50% in gravel and sand. The greater the moisture content in a soil, the more it tends to behave like a liquid, hence less shear strength. The lesser the moisture content of a soil the better its density and shear strength. The moisture content values obtained are considerably low and soils having low moisture content tend to have high shear strength, and this is a property of good subgrade material. It was calculated using equation 1 and plotted against as shown in Fig 3.

4.3 Bulk Density Result

The values of the Bulk Density range from 1314.61 – 1534.01 for BH1 1, 1573.71 – 1701.58 kg/cm^3 for BH2 and 1479.55 – 1637.93 kg/cm^3 for BH3. The bulk density was calculated using equation 2.

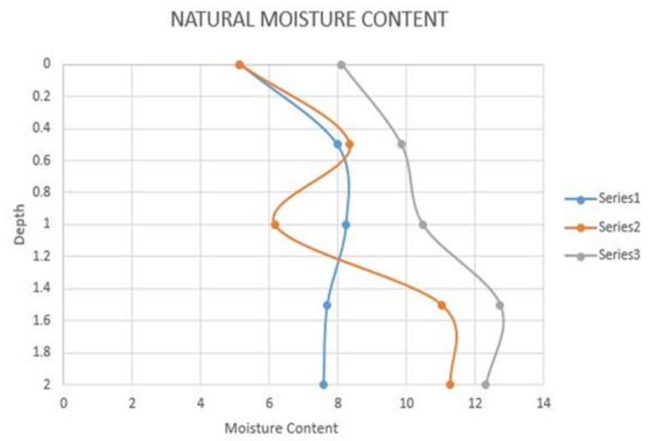

Fig. 3: Summary of Moisture Content Result

4.4 Particle Size Distribution Results

The coefficient of uniformity (CU) at depth 0.5 meter and 1.0 meter at BH1 is less than five, this shows that the soil is poorly graded (Nnurum et al., 2021), those at 1.5 meter and 2.0 meter has coefficient of uniformity values greater than five (5) and this shows that the soils are well graded. Also, the topsoil and soils at 1.0 meter at BH2 have coefficient of uniformity (CU) greater than five (5), thus the soils are well graded. Well-graded soils are preferable for building because they compact easily with fewer voids (Nnurum et al, 2021), whereas badly graded sands frequently result in significant immediate settlement due to large pore spaces. According to American Association for State Highway and Transportation Officials (AASHTO, 1993) classification any material with percentage passing sieve #200 (0.075mm) less or equal to 35%, makes an excellent to good subgrade material. The average result shows that the mass passing sieve #200 (0.075mm) is 23.9% and so the soil makes excellent to good subgrade material. Equation 3 was used to calculate the percentage passing and it is summarized in Table 1.

4.5 Atterberg Limit Result

From the results, the Liquid Limit of the soils fall between 25.0-27.0% with average of 26.2% for BH1, 22.2-31.1% with average of 26.3% for BH2 and 25.0-32.8 with average of 29.5% for BH3. These values are below 35% and according to Code of Practice for Site Investigation (BS5930, 1981) liquid limit values below 35% are of low plasticity. Hence the soil are of low plasticity which is a property of good subgrade material. The Plastic Limit ranges from 16.8-17.1% with average of 16.9% for BH2 and 15.6-28.7% with average of 19.6% for BH3. These values fall between the plastic ranges (16-35) of Code of Practice for Site Investigation (BS5930, 1981) thus soils at BH2 and BH3 are plastic. The soils at BH1 are non-plastic and this is a property of good subgrade material. The Plasticity Index as calculated using equation 4, fall between 12.2-13.9 % with average of 13.1% for BH2 and 3.1-15.4% with average of 9.9% for BH3. These values fall between 0-15% in the according to Code of Practice for Site Investigation (BS5930, 1981), plasticity index within this range is of low swelling potential. the soil's low cohesive value indicates that it has little clay and little binding power (Udoh et al, 2023). Hence, the soils in these locations are of low swelling potential. Soils at BH1 has no plasticity index values thus they have little or no swelling potential, check Table 2 for the summary.

TABLE 1: Summary of Particle Size Distribution results

Boreholes	Depth (M)	% passing sieve Diameter (mm)						% fine	% sand	CU	Cc
BH1		2	1	0.425	0.250	0.150	0.063				
	Topsoil	100	97.5	72.3	44.9	34.6	13.7	20.9	79.1		
	0.5	100	97.3	72.8	45.3	24.2	19.1	19.1	80.9	4.3	0.8
	1.0	100	96.7	66.5	35.2	11.9	4.2	4.2	95.8	2.8	0.9
	1.5	100	96.7	68.5	41.0	24.1	15.8	15.8	84.2	5.3	1.3
	2.0	100	97.3	70.9	43.8	29.1	17.3	17.3	82.3	17.5	3.7
BH2	Topsoil	99.9	98.4	78.6	50.3	31.4	16.4	16.4	83.5	7.8	1.2
	0.5	99.9	98.5	82.5	61.2	45.1	33.2	33.3	66.6		
	1.0	100	99.3	79.4	54.9	32.2	18.2	18.2	81.8	5.8	0.3
	1.5	99.0	95.4	75.3	59.0	44.8	32.7	32.7	66.4		
	2.0	99.9	96.0	71.1	51.2	35.7	20.5	20.5	79.4		
BH3	Topsoil	100	97.7	74.8	51.8	37.6	33.6	33.6	66.4	7.8	0.5
	0.5	100	97.5	74.7	51.7	34.8	30.9	30.9	69.1		
	1.0	100	96.6	72.8	50.6	34.4	27.1	27.1	72.9		
	1.5	100	96.3	73.6	54.5	45.1	34.9	34.9	65.1		
	2.0	100	96.3	72.9	53.3	41.3	33.0	33.0	67.0		
Range of % sand and fine								4.2-34.9	66.4-95.8		
Average of % sand and fine								23.9	76.0		

TABLE 2: Summary of Atterberg Limit Result

Location	Depth(M)	Liquid Limit (LL)%	Plastic Limit (PL)%	Plasticity Index (PI)	Soil Class (USC)
BH1	0.5	25.0	Non-plastic		SM
	1.0	26.0	Non-plastic		SM
	1.5	27.0	Non-plastic		SM
	2.0	26.8	Non-plastic		SM
	Range	25-27	Non-plastic		SM
	Average	26.2	Non-plastic		SM
BH2	0.5	23.0	Non-plastic		SM
	1.0	22.2	Non-plastic		SM
	1.5	29.0	16.8	12.2	SC
	2.0	31.1	17.1	13.9	SC
	Range	22.2-31.1	16.8-17.1	12.2-13.9	SM-SC
	Average	26.3	16.9	13.1	SM-SC
BH3	0.5	28.3	15.6	12.7	SC
	1.0	25.0	16.8	8.4	SC
	1.5	32.0	28.7	3.1	SC
	2.0	32.8	17.4	15.4	SC
	Range	25.0-32.8	15.6 - 28.7	3.1 - 15.4	SC
	Average	29.5	19.6	9.9	SC

N/B: G= Gravels, S= Sand, M= Silt, C= Clay, O= Organic

4.6 Compaction Test Result

According to Emesiobi (2000), soil can be classified as good subgrade material because the maximum dry density (MDD) falls between the ranges of 1958-2121Kg/m^3. Akpokodje (1986) gave maximum dry density (MDD) and optimum Moisture content of compaction tests for good subgrade material to fall between 1700 – 1900kg/m^3 and 7 – 15% respectively. Orthiz and Priesto (1979) specified that maximum dry density of 17.0 – 18.5KN/M3 is suitable as earth fill material. The MDD and OMC for this research as shown in table 3 shows that the soil is suitable as sub-grade and earth fill material. The rating is summarized in Table 4 and the compaction graph is shown in Fig 4. The Compaction results was calculated using equation 2,5 and 6.

TABLE 3: Summary of Compaction Test Result

Location	Depth(m)	MDD(Kg/m^3)	OMC
Ozuohoro-Aguata Umudi	2.0	2036.4	10.9

V. CONCLUSION

The study of soil samples from Umuaku-Isuochi, Umunneochi LGA, Abia State was undertaken to classify the soil and ascertain the suitability of the soil as subgrade or backfill material. The soils are predominantly darkish to reddish brown clayey silty sand. The natural moisture content of the soils at BH1, BH2 and BH3 has average values of 7.3%, 8.4% and 10.7%. The greater the moisture content in a soil, the more it tends to behave like a liquid, hence less shear strength and lesser the moisture content of a soil the better its density and shear strength. The moisture content values obtained are considerably low, thus high shear strength, and this is a property of good subgrade material.

International Journal of Scientific Engineering and Science
Volume 9, Issue 6, pp. 29-34, 2025. ISSN (Online): 2456-7361

TABLE 4: Classification According to Unified Soil Classification System and American Association for State and Highway Transportation Officials

BH	Depth(m)	Soil class (USC)	AASHTO	Soil Description	General rating as Subgrade material
BH1	Topsoil	SM		Silty sands, sand silt mixtures	Excellent to good
	0.5	SM	A-2-4	Silty sands, sand silt mixtures	Excellent to good
	1.0	SM	A-2-4	Silty sands, sand silt mixtures	Excellent to good
	1.5	SM	A-2-4	Silty sands, sand silt mixtures	Excellent to good
	2.0	SM	A-2-4	Silty sands, sand silt mixtures	Excellent to good
BH2	Topsoil	SM		Silty sands, sand silt mixtures	
	0.5	SM	A-2-4	Silty sands, sand silt mixtures	Excellent to good
	1.0	SM	A-2-4	Silty sands, sand silt mixtures	Excellent to good
	1.5	SC	A-2-6	Clayey sands, sand clay mixtures	Excellent to good
	2.0	SC	A-2-6	Clayey sands, sand clay mixtures	Excellent to good
BH3	Topsoil	SM		Silty sands, sand silt mixtures	
	0.5	SC	A-2-6	Clayey sands, sand clay mixtures	Excellent to good
	1.0	SC	A-2-4	Clayey sands, sand clay mixtures	Excellent to good
	1.5	SC	A-2-6	Clayey sands, sand clay mixtures	Excellent to good
	2.0	SC	A-2-6	Clayey sands, sand clay mixtures	Excellent to good

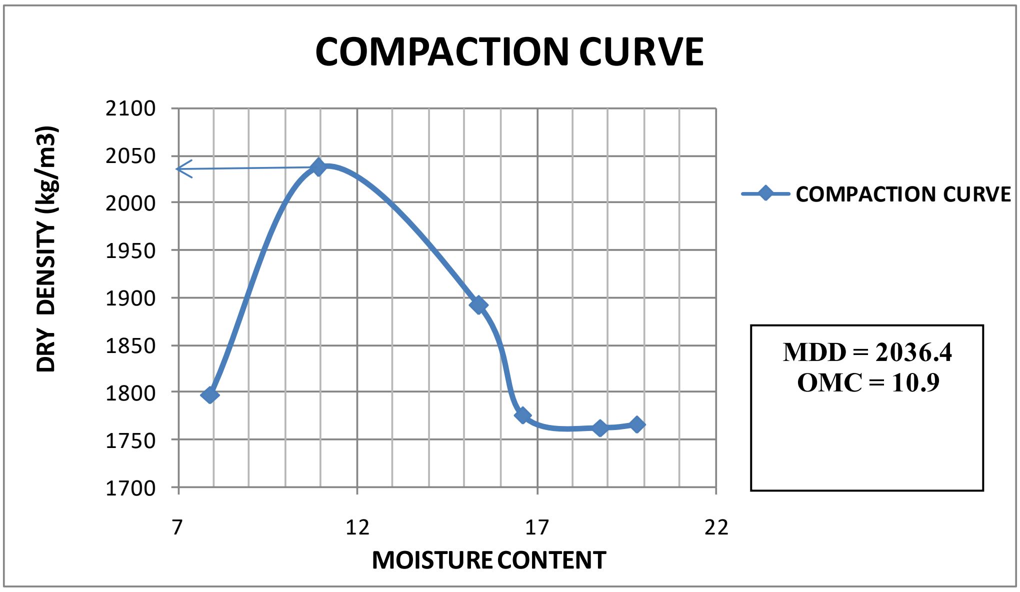

Fig. 4: Graph showing Compaction Curve

The Particle Size Distribution of the soils fall between 66.4 – 95.8% sand and 4.2 -34.9% fines, with average values of 76.0% and 23.9% respectively. The average result shows that the mass passing sieve #200 (0.075mm) is 23.9% and so the soil makes excellent to good subgrade material (according to AASHTO). From the Atterberg limit test, liquid limit and plasticity index of the soils falls between 22.2 – 32.8% and 3.1 – 15.4% respectively. Also, their average values are 27.4% and 11.0% respectively. These values were utilized in the classification of the soil mainly as clayey/silty sand (USC). Also, from the American Association for State and Highway Transportation Officials (AASHTO) soil classification system, the soils at BH1 (0.5 -2.0 meter) to BH2 (0.5 and 1.0 meter) and BH2 (1.5 and 2.0 meter) to BH3 (0.5 to 2.0 meter) were classified as A-2-4 and A-2-6, which rates the soil as excellent to good subgrade material. The maximum moisture content (MDD) and optimum moisture content (OMC) from compaction test are 2036.4 kg/m^3 and 10.9% respectively, and these values meet the standard as subgrade or backfill material.

Recommendations

Although the soil is classified as excellent to good subgrade material, soil stabilization is recommended for optimum performance.

Contribution to Knowledge

This research project work provides additional knowledge on the geotechnical properties of soil in some parts of Umuaku-Isuochi which can be of great assistance to civil engineering projects in the area.

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