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ASSESSMENT OF SELECTED EARTH DAM FILL MATERIALS FOR CONSTRUCTION AND SUSTAINABLE DEVELOPMENT

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ABSTRACT

This study presents assessment of some geotechnical properties of selected fill materials around Minna, Niger State for earth dam construction. Standard tests were carried out on 27 lateritic soil samples collected. Particle size analysis revealed that ten of the lateritic samples were gap-graded, while six were poorly graded. The compaction characteristics, MDD ranged between 1.65 to 1.99 g/cm^3, with the OMC range of 9.8 – 21.2%. The hydraulic conductivity (k) ranged from 10^{-5}-10^{-9} cm/s. The work further revealed average values of confined compressive strength (*CCS*), Cohesion (C), angle of internal friction (φ) as 397.7 kN/m^2, 99.49 kN/m^2 and 20.60 respectively. These range of values are within the threshold for soil suitable as fill materials for earth dam construction. Knowing the properties and sources of good materials for dam construction, will not only check the rising flood menace but also contribute to sustainable socio-economic development of the nation and enhances green infrastructure.

Keywords: *Dam construction, Embankments, Fill materials, Geotechnical properties, Soil*.

1. INTRODUCTION

The geotechnical properties of fill materials for earth dam construction is of paramount importance in the construction industry. The type of soil depends on the rock type, its mineral constituents and the climatic regime of the area. Soil used as constituent material in civil engineering structures are founded in or on the earth surface. Geotechnical properties of soils influence the stability of civil engineering structures (Surendra and Sanjeev, 2017).

Civil engineering structures like building, bridge, highway, tunnel, dam and towers are founded below or on the surface of the earth. To check the suitability of soil to be used as foundation or as construction materials, its properties are required to be assessed (Laskar and Pal, 2012; Craig, 2004).

According to Ogedengbe and Oke (2006), assessing geotechnical properties of subsoil at project site is necessary for generating germane input data for design and construction of foundations for the proposed structures. Ogedengbe and Oke (2010) affirmed that, proper design and construction of civil engineering structures prevent an adverse environmental impact or structural failure or post construction problems. Detailed explorations are carried out to determine the engineering properties of soils (Arora, 2008).

Dams are constructed to impound water for diverse uses. This include, domestic, industrial, construction, irrigation and hydro-electric power generation. Earth dams still strive in Africa because of the ease of construction and relatively lower cost, when compared with other types of dam (Ogedengbe and Oke, 2010).

The compromises of guidelines and standards for materials have contributed to the collapse of dams and other hydraulic structures in Nigeria in the past years (Ogedengbe and Oke, 2006). Soil materials used in embankment dams are commonly obtained by mass production from local borrow pits, and from required excavations where suitable (USSD, 2011).

Leakage due to improper fill materials has be linked to 40% failure in dam (FAO, 2001). Fill materials must be properly selected and studied to be free from soluble element such as sodium which can easily be mobilize when wet and under load thereby making the dam unstable (FAO,2006). Inadequate control of the compaction characteristics of fill materials causes the occurrence of internal erosion and piping (Flores-Berrones and López-Acosta, 2019).

According to Karsten *et al.* (2006), the shear strength of fill material is one of the fundamental parameters for analyzing and solving stability problems of determining earth pressure, bearing capacity of footings and foundations, slope stability or stability of embankments and earth dams. Jain *et al*., (2015), reported that the stability of soil strength and slope stability depend on the shear strength parameter of clayey soil due to the high compactive effort when applied to such soil. Also James *et al*. (1963) indicate that for a stable embankment slope, the soil most exhibit low angle of friction and relative high cohesion. Most unsaturated soils have good shear strength properties required for both earth dam and rock-filled dams (Alonso and Cardoso, 2014). Although the effect and control of seepage through earth-fill dam can be herculean, having a fill material with good properties ameliorates these task (Omofunmi *et al*., 2017; Dafalla, 2013)

Knowing the properties and sources of good fill materials for dam construction, will not only check the rising flood menace but also contribute to sustainable socio-economic development of the state, and nation at large. It will also enhance green infrastructure. This study assessed the geotechnical properties of selected fill materials in Minna, Niger, State for earth dam construction and other socio-economic developmental purposes.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials for the study was collected from three selected borrow pits; Maikunkele, Pyata and LapaiGwari, all located in the suburbs of Minna, Niger State. Using disturbed sample collection technique, sample materials were collected at 0.5, 1.0 and 1.5m depth. The samples were transported to Geotechnical laboratory, Civil Engineering department, Federal University of Technology, Minna for analysis.

2.2 Methods

Index properties of fill materials: Natural moisture content, specific gravities, particle size analysis and Atterberg limits tests were conducted in accordance with tests procedures specified in BS 1377 (1990).

Compaction characteristics: Compaction of the samples was conducted in accordance with the guidelines specified in BS 1377 (1990) to compute the required parameters. The Reduced British Standard Heavy (RBSH) compactive effort was used. The RBSH compaction is the energy resulting from 4.5 kg rammer falling through a height of 30 cm onto three layers, each receiving 25 blows to determine MDD and OMC of the samples according to ASTM D-698 (1992) and ASTM D-1557 (1992).

Confined compressive strength (CCS): The CCS test was conducted in accordance with the procedure specified in BS, 1377 (1990), to determine the values of C and φ using the values of OMC obtained during compaction results from Reduced British Standard Heavy compaction method.

Hydraulic conductivity: The rate of drainage of water through wells and excavated foundation pits depends on the coefficient of permeability of the soils. Shear strength of soils also depends indirectly on its permeability, because dissipation of pore pressure is controlled by its permeability. According to United State Bureau of Reclamation (2011), soils are classified as (i) *Impervious*: for coefficient of permeability (k) less than 10^{-6} cm/sec (ii) *Semi pervious*: k between 10^{-6} to 10^{-4} cm/sec (iii) Pervious: k greater than 10^{-4} cm/sec according to ASTM D-7664 -10 (2018).

Figure 1: Compacted samples in moulds

Figure 2: Samples in permeability apparatus

3.0 DISCUSSION OF RESULTS

3.1 Index properties of the samples

Natural moisture content: The moisture content of the soil obtained soil gave wide range of values. An average value of 19.32% range of 18.21-20.40 % from Maikunkele borrow pit, an average of 15.70% with range from 13.59-16.45% from Pyata borrow pit and an average of 17.97% with range of 15.70-22.43% from LapaiGwari borrow pit was obtained for natural moisture content. Detail of natural moisture test results is shown on Table 1.

Table: 1 Natural moisture content of fill materials samples

Location	Natural moisture (%)	Average (%)
Maikunkele		
A	18.21	
B	19.36	19.32
C	20.40	
Pyata		
A	13.59	
B	16.45	15.33
C	15.99	
Lapai Gwari		
A	22.43	
B	15.70	17.97
C	15.79	

Consistency Properties of Soil Samples:

Consistency or Atterberg limits are defined by Liquid limits, LL; plastic limits, PL and shrinkage limit, SL. Atterberg limits reveals the consistency of soils.

The difference between the LL and PL is known as the plasticity index (PI). Index property tests conducted on the lateritic soil samples yielded the following results. An average value of 19.32%, 15.70% and 17.97% for the natural moisture content of samples from Maikunkele, Pyata and LapaiGwari borrow pits respectively.

An average value of 51.50% and 15.59%, 50.89% and 11.96%, 44.26% and 14.47% for Liquid limits and Plasticity indexes of samples from Maikunkele, Pyata and LapaiGwari borrow pits respectively.

Compaction test of the fill material: The compaction characteristics of the individual lateritic soil samples were determined in the laboratory by the British Standard Heavy (BSH) method, in tandem with the intended purpose, which is dam construction.

The compaction characteristics also referred to as the moisture density relationship include maximum dry density (MDD) and optimum moisture content (OMC).

The range of MDD values were between 1.6597 – 1.8097 g/cm^3 with mean value of 1.7262 g/cm^3 for Maikunkele borrow pit and OMC ranges from 12.260 – 17.580% with mean OMC of 15.89%, the MDD ranges from 1.6123 –1.9384% with mean value of 1.7668% and the OMC ranges from 11.810 – 18.050% with mean value of 15.1317% for Pyata borrow pit and MDD ranges from 1.7293 – 1.9907% with mean value of 1.8471% and the OMC ranges from 9.820 – 21.180% the mean value is 14.4167% from LapaiGwari borrow pit as shown in Table 2.

Table 2: Compaction test result

Location	Depth (m)	Maximum dry density (g/cm^3)	Optimum moisture content (%)
MKL A1	0.5	1.7530	17.580
MKL A2	1.0	1.6986	15.610
MKL A3	1.5	1.7258	15.690
MKL B1	0.5	1.6802	15.230
MKL B2	1.0	1.6597	18.210
MKL B3	1.5	1.8097	12.260
MKL C1	0.5	1.7018	16.930
MKL C2	1.0	1.7349	17.540
MKL C3	1.5	1.7723	13.975
PYT A1	0.5	1.7584	18.050
PYT A2	1.0	1.7297	16.550
PYY A3	1.5	1.7874	14.940
PYT B1	0.5	1.6869	15.690
PYT B2	1.0	1.6123	18.980
PYT B3	1.5	1.6778	12.790
PYT C1	0.5	1.9378	13.470
PYT C2	1.0	1.9384	11.810
PYT C3	1.5	1.7727	13.450
LPG A1	0.5	1.8260	11.210
LPG A2	1.0	1.8793	10.770
LPG A3	1.5	1.7254	21.180
LPG B1	0.5	1.8026	14.620
LPG B2	1.0	1.8797	9.820
LPG B3	1.5	1.7293	13.920
LPG C1	0.5	1.9907	10.330
LPG C2	1.0	1.8601	12.130
LPG C3	1.5	1.9304	12.320

Hydraulic conductivity: The results shows that the coefficient of permeability ranges from 10^{-6}–10^{-9} cm/s which is an indication that the soil is silt to clay. Samples from Maikunkele borrow pit has a range from 10^{-6} – 10^{-9} cm/s, with mean value of 10^{-8} cm/s. According to Bear (1972) and Kanchana and Prasanna (2015, the soil is impervious, that is an indication that the soil is silt and clay which is a very good embankment fill material to serve as core due to its impervious nature. Pyata borrow pit has value range from 10^{-6} – 10^{-8} cm/s, it is also imperious it shows that the soil is fine sand and silt with little clay content. It can only be used as core for the embankment fill. LapaiGwari borrow pit has a range from 10^{-5}–10^{-8} cm/s that is from semi-pervious to impervious soil as shown in Table 3. From this results, and using Casagrande (1940), which stated that, the lower the hydraulic conductivity the lower the movement of water through the soil.

Therefore, in the whole, the sample from Maikunkele has higher ability to retain water, followed by sample from Pyata while LapaiGwari has the least ability to retain water and less suitable as filled material for dam construction.

Table 3: Hydraulic conductivity of samples

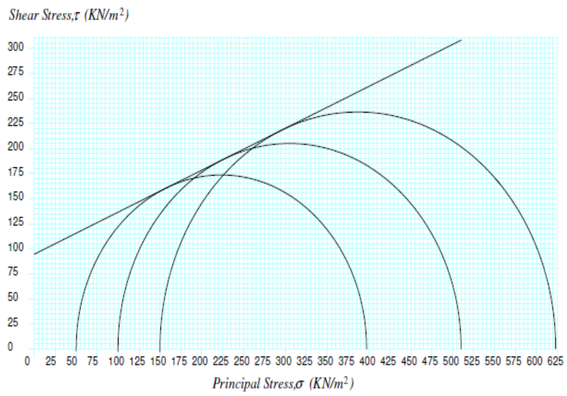
Location	Depth (m)	Value of k(cm/s)
MKL A1	0.5	1.5909×10^{-7}
MKL A2	1.0	1.2113×10^{-8}
MKL A3	1.5	7.494×10^{-7}
MKL B1	0.5	3.1580×10^{-6}
MKL B2	1.0	1.5606×10^{-6}
MKL B3	1.5	1.4349×10^{-8}
MKL C1	0.5	2.3802×10^{-9}
MKL C2	1.0	1.5203×10^{-8}
MKL C3	1.5	2.3920×10^{-6}
PYT A1	0.5	2.7790×10^{-7}
PYT A2	1.0	6.9480×10^{-8}
PYT A3	1.5	9.4349×10^{-8}
PYT B1	0.5	8.1060×10^{-6}
PYT B2	1.0	1.4825×10^{-8}
PYT B3	1.5	1.3021×10^{-6}
PYT C1	0.5	2.1210×10^{-6}
PYT C2	1.0	1.8230×10^{-8}
PYT C3	1.5	1.5100×10^{-7}
LPG A1	0.5	2.7790×10^{-6}
LPG A2	1.0	1.3890×10^{-5}
LPG A3	1.5	2.9480×10^{-6}
LPG B1	0.5	1.3202×10^{-7}
LPG B2	1.0	2.2990×10^{-7}
LPG B3	1.5	3.0364×10^{-8}
LPG C1	0.5	1.6213×10^{-7}
LPG C2	1.0	2.0265×10^{-7}
LPG C3	1.5	2.3161×10^{-7}

The result obtained from shear strength test, the soil that contain mostly granular materials classified as A-3, with angle of internal friction (φ) of 22.73° and cohesion (*C*) 94.46 kN/m^2, A-5 and A-6 which contain mostly silt and clayey materials has angle of internal friction (φ) 12.27° and 18.36°, and cohesion (*C*) of 148.67 kN/m^2 and 60.98 kN/m^2 respectively. A-7-5 and A-7-6 soil also contain silt and clayey materials mostly with angle of internal friction (φ) 23.87° and 25.78°, and cohesion (*C*) of 67.37 kN/m^2 and 125.49 kN/m^2. According to Unified Soil Classification (USC) and American Association of State Highways Transportation Officers (AASHTO) systems, the soil ranges from inorganic silt to inorganic clay of high plasticity (CH to MH) or A-3, A-5, A-6, A-7-5 and A-7-6 majorly

Triaxial test of Samples: The results of the triaxial test of samples was analyzed and to obtain the Confined Compressive Strength (CCS). The Mohr cycle diagrams of representative cluster samples are shown in Figures 3-7.

Test no:	Cell Pressure, σ_3 (KN/m^2)	Compressive Strength, σ_2 (KN/m^2)	Principal Stress, σ_1 (KN/m^2)	Bulk Density	Moisture Content
1	50	347,00	397	17.53	14.94
2	100	410,00	510	17.53	14.94
3	150	473,00	623	17.53	14.94

ϕ = 22,73 c = 94,46

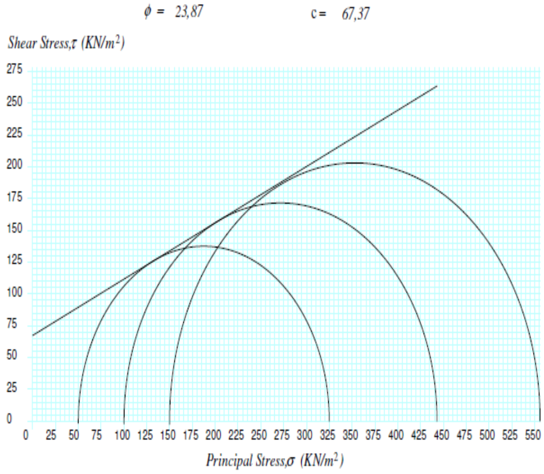


Test executed by : Engr. Ramatu Ibrahim

Figure 3: Mohr cycle diagram for A-3 soil

Test no:	Cell Pressure, σ_3 (KN/m^2)	Compressive Strength, σ_2 (KN/m^2)	Principal Stress, σ_1 (KN/m^2)	Bulk Density	Moisture Content
1	50	275,00	325	17.68	14.62
2	100	343,00	443	17.68	14.62
3	150	406,00	556	17.68	14.62

ϕ = 23,87 c = 67,37

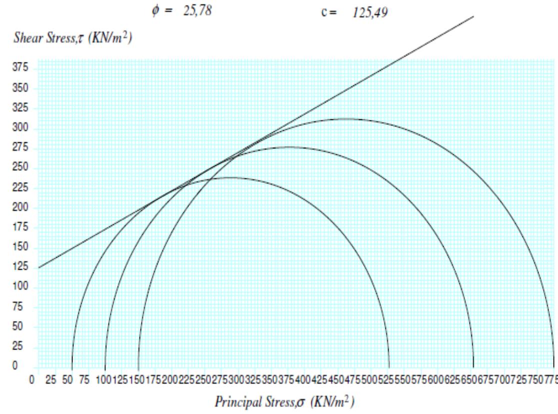


Test executed by : Engr. Ramatu Ibrahim

Figure 4: Mohr cycle diagram for A-7-5 soil

Test no:	Cell Pressure, σ_3 (KN/m^2)	Compressive Strength, σ_2 (KN/m^2)	Principal Stress, σ_1 (KN/m^2)	Bulk Density	Moisture Content
1	50	477,00	527	17.75	12.26
2	100	554,00	654	17.75	12.26
3	150	625,00	775	17.75	12.26

ϕ = 25,78 c = 125,49

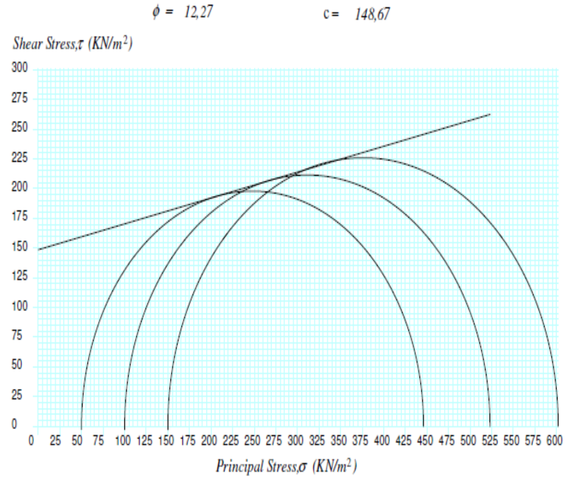


Test executed by : Engr. Ramatu Ibrahim

Figure 5: Mohr cycle diagram for A-7-6 soil

Test no:	Cell Pressure, σ_3 (KN/m^2)	Compressive Strength, σ_2 (KN/m^2)	Principal Stress, σ_1 (KN/m^2)	Bulk Density	Moisture Content
1	50	396,00	446	19.02	11.81
2	100	423,00	523	19.02	11.81
3	150	452,00	602	19.02	11.81

ϕ = 12,27 c = 148,67



Test executed by : Engr. Ramatu Ibrahim

Figure 6: Mohr cycle diagram for A-5 soil

Test no:	Cell Pressure, σ_3 (KN/m^2)	Compressive Strength, σ_2 (KN/m^2)	Principal Stress, σ_1 (KN/m^2)	Bulk Density	Moisture Content
1	50	215,00	265	16.96	13.92
2	100	261,00	361	16.96	13.92
3	150	312,00	462	16.96	13.92

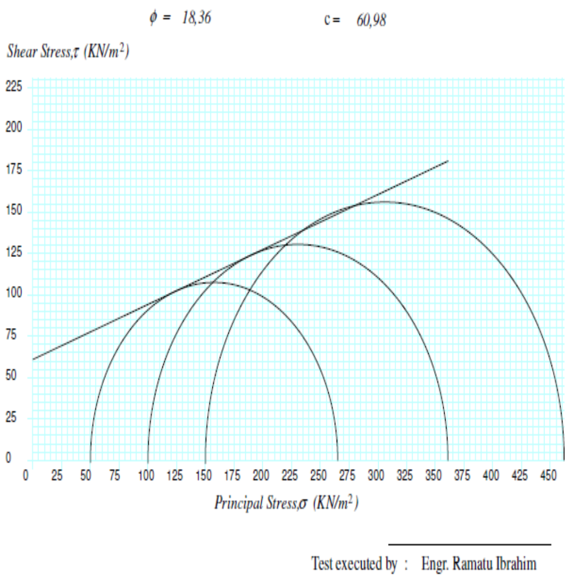


Figure 7: Mohr cycle diagram for A-6 soil

4.0 CONCLUSION

From the assessment of selected earth dam fill materials for construction and sustainable development, the following conclusions were drawn:

1. Ninety-six (96%, 26 out of 27) of the test samples are good fill materials for earth dam construction for maximum functionality.

2. The compaction characteristics, MDD ranged between 1.65 to 1.99 g/cm^3, with the OMC range of 9.8 – 21.2%. The hydraulic conductivity (k) ranged from 10-5-10-9 cm/s. The work further revealed average values of confined compressive strength (CCS), Cohesion (*C*), angle of internal friction (φ) as 397.7 kN/m^2, 99.49 kN/m^2 and 20.6^0 respectively.

3. Fill materials from borrow pits in Maikunkele, Pyata and LapaiGwari suburbs of Minna, Niger state, or from other places with exact or nearly exact geotechnical properties, could be used as fill materials for construction of earth dam.

4. With flashes of flood and its devastating impacts on socio-economic development recently, research into material sorting and sourcing for earth dam construction, where this water body can be channeled for application in irrigation, green infrastructural provision and other uses has been carried out.

5. Knowing the properties and sources of good fill materials for dam construction, will not only check the rising flood menace but also contribute to sustainable socio-economic development of the state, and the nation at large.

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