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Compaction Characteristics and Some Physical Properties of Otukpa Soils

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Abstract: The compaction characteristic and some physical analysis test were conducted on soils obtained from ten (10) different sites in Otukpa, Ogbadibo LGA of Benue State – Nigeria. Atterberg limits, natural moisture content, specific gravity, particle size analysis and compaction test were conducted on the samples. The results obtained shows that Otukpa soil predominantly constitute of lean clay and clayey sand soils based on unified soil classification system (USCS). It belongs to A-6 groups and described as clayey soils according to AASHTO classification system. The Atterberg limit test results shows that the liquid limits for lean clay ranges from 28 to 40%, while that of the clayey sand soil ranges from 20.50 to 25.00%. The research also revealed that the plasticity index for lean clay and clayey sand soils ranges from 10.27 to 24.41% and 5.25 to 9.48% respectively. The maximum dry density (MDD) obtained ranged from 1.50 Mg/m^3 to 1.72 Mg/m^3 while the optimum moisture content (OMC) was obtained to range from 7.00 to 15.00%. Based on these results, Otukpa soils should be taken as soils that contains clay in it and care should be taken during construction of building and even roads on it and in it.

Keywords: Otukpa Soils, Physical Analysis, Compaction Characteristics, Clay Soils

1. Introduction

Soils has different characteristics with the stability and performance of a structure constructed on it depending largely on the subsoil conditions, the soil surface features as well as the type of construction carried on it [1]. The geotechnical properties of soil determine the type of structure that should be constructed on such soils and the necessary actions to be taken and materials to be used during construction of a said structure. This leads to soil investigation by carrying out laboratory or in-situ test on soil samples to determine the type suitability of soils for a particular construction. The strength of soil needs to be high for it to carry desired load that is applied to it [2].

Otukpa is an area in which much development is taken place with construction projects being carried out in the community such as residential building (1-3 storeys), large capacity church halls, hospital wards and large water reservoirs. The structures within the areas suffer cracks with residents carrying out regular repairs on the cracks. Much is not known about the strength and compaction characteristics of the soil within the community. The soil may be seen as a problem soil if the cracks noticed are as a result of the nature of the soil. Problem soils can be seen as those which exhibit low strength and high expansive, compressibility, or collapsible characteristics [3]. The soil seems to possess some clay particles in it which this research will help to classify with a well define name for the nature of the soil in the area.

Otukpa is a district located in Ogbadibo Local Government Area (LGA) of Benue State, Nigeria which is also the headquarters of Ogbadibo LGA. Orokam and Owukpa districts are also part of the LGA. The three districts form the local government area. Otukpa is made up of three main clans; Ai'odo, Ai'ono and Olaichagbaha [4, 5].

Otukpa district lies between, 7^0 35`0" and 7^0 40'0" longitude and 7^0 05'0" and 7^0 15' latitude. The area is about 84 square miles [4]. Otukpa community occupy a portion of the waterless ridge of hills. It stands a height of 1200 feet above sea level, on the ridge of sandy hills which stretches south to Nsuka [5].

The population density of Otukpa community was estimated to be about 21,686 people during 2006 census [6]. The climate is the tropical type with distinct dry and wet seasons. Rain often comes around early April and last till end of October every year. The precipitation is always highest between August and September [5].

The aim of this research is to determine the compaction characteristic of the soil found in Otukpa area, the physical properties and to classify the soil according to USCS and AASHTO classification.

2. Materials and Methods

2.1. Sample Collection

Ten (10) disturbed samples were collected from the three main clans of Otukpa community with three (3) from Ai'odo, three (3) from Ai'ono and four (4) from Olaichagbaha. The samples were excavated from trial pits from the area to give a representation of Otukpa residual soils at a depth of 1.2 m before samples were collected. The samples were collected into ten different air tight polythene bags to preserve the natural water content of the samples.

The collected samples were taken to the soil Laboratory of the Department of Civil Engineering, University of Agriculture, Makurdi and were tested according to [7].

2.2. Physical Analysis Conducted

Some of the physical analysis tests carried out are natural moisture content, Atterberg limit, specific gravity and particle size analysis.

2.2.1. Natural Moisture Content

The water content (w) or moisture content which is the ratio of the mass of water in a given soil to the mass of solid particles expressed in percentage was determined on the ten samples according to the procedure in [8]. The water content was determined by weighing a sample of the wet soil (M_w), then oven drying the sample for a period of 24 hours and weighing it (M_s). The water content was calculated using the following expression

$$\text{Water Content (w)} = = \frac{M_2 - M_3}{M_3 - M_1} \times 100\% = \frac{M_w}{M_s} \times 100\% \quad (1)$$

Where M_1 = Mass of empty can
M_2 = Mass of wet soil + can
M_1 = Mass of dried soil + can

2.2.2. Atterberg Limits

The Atterberg limits test was conducted to determine the consistency of the soil. This consistency test includes liquid limit, plastic limit and Shrinkage limit. The procedures for all these tests are recorded in [8].

Liquid limit (LL) is the water content at which the soil changes from the liquid state to the plastic state [9]. This is carried out with the help of casagrande apparatus as detailed in [7] and is the water content at which soil sample with particle size smaller than 0.425 mm closes its groove in a casagrande cup at 25 blows.

Plastic limit (PL) is known as the water content at which a soil becomes semi solid [9]. It is taken as the minimum water content at which a soil is rolled into 3 mm without broking into pieces [10].

Plasticity index (PI) is an important index property of fine-grained soils which is the numerical difference between the liquid limit and the plastic limit of the soil. It is given by the expression,

$$\text{PI} = \text{LL} - \text{PL} \quad (2)$$

Shrinkage limit (SL) is known as the water content at which the soil changes from semi-solid state to the solid state [9]. It is also said to be the linear shrinkage of soil due to loss of moisture [10]. Linear shrinkage was determined with the following expression

$$\text{Linear Shrinkage} = \frac{L_1 - L_2}{L_1} \times 100\% \quad (3)$$

where L_1 = length of mould
L_2 = length of dried sample

The values of Liquid limit (LL) and plasticity index (PI) aids soil classification using plasticity chart (figure 1).

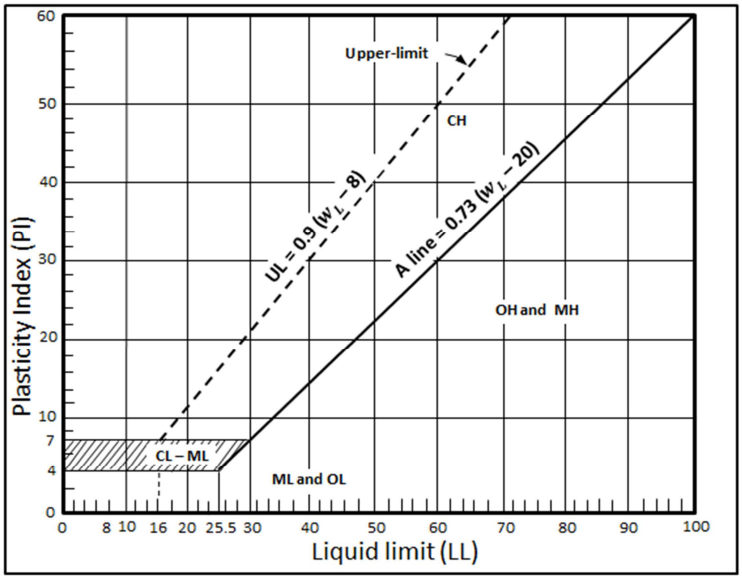

Figure 1. *Plasticity Chart [1].*

2.2.3. Specific Gravity

The specific gravity test was conducted on the sample according to the procedure in [7] to determine the ratio of its given mass to an equal volume of water. The expression used for this is given as:

$$\text{Specific gravity (Gs)} = \frac{weight\ of\ soil}{weight\ of\ equal\ volume\ of\ water} \quad (4)$$

The simple form of (4) is express as (5)

$$\text{Gs} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_1)} \quad (5)$$

Where W_1 = mass of empty bottle in grams
W_2 = mass of bottle + soil in grams
W_3 = mass of bottle + soil + water in grams
W_4 = mass of bottle + water in grams

2.2.4. Particle Size Distribution

The particle size distribution was carried out to determine the particle size gradation of the soil samples. The mechanical sieve analysis and hydrometer test were conducted on the samples. The particle size distribution curve plotted from these test aided in grouping and naming the soil according to USCS. The procedure adopted here is given in [8]. The percentage passing sieve no. 200, the coefficient of uniformity (Cu) and the coefficient of curvature (Cc) were determined using the following expressions.

$$\text{Percentage passing a sieve} = \frac{mass\ passing\ sieve}{mass\ of\ sample} \times 100\% \quad (6)$$

$$\text{Coefficient of Uniformity, } C_u = \frac{D_{60}}{D_{10}} \quad (7)$$

$$\text{Coefficient of curvature, } C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \quad (8)$$

Where D_{10} = particle passing by 10%
D_{30} = particle passing by 30%
D_{60} = particle passing by 60%
Three points D_{10}, D_{30} and D_{60} on a simple grading curve are shown in figure 1, which represent how the values are obtained from a grading curve.

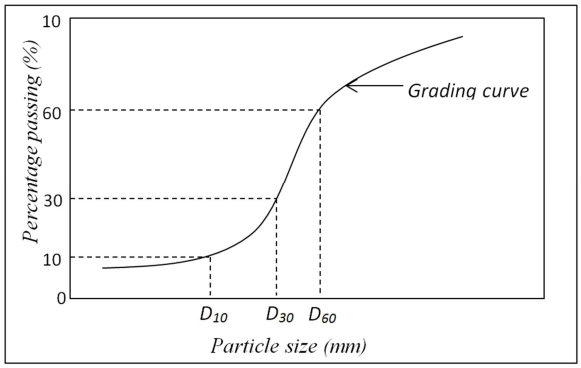

Figure 2. *Simple grading curve showing how to obtain D_{10}, D_{30} and D_{60} from the curve.*

2.3. Compaction Test

Compaction test was carried out according to [8]. Compaction of soil is the measure of the bulk density (ρ) of the compacted soil, which is the mass of soil (solid particles plus any contained water) per unit volume including voids. Bulk density in Mg/m^3 is expressed as follows:

$$\text{Bulk density } (\rho) = \frac{m_2 - m_1}{V} \quad (9)$$

Where m_1 = mass of mould + baseplate (in g)
m_2 = mass of mould + baseplate + compacted soil (in g)
V = the internal volume of mould in cm^3

The compaction also reveals the optimum moisture content at which the soil reaches its maximum denseness. The dry density, ρ_d (in Mg/m^3) which is the mass of the dry soil contained in unit volume of undried soil was determine from the following expression

$$\text{Dry density } (\rho_d) = \frac{100\rho}{100 + w} \quad (10)$$

where w is the moisture content (in%)

3. Results

Table 1. *Natural moisture content of Otukpa soil.*

Trial pit	1	2	3	4	5	6	7	8	9	10
Moisture content (%)	29.83	25.63	19.00	28.68	25.30	21.47	16.57	15.28	15.36	24.29

Table 2. *Atterberg limits of Otukpa soil.*

Trial Pit	Liquid limit (LL)	Plastic limit (PL)	Plasticity index (PI)	Linear shrinkage (LS)
1	32.50	18.60	13.90	10.71
2	40.00	15.79	24.21	9.29
3	34.00	23.73	10.27	10.71
4	28.00	13.33	14.67	7.14
5	34.00	23.73	10.27	10.71
6	23.50	16.09	7.41	5.91
7	25.00	15.52	9.48	3.57
8	25.00	15.52	9.48	3.57
9	22.00	16.75	5.25	3.57
10	20.50	14.09	6.41	5.91

Table 3. *Specific gravity of Otukpa soils.*

Trial pit	1	2	3	4	5	6	7	8	9	10
Specific gravity	2.50	2.60	2.55	2.55	2.45	2.50	2.60	2.80	2.70	2.80

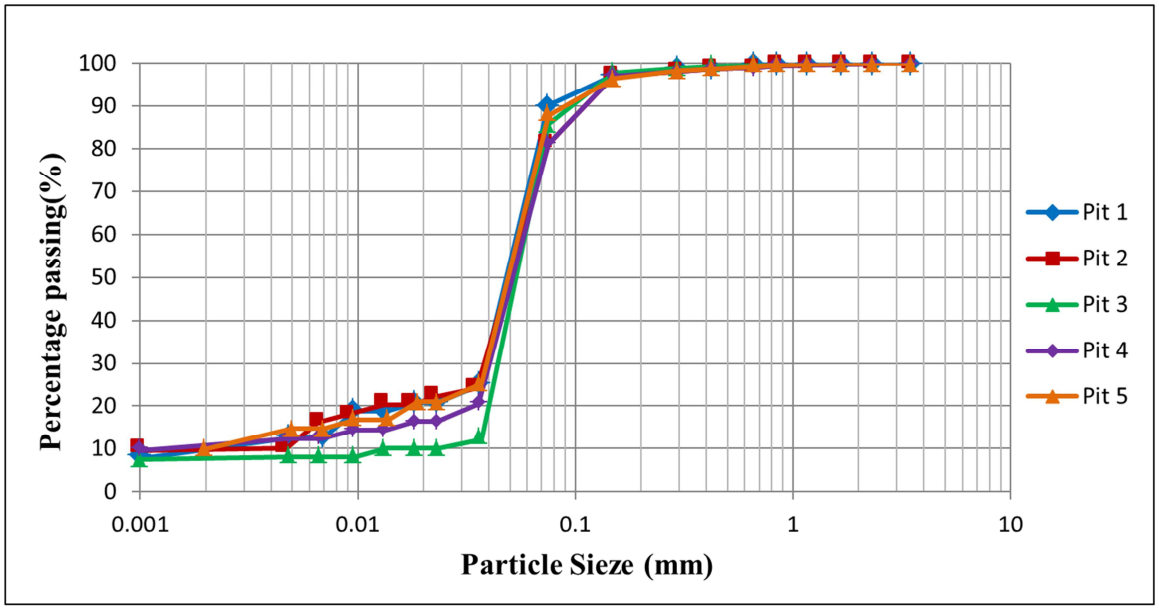

Figure 3. *Sieve analysis graph for samples from Pit 1, 2, 3, 4 and 5.*

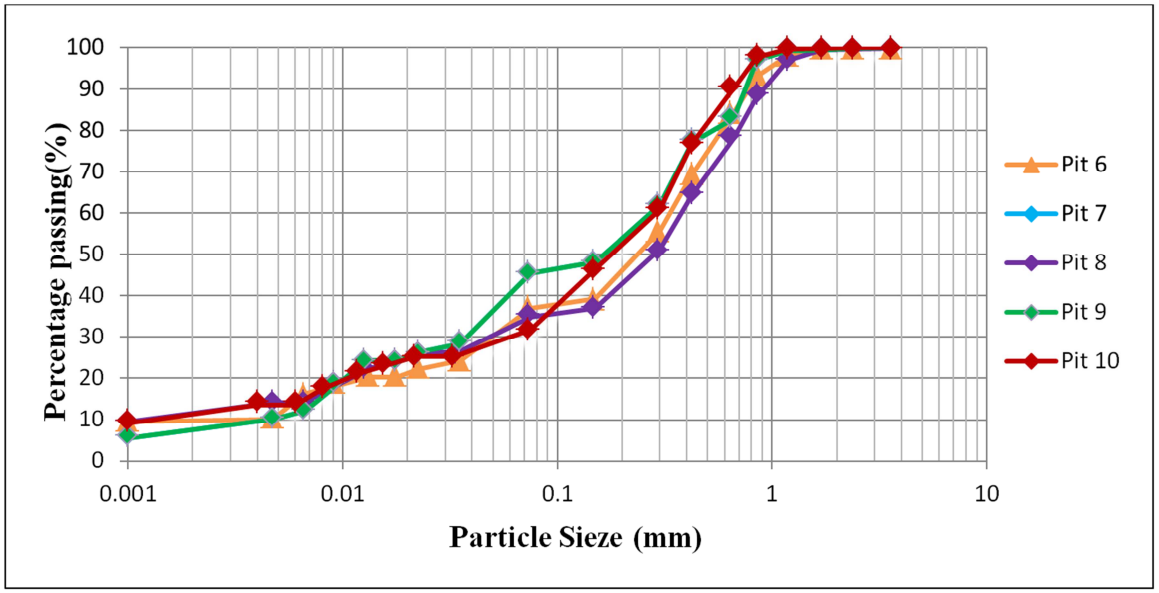

Figure 4. *Sieve analysis graph for soil samples from Pit 6, 7, 8, 9 and 10.*

Table 4. *Otukpa soil result from particle size classification and soils name.*

Trial pit	Coefficient of Uniformity (*Cu*)	Coefficient of Curvature (*Cc*)	Cumulative Retain on (R_{200}) (%)	Percentage Finer on Sieve no. 200 (F_{200})%	Group symbol	Soil Name
1	20.40	11.93	9.87	90.13	CL	Lean clay
2	20.40	11.93	18.87	81.13	CL	Lean clay with sand
3	20.40	11.93	14.22	85.78	CL	Lean clay
4	20.40	11.93	18.87	81.13	CL	Lean clay
5	20.40	11.93	12.27	87.73	CL	Lean clay
6	20.40	11.93	63.10	36.90	SC	Clayey sand
7	20.40	11.93	54.50	45.50	SC	Clayey sand
8	59.57	12.16	65.10	34.90	SC	Clayey sand
9	61.7	1.38	54.50	45.50	SC	Clayey sand
10	21053	6.26	68.20	31.80	SC	Clayey sand

Table 5. *Compaction test results of Otukpa soil.*

Trial Pits	Optimum moisture content, OMC (%)	Maximum Dry density (Mg/m^3)	Maximum Dry Density (kN/m^3)
1	14.80	1.50	14.72
2	13.80	1.55	15.21
3	10.40	1.57	15.40
4	14.80	1.58	15.50
5	15.00	1.62	15.89
6	09.50	1.62	15.89
7	12.80	1.72	16.87
8	14.00	1.66	16.28
9	07.00	1.64	16.09
10	09.00	1.65	16.19

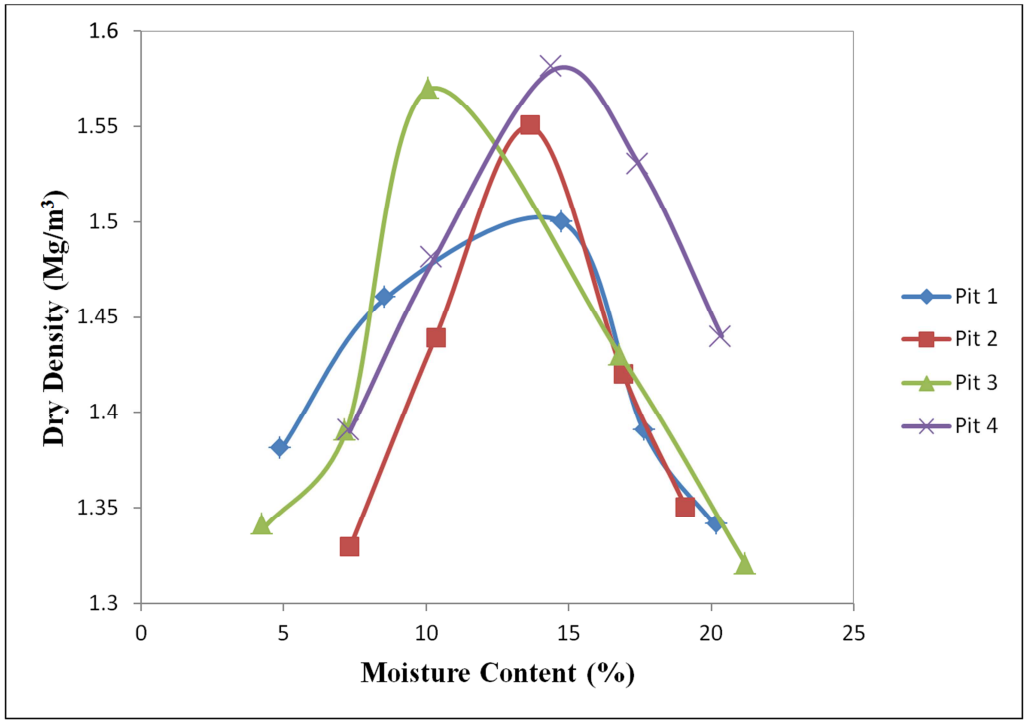

Figure 5. *Dry density-water content relationship plots for Pit 1, 2, 3 and 4.*

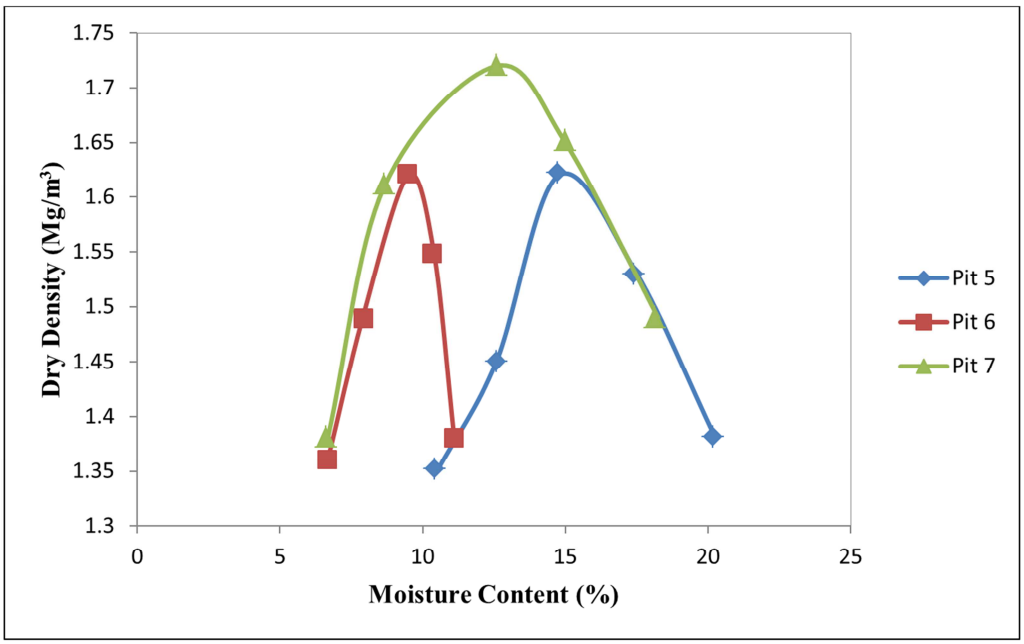

Figure 6. *Dry density-water content relationship plots for Pit 5, 6 and 7.*

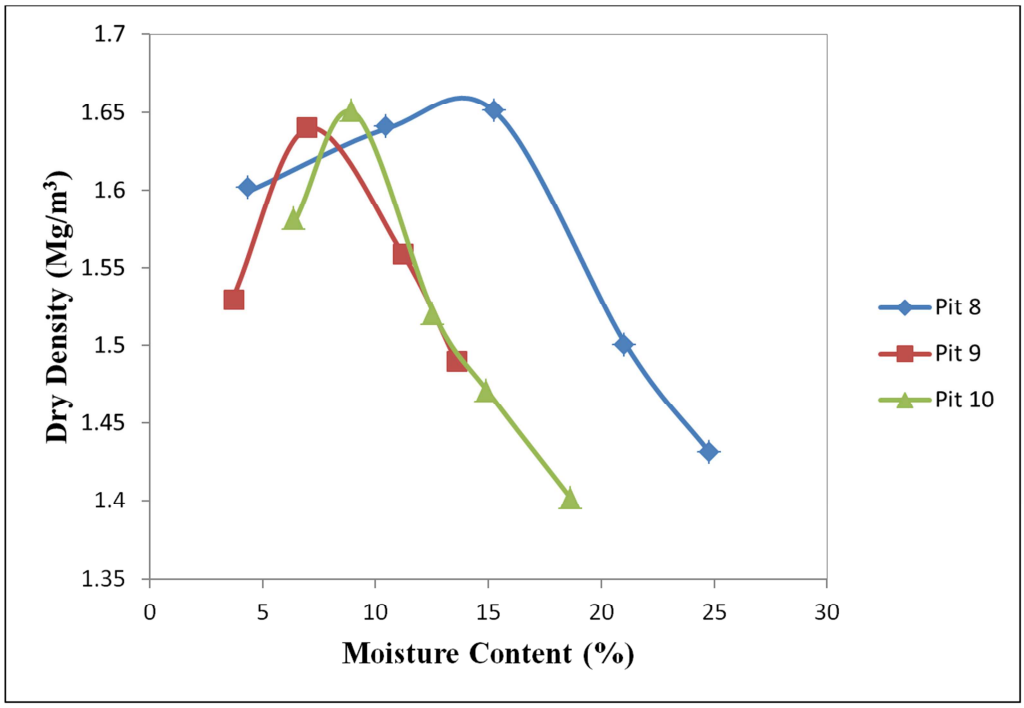

Figure 7. *Dry density-water content relationship plots for Pit 8, 9 and 10.*

4. Discussion of Results

Table 1 shows the moisture content of all the ten (10) samples collected at selected places in Otukpa community. It ranges from a lower value of 15.20% to a maximum value of 29.83% which belongs to pit 8 and pit 1 respectively. The average moisture content of soils is about 22.14%.

According to [11], if the plasticity index of soils ranges from 0 – 15, it indicates low plasticity, with range of 15 – 30 indicating moderate plasticity. This follows that pit 2 is a sample with moderate plasticity while the other samples are of low plasticity as shown in table 2.

Also [12] says that liquid limit below 30% indicates a low liquid limits, with liquid limit between 30 – 40% is described as medium while 40% and above is refers to as high liquid limit. This implies that in table 2, soil samples from pit 1 to 5 has medium liquid limits while that of pit 6 – 10 has low liquid limits.

Table 3 gives the specific gravity of the soil particles of samples collected from pit 1 to pit 10. The lowest value is sample from pit 5 with 2.45 with highest being sample from pit 8 and pit 10 which are both 2.8. According to [9], typical values of specific gravity of clay ranges from 2.70 – 2.80 which shows that samples from pit 8, 9 and 10 are clay soil particles.

Figure 1 and 2 shows the sieve analysis grading curves from the combination of both mechanical sieve analysis and hydrometer tests. The grading curves show that the soils are well-graded. Table 4 shows the results of coefficient of uniformity (Cu) and coefficient of curvature (Cc) obtained from the graphs and the percentage passing BS sieve no. 200 (0.075 mm) which helps in naming the soils and soil symbol. This shows that the soil is made up of high clay soil particles with samples from pit 6 to 10 described as clayey sand and that of pit 1 to 5 being more of lean clay.

Result from tables 1, 2 and 4 with the help of AASHTO classification system was also used to classify the soil according AASHTO which shows that the soils falls under group A-6 soils with the significant constituent material being clayey soil. This corresponds with the results for the specific gravity of pit 6 to 10.

From the compaction test, Figure 1 shows the dry density-moisture content relationship of pit 1 to 4 samples, figure 2 shows that of pit 5 to 7 while figure 3 shows that of pit 8 to 10. The optimum moisture content (OMC) and maximum dry density (MDD) are obtained from the graphs. Table 5 shows the OMC and MDD of the various pit samples obtained from compaction test graphs. The results shows that samples from pit 9 has the lowest OMC of 7.0% with that of pit 5 having the highest at 15.0%. The average OMC of all the samples is 12.11%. The MDD obtained shows that sample from pit 7 has the highest at 1.72 Mg/m^3 while pit 1 has the lowest at 1.50 Mg/m^3. The average MDD of all the samples is 1.61 Mg/m^3.

5. Conclusion

The tests results obtained reviews that Otukpa soil particles have high percentage of clay in it with lean clay and clayey sand the major two types of soils found in Otukpa. The liquid limit of lean clay ranges from 28 to 40%, while that of clayey sand ranges from 20.50 to 25%. The plasticity index ranges from 10.27 to 24. 41% and 5.25 to 9.48% for the lean clay and clayey sand respectively. The specific gravity of the soil particles (*Gs*) of the lean clay soil ranges from 2.45 to 2.60 which suggest some organic matter in the

samples while the *Gs* of clayey soils range from 2.70 to 2.80. The maximum dry density (MDD) of the soil ranges from 1.50 Mg/m^3 to 1.72 Mg/m^3 while the optimum moisture content (OMC) ranges from 7.00% to 15.00%.

The silty clay, clayey-sand and mixture of clay particles being predominant in Otukpa soils imply that the soil is cohesive. This type of soils exhibit undesirable engineering properties compare to granular soils [13]. Clayey soils exhibit low shear strength and upon wetting can lose shear strength. They can be plastic and compressible, expands upon wetting and shrinks upon drying. When cohesive soils are subjected under constant load for a given period of time, they exhibit a relatively large volume change when the soil is saturated or dried and deform plastically (creep) [13, 14].

Since Otukpa soil is predominately clay, the swell and cracks movement (alternate expansion and contraction) could be responsible for the cracks observed on buildings in Otukpa. Hence engineers are advice to take this into play when designing structures for the area.

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