Uniport Journal of Engineering and Scientific Research (UJESR)

Vol. 8, Issue 1, 2023, Page 137-151
ISSN: 2616-1192

(www.ujesr.org)

Evaluation of Compaction Methods on Some Cohesive Soils in Benin City

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Abstract
Out of the different types of compaction methods, the standard compaction and modified compaction methods have been two very common methods used in the laboratory to determine the compaction characteristics of soils. This paper evaluated the modified proctor compaction parameters and standard proctor compaction parameters of different cohesive soils collected from different sites in Ovia North East Local Government Area of Benin City. Disturbed soil samples were collected from Oluku, Nitel, Ovbioghie and Iwu areas in Ovia North East Local Government Area, at depths of 0.5m, 1.0m, 1.5m and 2.0m by means of hand auger. Index properties tests were conducted to classify soil samples collected and then Standard Proctor Compaction Test and Modified proctor Compaction Tests were also conducted. The initial examination of soil properties indicated specific gravity values spanning from 2.42 to 2.73. The Atterberg limits revealed variations in plasticity, with liquid limits ranging from 30.00% to 46.00% and plastic limits from 9.85% to 21.55%. These soils, falling within the medium plasticity range, were classified as transitioning from organic clay to inorganic clay, containing fines exceeding 35%. For the standard proctor compaction test the maximum dry densities were between 1.533g/cm^3 and 1.725g/cm^3 while the optimum moisture contents were 11.2% and 17.45%. But for the modified proctor compaction tests, the maximum dry densities were within the ranges of 1.668g/cm^3 and 1.729g/cm^3 while the corresponding ranges of the optimum moisture content were 9.33% and 12.03%. It can be concluded that the modified proctor compaction will result in a denser soil than when the soil is compacted with the standard proctor method. Also, the quantity of water needed will be less for the modified compaction test than the standard compaction test method.

Keywords: *Standard proctor; Modified proctor; Compaction; Index properties; Dry density; Optimum moisture content*

Received: 20th December, 2023 *Accepted: 31st December, 2023*

1. Introduction

In earthwork construction, field compaction is a crucial process in which soil particles are brought closer to each other by the application of compactive effort, which in turn results in increase in shear strength, decrease in compressibility and permeability of the soil mass. Engineering projects such as road embankments, earthen dams, river dykes, railway formations borrowed materials are required to be compacted for the formation of earth embankment, and to avoid failure of these earthen structures, field compaction control of the borrow materials after placement is a major necessity (Kuhn and Johnson , 2020). Through the years, most road pavements are experiencing failure due to the increasing traffic density, axle loading and poor maintenance routine that is being carried out by the government. Poor compaction has been a major cause of the failure of these roads as most are compacted well below the compaction energy and the compaction parameters (Mahmoud *et al.*, 2012; Emmanuel *et al.*, 2021). The application of field compaction of cohesive soils usually involves the use of various processes and equipment with substantially varying compaction energy. Hence, laboratory tests are performed at different compaction energy levels e.g. standard proctor test and modified compaction test. Though, higher compaction basically results in the improvement of the engineering properties of soil, but it can also lead to undesirable swelling of expansive soils as well when these soils come in contact with moisture under unfavourable conditions (Hussain 2017). Out of the different types of compaction methods which include standard proctor, AASHTO compaction test, West Africa, modified proctor test, the standard compaction and modified compaction method have been the two very common methods used in the laboratory to determine the compaction characteristics of soils (Khalid and Rehman, 2018; Masoud *et al*., 2020). Efforts have been carried out in the past in comparing the compaction parameters obtained from these two tests method. It had been found that the standard compaction parameters were applied for light-weight infrastructures, while the modified compaction parameters were applicable for heavy-weight infrastructures (Khalid and Rehman, 2018). Understanding the compaction behaviour of cohesive soils is essential for geotechnical engineers to determine the soil's strength, settlement characteristics, and bearing capacity.

Benin City, like many urban centres, is experiencing rapid infrastructural development and population growth. As a result, the demand for construction and land development is increasing. However, the presence of cohesive soils, particularly expansive clays, complicates these projects due to their high swelling and shrinking potential. This study addressed the specific challenges faced in the Ovia North East Local Government Area, serving as a template for similar regions in the city.

2. Materials and methods

2.1 Study area

Ovia North East Local Government Area is a Local Government Area in Benin-City, the capital and largest city of Edo State in southern Nigeria (Fig. 1). With the city situated approximately 40 km north of the Benin River and 320 km by road east of Lagos. The Geographical coordinates of the study area lies between $5^0$36’35.18” E, $6^0$23’16.87” N for Oluku, $5^0$35’55.18” E, $6^0$26’15.74’N for Nitel area, $5^0$34’52.92” E, $6^0$29’09.45” N for Ovbioghie area and $5^0$34’18.91” E, $6^0$29’44.23” N for Iwu area.

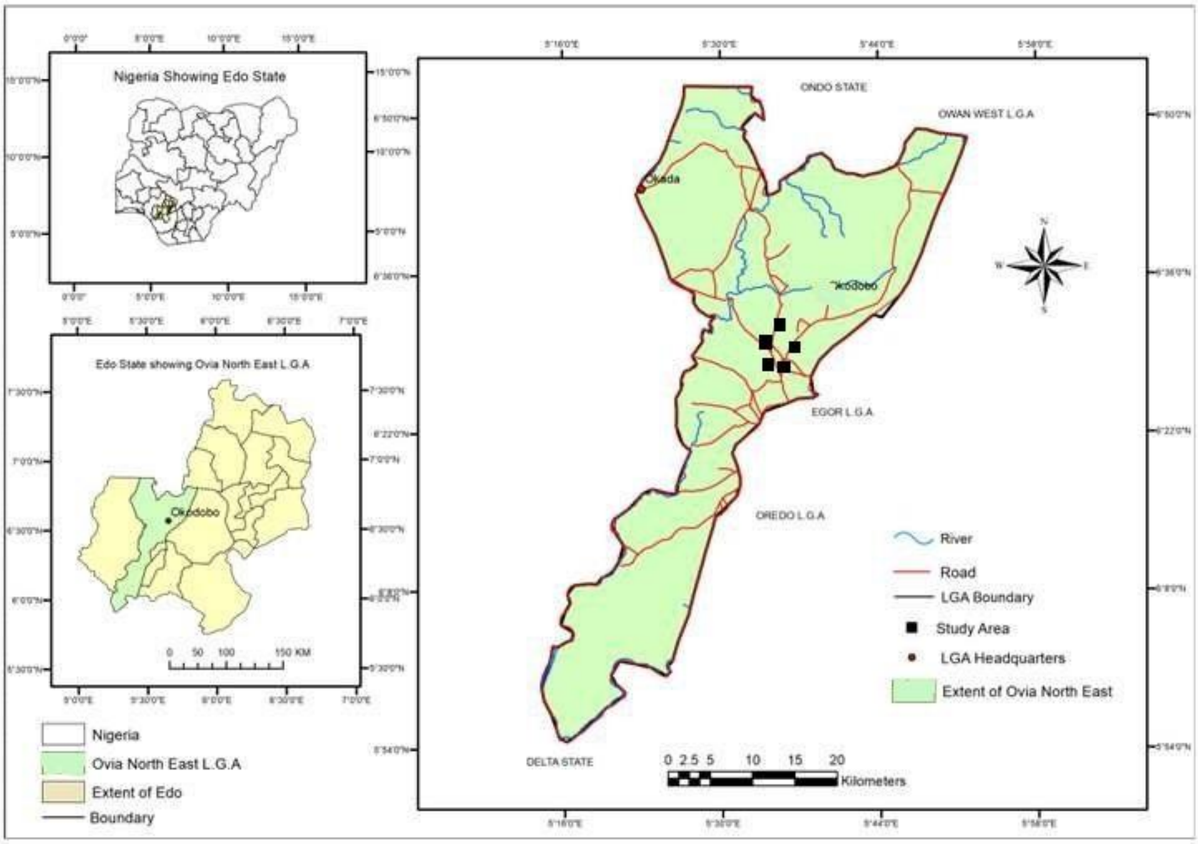

Fig. 1: Map of the study area

2.2 Reconnaissance of the study area/ sample collection

Soil samples were obtained from 4 locations in Ovia North East Local Government Area in Benin-City. A total of 80 samples were collected at a maximum depth of 2m using a hand auger. The locations where the samples were collected include Nitel area, Oluku, Ovbiogie, and Iwu as shown in Fig. 1.

2.3 Laboratory test

The geotechnical tests conducted were Specific Gravity, Sieve analysis, Atterberg's Limits tests, Standard Proctor and Modified Proctor Compaction tests also in accordance with BS 1377 – 2: 1990 and ASTM 698-12. (2021).

2.4 Analysis of compaction parameters

The comparative analysis and the descriptive statistics of the compaction parameters were carried out.

3. Results and discussion

3.1 Index properties

The results of the index properties on the natural soils as obtained from the locations of study are as summarized in Tables.1 to 4. From Table 1, the specific gravity of the borehole samples has the least specific gravity of 2.42, thus indicating that they have some amount of organic matter or porous matter in them, while according to Das (2012) and Arora (2003), most of the samples from the bore holes belong to the organic clay group as their specific gravity is below 2.65. Also, since the percentage passing the 0.075mm sieves from the samples are greater than 35%, the soil samples are said to be fine grained soil (Das 2012). With respect to the plasticity chart as presented by Casagrande, the soil samples were found to be Clay of medium plasticity (CI).

Table .2 shows that the specific gravity of the borehole samples has the least specific gravity of 2.51, thus indicating that they have some amount of organic matter or porous matter in them, while according to Das (2012), Arora (2003) and Murthy (2006), most of the samples from the bore holes belong to the organic clay group as their specific gravity is below 2.65. Also, since the percentage passing the 0.075mm sieves from the samples are greater than 35%, the soil samples are said to be fine grained soil (Das 2012). With respect to the plasticity chart as presented by Casagrande, the soil samples were found to be Clay of medium plasticity (CI).

Table 3 show the result of the index properties tests conducted on the samples collected from Ovbioghie. It was observed that the specific gravity of the soils was within the range of 2.52 to 2.72. This implies that the soil samples with their specific gravity between the ranges of 2.52 to 2.68 consist of organic clay minerals as stated by Das (2012), while the samples with specific gravity between the ranges of 2.68 to 2.72 are inorganic clay. In addition, the percentage passing the 0.075mm sieves from the samples are greater than 35%, the soil samples are said to be fine grained soil (Das 2012). Also, the soil samples as shown from the plasticity chart shows that they are clay soils with medium plasticity.

From Table 4, it can be seen that the samples from borehole 1 have their specific gravity from 2.68 to 2.71, thus indicating that they are inorganic clay soil as according to the plasticity chart they belong to soil samples with clay and having medium plasticity and with their sieve analysis having fines content greater than 35% (Das, 2012). In addition, samples from borehole 2 have their specific gravity within the ranges of 2.64 to 2.70, the content greater than 35% which indicate that they can be clay or silt, but with the plasticity chart it was found that they also belong to clay soil with medium plasticity. Samples from borehole 3 showed that their specific gravity were between 2.64 to 2.69 which indicates that some of the samples have organic matter in them. The sieve analysis showed that they belong to either clay or silt due to the high fine content as it is greater than 35%, but with the plasticity chart it was seen that the soils are clay with medium plasticity. Samples from borehole 4, have their specific gravity between 2.51 to 2.59, which showed that they have large amount of organic matter or porous matter, with the sieve analysis, they belong to either clay or silt as the percentage fines is greater than 35%, but with the plasticity chart the soils belong to clay with medium plasticity. And for borehole 5, the specific gravities were within 2.55 to 2.67, with percentage fines greater than 35% and from the plasticity chart the soils samples belong to clay with medium plasticity.

Table 1: Index properties of soils collected from Oluku

Sample Location: Oluku								
		Specific Gravity (Gs)	Atterberg Limits			Sieve Analysis		
Borehole Number	Depth (m)		LL	PL	PI	1.18mm	0.425mm	0.075mm
BH1	0.50	2.72	37.00	13.90	23.10	90.25	74.85	47.90
	1.00	2.64	34.50	17.67	16.83	95.40	82.35	44.05

	1.50	2.55	33.00	14.52	18.48	96.40	82.25	46.50
	2.00	2.65	30.00	9.85	20.15	91.85	75.10	45.80
BH2	0.50	2.6	39.00	12.16	26.84	94.85	79.45	45.20
	1.00	2.65	41.50	10.88	30.62	92.85	81.10	45.50
	1.50	2.61	45.00	12.25	32.75	93.70	83.05	48.50
	2.00	2.65	41.50	11.74	29.76	93.95	80.20	47.45
BH3	0.50	2.51	34.50	15.44	19.06	94.60	82.35	43.35
	1.00	2.55	35.50	14.26	21.24	91.80	80.60	46.60
	1.50	2.49	41.75	14.54	27.21	91.50	80.55	49.90
	2.00	2.44	44.00	13.90	30.10	91.80	80.20	41.50
BH4	0.50	2.42	33.50	10.87	22.63	94.30	80.50	45.00
	1.00	2.57	32.78	13.96	18.82	93.85	78.90	43.95
	1.50	2.53	34.00	12.29	21.71	89.00	79.50	49.95
	2.00	2.6	42.50	14.33	28.17	91.05	79.00	43.35
BH5	0.50	2.59	33.50	12.87	20.63	92.35	79.10	44.35
	1.00	2.55	32.75	14.25	18.50	96.60	85.55	50.85
	1.50	2.53	34.50	12.87	21.63	92.95	80.20	51.45
	2.00	2.6	40.50	15.81	24.69	91.65	80.20	46.95

Table 2: Index properties of soils collected from Nitel

Sample Location: Nitel								
		Specific Gravity (Gs)	Atterberg Limits			Sieve Analysis		
Borehole Number	Depth (m)		LL	PL	PI	1.18mm	0.425mm	0.075mm
BH1	0.50	2.54	36.00	15.48	20.52	98.60	84.50	56.05
	1.00	2.51	35.00	20.03	14.97	95.80	83.80	50.00
	1.50	2.56	38.25	18.76	19.49	96.90	85.60	52.90
	2.00	2.57	38.00	14.76	23.24	93.00	78.55	42.75
BH2	0.50	2.62	32.50	17.34	15.16	97.25	84.00	52.10
	1.00	2.65	39.25	13.08	26.17	94.40	80.80	54.80
	1.50	2.65	37.85	14.27	23.58	94.15	86.00	48.30
	2.00	2.66	39.05	16.51	22.54	93.60	79.30	51.50
BH3	0.50	2.57	38.00	12.65	25.35	94.30	73.05	45.90
	1.00	2.57	37.00	15.53	21.47	97.00	80.70	50.20
	1.50	2.58	41.50	15.63	25.87	92.55	78.80	46.45
	2.00	2.54	44.15	17.15	27.00	94.10	79.30	53.50
BH4	0.50	2.62	41.35	15.41	25.94	96.95	80.50	49.00
	1.00	2.63	45.05	13.17	31.88	97.85	79.55	53.35
	1.50	2.62	41.75	17.28	24.47	96.60	84.95	52.55
	2.00	2.64	41.25	15.21	26.04	96.15	78.10	55.35
BH5	0.50	2.67	42.00	16.33	25.67	94.90	77.80	50.25
	1.00	2.57	39.00	18.08	20.92	98.95	87.75	53.20
	1.50	2.67	42.00	18.62	23.38	98.85	86.90	49.55

	2.00	2.65	42.78	17.55	25.23	98.75	79.75	52.45

Table 3: Index properties of soils collected from Ovbioghie

Sample Location: Ovbioghie								
		Specific Gravity (Gs)	Atterberg Limits			Sieve Analysis		
Borehole Number	Depth (m)		LL	PL	PI	1.18mm	0.425mm	0.075mm
BH1	0.50	2.67	41.00	21.55	19.45	98.60	83.15	41.95
	1.00	2.72	41.95	19.47	22.48	94.50	79.45	41.30
	1.50	2.67	39.00	15.79	23.21	93.15	77.35	41.70
	2.00	2.71	43.75	16.61	27.14	89.10	64.75	37.80
BH2	0.50	2.52	1.48	14.10	12.62	98.85	82.20	50.45
	1.00	2.73	39.25	14.72	24.53	95.45	79.75	45.70
	1.50	2.57	40.05	12.55	27.50	88.80	76.80	38.95
	2.00	2.65	41.00	17.39	23.61	94.60	80.00	48.45
BH3	0.50	2.59	41.50	18.93	22.57	96.00	77.55	47.75
	1.00	2.64	40.50	18.89	21.61	97.55	77.10	50.80
	1.50	2.70	40.00	13.84	26.16	91.60	70.40	43.45
	2.00	2.62	43.97	16.81	27.16	95.25	75.30	46.10
BH4	0.50	2.61	38.00	15.48	22.52	96.00	76.15	46.05
	1.00	2.72	41.25	17.64	23.61	98.25	76.90	47.50
	1.50	2.60	40.15	18.75	21.40	96.15	85.40	53.00
	2.00	2.70	43.75	17.45	26.30	96.15	78.25	52.75
BH5	0.50	2.66	42.00	16.21	25.79	93.70	75.35	42.65
	1.00	2.67	39.00	14.87	24.13	97.20	87.25	43.65
	1.50	2.72	42.00	20.34	21.66	95.80	83.65	49.20
	2.00	2.69	43.00	18.99	24.01	98.20	78.85	49.40

Table 4: Index properties of soils collected from Iwu

Sample Location: Iwu								
		Specific Gravity (Gs)	Atterberg Limits			Sieve Analysis		
Borehole Number	Depth (m)		LL	PL	PI	1.18mm	0.425mm	0.075mm
BH1	0.50	2.71	45.00	14.65	30.35	92.50	80.70	53.25
	1.00	2.68	46.00	14.02	31.98	94.00	81.05	49.10
	1.50	2.69	42.00	13.36	28.64	97.75	86.65	55.40
	2.00	2.69	44.50	12.95	31.55	93.55	79.25	46.10
BH2	0.50	2.65	47.00	15.19	31.81	94.05	79.45	45.95
	1.00	2.70	41.50	10.88	30.62	90.40	82.00	56.25
	1.50	2.64	41.00	14.00	27.00	92.35	80.35	45.35
	2.00	2.70	40.90	13.50	27.40	92.45	80.30	47.55
BH3	0.50	2.64	38.50	12.12	26.38	92.90	70.00	44.30

	1.00	2.64	43.20	12.74	30.46	97.95	81.65	51.80
	1.50	2.65	40.25	12.22	28.03	92.55	78.80	46.45
	2.00	2.69	40.00	13.39	26.61	91.50	76.50	43.60
BH4	0.50	2.56	38.20	12.83	25.37	96.45	80.20	43.45
	1.00	2.59	36.25	15.64	20.61	98.45	80.60	49.00
	1.50	2.56	38.05	13.22	24.83	97.30	82.35	50.60
	2.00	2.51	39.00	14.10	24.90	95.05	78.90	48.70
BH5	0.50	2.55	38.50	15.88	22.62	94.75	76.05	50.90
	1.00	2.57	37.00	16.01	20.99	98.95	86.45	53.30
	1.50	2.67	41.50	14.94	26.56	93.15	79.55	45.70
	2.00	2.63	37.75	14.79	22.96	95.75	82.15	51.95

3.2 Standard compaction

The standard proctor tests conducted on the samples are as seen in Table 5. Table 5 showed the compaction parameters results carried out on Oluku soil samples from borehole 1 to borehole 5. It can be seen that the maximum dry densities of the soils within the sample locations were within the ranges of 1.571g/cm^3 to 1.725g/cm^3. It was also observed that the moisture contents were within the ranges of 11.99% to 17.45% and this corroborated with the study by Emmanuel *et al.* (2021) and Amadi et al. (2015) who reported the range of the maximum dry density of some lateritic soils in Nigeria to be within the range of 1.54g/ cm^3 to 2.3368g/ cm^3 while the corresponding limits of the OMC were 6.30% to 20.7%.

Table 5: Standard proctor result on Oluku sample

Sample Location: Oluku			
Borehole Number	Depth (m)	MDD (g/cm^3)	OMC (%)
BH1	0.50	1.613	12.4
	1.00	1.601	17.45
	1.50	1.713	14.04
	2.00	1.725	13.71
BH2	0.50	1.668	16.08
	1.00	1.622	16.06
	1.50	1.715	15.53
	2.00	1.709	13.26
BH3	0.50	1.594	13.15
	1.00	1.571	15.17
	1.50	1.683	15.58
	2.00	1.672	13.12
BH4	0.50	1.598	16.16
	1.00	1.612	16.76
	1.50	1.678	13.25
	2.00	1.638	15.25
BH5	0.50	1.573	12.85
	1.00	1.587	16.73
	1.50	1.687	15.75

	2.00	1.673	11.99

Table 6 shows the maximum dry density and optimum moisture content of the standard proctor compaction results carried out on soil samples from Nitel area of Benin-City, from borehole 1 to borehole 5. It can be seen that the maximum dry density of the soils within the sample locations were within the ranges of 1.556g/cm^3 to 1.673g/cm^3. It was also observed that the moisture contents were within the ranges of 12.24% to 16.56%. This is also in line with Emmanuel et al. (2021) and Amadi et al. (2015).

Table 6: Standard proctor result on Nitel sample

Sample Location: Nitel			
Borehole Number	Depth (m)	MDD (g/cm^3)	OMC (%)
BH1	0.50	1.592	12.24
	1.00	1.571	13.44
	1.50	1.648	12.66
	2.00	1.663	13.28
BH2	0.50	1.638	14.75
	1.00	1.586	14.63
	1.50	1.598	12.85
	2.00	1.632	12.55
BH3	0.50	1.563	14.87
	1.00	1.556	14.85
	1.50	1.608	15.43
	2.00	1.662	13.44
BH4	0.50	1.659	16.56
	1.00	1.609	14.02
	1.50	1.673	14.48
	2.00	1.579	15.26
BH5	0.50	1.585	12.78
	1.00	1.562	16.48
	1.50	1.638	13.86
	2.00	1.647	13.48

Table 7 showed the maximum dry density and optimum moisture content of the standard proctor compaction results carried out on soil samples from Ovbioghie area of Benin-City, from borehole 1 to borehole 5. It can be seen that the maximum dry density of the soils within the sample locations were within the ranges of 1.546g/cm^3 to 1.647g/cm^3. It was also observed that the moisture contents were within the ranges of 11.20% to 16.37% and this also agrees with the studies by Emmanuel et al. (2021) and Amadi et al. (2015).

Table 8 showed the maximum dry density and optimum moisture content of the standard proctor compaction results carried out on soil samples from Iwu area of Benin-City, from borehole 1 to borehole 5. It can be seen that the maximum dry density of the soils within the sample locations were within the ranges of 1.533/cm^3 to 1.703g/cm^3. It was also observed that the moisture contents were within the ranges of 11.76% to 16.72%, and finally this agrees with Emmanuel et al. (2021) and Amadi et al. (2015).

Table 7: Standard proctor result on Ovbioghie sample

Sample Location: Ovbioghie			
Borehole Number	Depth (m)	MDD (g/cm^3)	OMC (%)
BH1	0.50	1.647	13.48
	1.00	1.571	12.1
	1.50	1.623	11.76
	2.00	1.605	12.26
BH2	0.50	1.604	13.18
	1.00	1.637	14.05
	1.50	1.581	13.36
	2.00	1.603	15.65
BH3	0.50	1.631	13.25
	1.00	1.587	12.92
	1.50	1.573	15.65
	2.00	1.607	14.58
BH4	0.50	1.589	11.2
	1.00	1.591	13.71
	1.50	1.571	13.82
	2.00	1.642	15.81
BH5	0.50	1.600	14.73
	1.00	1.549	12.58
	1.50	1.579	12.65
	2.00	1.588	16.37

Table 8: Standard proctor result on Iwu sample

Sample Location: Iwu			
Borehole Number	Depth (m)	MDD (g/cm^3)	OMC (%)
BH1	0.50	1.538	12.80
	1.00	1.594	13.96
	1.50	1.586	13.95
	2.00	1.683	13.45
BH2	0.50	1.665	15.65
	1.00	1.604	15.62
	1.50	1.647	14.51
	2.00	1.674	12.75
BH3	0.50	1.553	13.56
	1.00	1.593	16.72
	1.50	1.703	15.96
	2.00	1.664	13.38

BH4	0.50	1.595	15.90
	1.00	1.588	15.93
	1.50	1.696	13.62
	2.00	1.533	15.92
BH5	0.50	1.582	12.80
	1.00	1.579	16.10
	1.50	1.669	15.14
	2.00	1.645	15.03

3.3 Modified proctor compaction

The results of the modified proctor compaction tests which were carried out by subjecting the soils to five layers and 25 blows on each layer are as shown in Tables 9 – 12. Table 9 showed the compaction parameters results carried out on Oluku soil samples from borehole 1 to borehole 5. It can be seen that the maximum dry density of the soils within the sample locations were within the ranges of 1.687g/cm^3 to 1.805g/cm^3. It was also observed that the moisture contents were within the ranges of 9.33% to 11.80%. Studies conducted by Emmanuel et al. (2021) and Amadi et al. (2015) showed that these parameters were within the limits for some lateritic soils in Nigeria.

The summary of the modified proctor compaction that was carried out on samples from Nitel is as shown in Table 10. It can be seen that the maximum dry density of the soils collected at Nitel were within the ranges of 1.692g/cm^3 to 1.763g/cm^3. It was also observed that the moisture contents were within the ranges of 9.44% to 12.03%, this corresponds to the study conducted by Emmanuel et al. (2021) and Amadi et al. (2015).

Table 11 shows the summary of the modified proctor compaction that was carried out on samples from Ovbioghie. It can be observed that the maximum dry density of the modified compaction carried out on the samples from Ovbioghie were within the ranges of 1.668g/cm^3 to 1.745g/cm^3 and the corresponding optimum moisture contents were also within the ranges of 10.04% to 11.93%. Studies from Emmanuel et al. (2021) and Amadi et al. (2015) showed that the compaction parameters of the soils in this location were within their stated limits.

From Table 12, it can be seen the maximum dry density of the soil samples collected from Iwu were within the ranges of 1.668g/cm^3 and 1.796g/cm^3 and the corresponding optimum moisture contents were within the ranges of 9.58% and 11.96%. And studies from Emmanuel et al. (2021) and Amadi et al. (2015) showed that the compaction parameters of the soils in this location were within their stated limits.

Table 9: Summary of modified proctor compaction test result on Oluku samples

Sample Location: Oluku			
Borehole Number	Depth (m)	MDD (g/cm^3)	OMC (%)
BH1	0.50	1.776	11.8
	1.00	1.742	9.62
	1.50	1.775	11.66
	2.00	1.778	11.52
BH2	0.50	1.712	10.72
	1.00	1.714	9.54
	1.50	1.789	10.92
	2.00	1.805	11.25
BH3	0.50	1.715	10.75
	1.00	1.688	10.05
	1.50	1.742	10.28

	2.00	1.741	10.83
BH4	0.50	1.713	9.65
	1.00	1.720	9.33
	1.50	1.724	10.79
	2.00	1.743	10.34
BH5	0.50	1.687	10.91
	1.00	1.741	9.74
	1.50	1.747	10.14
	2.00	1.753	10.57

Table 10: Summary of modified proctor compaction test on Nitel samples

Sample Location: Nitel			
Borehole Number	Depth (m)	MDD (g/cm^3)	OMC (%)
BH1	0.50	1.703	12.03
	1.00	1.695	10.84
	1.50	1.758	11.86
	2.00	1.763	11.03
BH2	0.50	1.724	10.65
	1.00	1.697	9.74
	1.50	1.718	10.92
	2.00	1.745	10.45
BH3	0.50	1.692	10.54
	1.00	1.695	9.86
	1.50	1.722	10.12
	2.00	1.758	10.69
BH4	0.50	1.761	10.02
	1.00	1.725	10.62
	1.50	1.752	10.63
	2.00	1.711	10.27
BH5	0.50	1.694	11.28
	1.00	1.742	9.44
	1.50	1.745	9.91
	2.00	1.753	9.97

Table 11: Summary of modified proctor compaction test on Ovbioghie samples

Sample Location: Ovbioghie			
Borehole Number	Depth (m)	MDD (g/cm^3)	OMC (%)
BH1	0.50	1.685	11.63
	1.00	1.729	11.93
	1.50	1.712	10.83
	2.00	1.713	11.24

BH2	0.50	1.746	10.55
	1.00	1.695	11.25
	1.50	1.711	10.43
	2.00	1.728	10.95
BH3	0.50	1.702	10.97
	1.00	1.738	10.21
	1.50	1.718	10.69
	2.00	1.734	11.48
BH4	0.50	1.701	11.39
	1.00	1.683	10.72
	1.50	1.734	10.33
	2.00	1.726	10.52
BH5	0.50	1.668	11.68
	1.00	1.731	11.31
	1.50	1.702	10.04
	2.00	1.748	10.16

Table 12: Summary of modified proctor compaction test on Iwu samples

Sample Location: Iwu			
Borehole Number	Depth (m)	MDD (g/cm^3)	OMC (%)
BH1	0.50	1.672	11.96
	1.00	1.699	11.76
	1.50	1.712	10.78
	2.00	1.789	10.92
BH2	0.50	1.771	10.21
	1.00	1.715	10.87
	1.50	1.756	10.54
	2.00	1.786	10.99
BH3	0.50	1.668	11.04
	1.00	1.730	9.58
	1.50	1.796	10.18
	2.00	1.767	10.84
BH4	0.50	1.707	10.63
	1.00	1.695	9.92
	1.50	1.794	10.75
	2.00	1.684	10.41
BH5	0.50	1.695	11.47
	1.00	1.703	10.26
	1.50	1.749	10.39
	2.00	1.752	10.55

3.5 Analysis of compaction parameters

Table 13 shows the combined result of the standard proctor compaction tests and the modified proctor compaction tests carried on the soil samples. The descriptive statistics of the results of both compaction tests are as summarized in Table 14.

From the samples, the range of the maximum dry density from the standard proctor compaction test were between 1.533g/cm^3 and 1.725g/cm^3 while the optimum moisture contents were 11.2% and 17.45%. But for the modified proctor compaction tests, the maximum dry densities were within the ranges of 1.668g/cm^3 and 1.729g/cm^3 while the corresponding ranges of the optimum moisture contents were 9.33% and 12.03%. This implies that the dry densities from the standard compaction tests were less than the densities from the modified proctor compaction tests and also, the optimum moisture contents of the standard compaction test were higher than those from the modified proctor compaction test. This implies that the dry density of the modified proctor compaction will result in a denser soil than when the soil is compacted with the standard proctor method (Shivaprakash and Sridharan, 2021). Also, the quantity of water needed will be less for the modified compaction test than the standard compaction test method.

Table 13: Compaction test from all locations

	Standard Proctor Test		Modified proctor	
Test No	γ_{ds}	OMC_s	γ_{dmod}	OMC_{mod}
1	1.613	12.4	1.776	11.8
2	1.601	17.45	1.742	9.62
3	1.713	14.04	1.775	11.66
4	1.725	13.71	1.778	11.52
5	1.668	16.08	1.712	10.72
6	1.622	16.06	1.714	9.54
7	1.715	15.53	1.789	10.92
8	1.709	13.26	1.805	11.25
9	1.594	13.15	1.715	10.75
10	1.571	15.17	1.688	10.05
11	1.683	15.58	1.742	10.28
12	1.672	13.12	1.741	10.83
13	1.598	16.16	1.713	9.65
14	1.612	16.76	1.720	9.33
15	1.678	13.25	1.724	10.79
16	1.638	15.25	1.743	10.34
17	1.573	12.85	1.687	10.91
18	1.587	16.73	1.741	9.74
19	1.687	15.75	1.747	10.14
20	1.673	11.99	1.753	10.57
21	1.592	12.24	1.703	12.03
22	1.571	13.44	1.695	10.84
23	1.648	12.66	1.758	11.86
24	1.663	13.28	1.763	11.03
25	1.638	14.75	1.724	10.65
26	1.586	14.63	1.697	9.74
27	1.598	12.85	1.718	10.92
28	1.632	12.55	1.745	10.45
29	1.563	14.87	1.692	10.54
30	1.556	14.85	1.695	9.86
31	1.608	15.43	1.722	10.12
32	1.662	13.44	1.758	10.69

33	1.659	16.56	1.761	10.02
34	1.609	14.02	1.725	10.62
35	1.673	14.48	1.752	10.63
36	1.579	15.26	1.711	10.27
37	1.585	12.78	1.694	11.28
38	1.562	16.48	1.742	9.44
39	1.638	13.86	1.745	9.91
40	1.647	13.48	1.753	9.97
41	1.571	12.1	1.685	11.63
42	1.623	11.76	1.729	11.93
43	1.605	12.26	1.712	10.83
44	1.604	13.18	1.713	11.24
45	1.637	14.05	1.746	10.55
46	1.581	13.36	1.695	11.25
47	1.603	15.65	1.711	10.43
48	1.631	13.25	1.728	10.95
49	1.587	12.92	1.702	10.97
50	1.573	15.65	1.738	10.21
51	1.607	14.58	1.718	10.69
52	1.589	11.2	1.734	11.48
53	1.591	13.71	1.701	11.39
54	1.571	13.82	1.683	10.72
55	1.642	15.81	1.734	10.33
56	1.600	14.73	1.726	10.52
57	1.549	12.58	1.668	11.68
58	1.579	12.65	1.731	11.31
59	1.588	16.37	1.702	10.04
60	1.618	16.18	1.748	10.16
61	1.538	12.8	1.672	11.96
62	1.594	13.96	1.699	11.76
63	1.586	13.95	1.712	10.78
64	1.683	13.45	1.789	10.92
65	1.665	15.65	1.771	10.21
66	1.604	15.62	1.715	10.87
67	1.647	14.51	1.756	10.54
68	1.674	12.75	1.786	10.99
69	1.553	13.56	1.668	11.04
70	1.593	16.72	1.730	9.58
71	1.703	15.96	1.796	10.18
72	1.664	13.38	1.767	10.84
73	1.595	15.9	1.707	10.63
74	1.588	15.93	1.695	9.92
75	1.696	13.62	1.794	10.75
76	1.533	15.92	1.684	10.41
77	1.582	12.8	1.695	11.47

78	1.579	16.1	1.703	10.26
79	1.669	15.14	1.749	10.39
80	1.645	15.03	1.752	10.55

Table 14: Descriptive statistics of data for the compaction analysis

	Standard Proctor Test		Modified proctor	
	γ_{ds}	OMC_s	γ_{dmod}	OMC_{mod}
Count	80	80	80	80
Range	0.192	6.250	0.137	2.700
Minimum	1.533	11.200	1.668	9.330
Maximum	1.725	17.450	1.805	12.030
Mean	1.619	14.310	1.729	10.671
Standard Error	0.005	0.164	0.004	0.072
Median	1.606	14.030	1.726	10.670
Standard Deviation	0.046	1.469	0.032	0.645
Variance	0.002	2.159	0.001	0.416
Kurtosis	-0.693	-1.065	-0.514	-0.470
Skewness	0.431	0.096	0.314	0.138

4. Conclusion

The following conclusions were drawn from the result gotten.

1. The preliminary tests of soil properties encompass specific gravity, Atterberg limits, and sieve analysis. Specific gravity values vary from 2.42 to 2.73, indicating differences in soil density. Atterberg limits show variations in plasticity; liquid limits span from 30.00% to 46.00%, while plastic limits range from 9.85% to 21.55%, contributing to diverse soil behaviours. Sieve analysis illustrates a wide distribution of particle sizes, with substantial differences observed across the various sieve sizes, and their fines content is greater than 35%. Thus, the soils within the areas belong to organic clay to inorganic clay with medium plasticity and having their fines content greater than 35%.
2. The conducted standard compaction tests reveal significant variations in maximum dry density (MDD) and optimal moisture content (OMC) across the soil samples. MDD values range from 1.538 g/cm³ to 1.713 g/cm³, demonstrating a broad spectrum of soil compaction potential. The OMC values span from 11.20% to 17.45%, indicating diverse moisture levels at which the soils exhibit maximum compaction. These results highlight the soil's complex response to compaction efforts, with some samples requiring higher moisture contents for optimal compaction, while others achieve compaction with lower moisture content.
3. Finally, the results of the modified Proctor compaction tests reveal variations in the soil's compaction characteristics, as indicated by the MDD and OMC values. MDD values range from 1.668 g/cm³ to 1.805 g/cm³, reflecting differences in soil densities achievable through compaction efforts. The OMC values vary from 9.33% to 12.03%, representing the moisture content at which the soils attain maximum compaction. These findings demonstrate the intricate relationship between moisture content and compaction, where some samples require higher moisture content for optimal density while others achieve it at lower moisture levels.

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