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Geotechnical Evaluation of Opa Dam, Obafemi Awolowo University, Ile-Ife, Nigeria

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Abstract
Geotechnical evaluation of Opa Dam situated at Obafemi Awolowo University, Ile-Ife, Nigeria, was carried out. Soil samples were collected from both the upstream and downstream sections of the dam; laboratory soil tests and analysis were carried out. The soils were found to be highly active, thus suggesting that excessive shrinkage during dry season may be a challenge.

Keywords *– compaction, dam, geotechnical properties, lateritic soil, shrinkage.*

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I. Introduction

Opa dam is an earth dam situated within the Obafemi Awolowo University (OAU) campus, Ile-Ife, serving the OAU community in terms of water needs/consumption. By virtue of its being an earth dam, an understanding of the geotechnical properties is of utmost importance, most especially considering the foundation materials and the embankments (lateritic soils). In the design of earth dam shear strength of soil, pore water pressure, consolidation of soil and permeability (among other considerations) are very essential factors to note [1, 2, 3, 4, 5]. The word soil to an engineer means any naturally occurring loose or soft deposit resulting from weathering or breakdown of rock formation or from the decay of vegetation [6]. Soil can also be defined as a material that can be built on (i.e. foundations to buildings and bridges); built in (i.e. tunnels, culverts and basements); built with (i.e. roads, runways, embankments and dams) and supported (i.e. retaining walls and quays).Laterite has been widely defined as a highly weathered material, rich in secondary oxides of iron, aluminum, or both. It is void or nearly void of bases primary silicates, but it may contain large amounts of quartz and kaolinite [7]. A distinctive feature of laterite and lateritic soils is the higher proportion of sesquioxides of iron and/or aluminium relative to the other chemical components. A soil is characterized as laterite, lateritic soil or non laterite according to the ratio of silica oxide and sesquioxides present in it. In laterites the ratios are less than 1.33; those between 1.33 and 2.0 are indicative of lateritic soil; and those greater than 2.0 are indicative of non-lateritic soil [8].

Latentic soils are formed in hot, wet tropical regions with an annual rainfall between 750mm to 3000mm (usually in area with a significant dry season) on a variety of different types of rocks with high iron content. The locations on the earth that characterized the condition fall in between latitudes 35^{o}S and 35^{o}N. Laterite formation factors include climate (precipitations, leaching, capillary rise, and temperature) to topography (drainage), vegetation, parent rock (iron – rich rocks) and time. Of all these primary factors, climate is considered the most important [9]. Laterites may occur as surface deposits of unhardened clayey soils, gravels, and as hard pans [10]. Thus, genesis and pedological factors (parent materials, climate, vegetation, topography, weathering period), degree or weathering (decomposition, sesguioxide enrichment, clay–size content, degree of leaching), position in the topographic site and depth of soil in the profile have great influence on the geotechnical properties, characteristics and field performance of lateritic soil [11]. It was observed that there are no available data on the geotechnical properties of lateritic soil within the study area. This scenario has therefore prompted the need for this study. Hence, the scope of this study is limited to geotechnical study of soils at Opa dam (excluding other factors which affect the performance of soil, for example clay mineralogy or chemical analysis).

1.1 Location and Geology of the Study Area

The soil samples used in this study were obtained from Opa dam, Obafemi Awolowo University (OAU), Ile-Ife. Ile –Ife lies between latitude 7° and 28°N and longitude 4° and 34°E. Fig. 1 is a location map of OAU showing the location of Opa dam. Geologically, the study area falls within the basement complex of southwestern Nigeria (Fig. 2). It forms part of the African crystalline shield which consists predominantly of migmatised and undifferentiated gneisses and quartzite [12, 13].

II. Materials And Methods

Preparation of Specimens: The materials used were soil samples taken from both the upstream (S1) and downstream (S2) sections of the dam location and 2% sodium hexametaphosphate (calgon) which was prepared by dissolving 2g of calgon in 1 liter of distilled water. Samples and specimens were prepared in accordance with [14] and [15]. Prior to preparing the test specimens, the natural moisture contents of the soil samples were determined after which the samples were air dried in the laboratory and then broken into smaller fragments, care being taken not to reduce the sizes of the individual particles.

Test Procedures: The following tests were conducted on the prepared soil samples: sieve analysis, Atterberg limit, linear shrinkage, specific gravity and compaction. The procedures of the tests are discussed below:

Sieve Analysis: The methods employed for the grain-size distribution analysis were dry sieving and wet sieving (hydrometer analysis). For dry sieving, representative sample of approximately 500g was used for the test after washing and oven-drying. The sieving was done by mechanical method using an automatic shakers and a set of sieves. For wet sieving (hydrometer analysis), about 500g of soil was washed through a 2mm BS sieve rested in a 63µm BS test sieve. The material passing through 63µm sieve containing the silt and clay was collected and allowed to settle. It was put into evaporating dishes and then put in the oven at 105^{o}C for about 24 hours. About 50g of the soil sample was obtained from the oven dried and mixed with water to create heavy slurry. 2g of sodium hexametaphosphate was mixed with the slurry. The mixture was placed inside the 1000ml cylinder to the 1000ml mark. The other 1000ml cylinder was filled with water to act as a constant temperature bath. Hydrometer readings of the suspension were then taken after periods of ½ min, 1 minute, 2 minutes and 4 minutes. The hydrometer was inserted into suspension and readings taken after periods of 8 minutes, 15 minutes, 30 minutes, 1 hour, 2 hours, 4 hours, 8 hours, 12 hours and 24 hours to complete a whole day. The temperature of the suspension was observed and recorded once during the first 15 minutes and then after every subsequent reading.

Liquid Limit Determination: Soil sample passing through 425µm sieve, weighing 200g was mixed with water to form a think homogeneous paste. The paste was collected inside the Casagrande's apparatus cup with a grove created and the number of blows to close it was recorded. Also, moisture contents were determined.

Plastic Limit Determination: Soil sample weighing 200g was taken from the material passing the 425µm test sieve and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3mm diameter. Therefore, the moisture contents were determined.

Natural Moisture Content: The soil samples used for natural water content determination were those collected from in-situ soil mass and were tested immediately. Two weighing cans were cleaned, dried and weighed to the nearest 0.01g. Representative samples were crumbled and place loosely in the containers. The containers and contents were then weighed to the nearest 0.01g, after which the containers plus contents were placed in the oven and dried at 105^{o}C for 24 hours. After drying, the containers were re-weighed to the nearest 0.01g. The moisture content was then calculated.

Specific Gravity: The apparatus used include gas jar, weighing balance. About 100g of the air-dried soil sample passing 425mm sieve was added to a clean gas jar. The gas jar was then half-filled with water and fit with the seal; the gas jar was shaken to form a suspension. The seal was then removed with more water added, first below the top of gas jar and finally to top it up. Extreme care was taken not to form froth or entrap air. The gas jar was then weighed. The gas jar was then thoroughly cleaned, and filled completely with water and reweighed.

Shrinkage Limit: The apparatus used were two palette knives, a flat glass plate, thermostatically controlled drying oven capable of maintaining a temperature of 105^{o}C to 110^{o}C, a linear shrinkage limit device and 425mm BS sieve. Some amount of soil sample that passed through the 425mm BS test sieve was mixed thoroughly with an amount of water which approximately equals to the plastic limit to form a uniform paste.

The paste was put in linear shrinkage device and the length (initial) of the soil was measured. The soil was air-dried for about 2-3 hours before being placed in the oven so that the soil does not lose water rapidly and cause cracking. The final length of soil in the device was measured after oven-drying for about 24 hours.

Compaction Test: The apparatus used included a cylindrical metal mould having a volume of 0.000956m^3, 4.kg rammer that falls through a height of 450mm, semi automatic balance, a scoop, a large tray, apparatus for moisture content determination, hydraulic extruder and the collar for the mould. About 3 kg of air-dried soil was mixed thoroughly with 6% water. The soil was then filled into the mould, which had been previously weighed. The extension collar was attached during compaction and the soil was compacted in three layers and each layer was given 25 blows. The collar was removed and the compacted soil was removed by making use of the extruder. Representative samples were then taken from the top and bottom of the specimen for moisture content determination. The soil was broken up, mixed with remaining soil and mixed with 3% of the water to give higher moisture content and the whole process of compaction was repeated.The whole procedure was repeated until the weight of mould and soil had fallen down appreciably. The corresponding dry density (DD) and moisture content (MC) were then evaluated and a graph of DD versus MC plotted to obtain the appropriate maximum dry density (MDD) and the corresponding optimum moisture content (OMC) for the samples.

III. RESULTS AND DISCUSSION

The implications of the value obtained for the natural moisture contents (16.90% and 14.75% for S1 and S2 respectively) cannot directly be identified with any of the soil engineering properties because of the fact that this moisture content level depends on prevailing climatic condition as at the time of sample collection.

Particle size distribution: From the results obtained from the sieve analysis, 55% of sample S1 passes through No. 200 BS sieve, while 64.60% of sample S2 passes No. 200 BS sieve. It therefore means that the soils could be described as silty-clay and fall to the category of A-7, according to Unified Soil Classification System (USCS).

Atterberg Limits: The liquid limit was found to be higher for sample S1 (41%) and its plastic limit was found to be 30.73%, as against 24.84% for S2. S1 also has a higher plasticity index of 10.27%, which implies that S1 (with the higher P.I value) has inherent swelling potential shrinkage tendency as evidenced in the shrinkage limit values in Table 4.

Specific gravity: The specific gravity of the tested samples is 2.86 for S1 and 2.94 for S2. [16] stated that the standard range of values of specific gravity of soils lies between 2.60 and 2.80. However, lower specific gravity values indicate a coarse soil, while higher values indicate a fine grained soil [14]. Thus, it could be concluded that the soils are fined grained.

Compaction: The maximum dry density for the soil samples shows that sample S1 has a value of 1.92mg/m^3 while sample S2 has a value of 1.95mg/m^3. The optimum moisture content values are 20.00% and 15.00% for samples S1 and S2 respectively. According to [17], as reported by [18], the range of values that may be anticipated when using the standard proctor test methods are: for clay, maximum dry density (MDD) may fall between 1.44mg/m^3 and 1.685mg/m^3 and optimum moisture content (OMC) may fall between 20-30%. For silty clay MDD is usually between 1.6 and 1.845mg/m^3 and OMC ranged between 15-25%. For sandy clay, MDD usually ranged between 1.76 and 2.165Mg/m^3 and OMC between 8 and 15%. This confirms that the soils are silty-clay. Physical properties of soil samples are presented in Table 1. Particle size and compaction results for the soil samples are illustrated in Fig. 3 and Fig. 4 respectively.

IV. Conclusion

The geotechnical evaluation of Opa Dam, Obafemi Awolowo University, Ile-Ife, Nigeria has been carried out in compliance with [14] and [15] methods of soil testing for Civil engineers. The results showed that the studied soil samples are active due to the fact that they have activity values greater than 1.25 [17], meaning that excess shrinkage during dry season may be a challenge at the site. The soils are classified as silty clay, belonging to subgroup classification A-7. The soils on the upstream and downstream behave almost the same way and this could be adduced to the geological genesis and the pedological factors (parent material) of the soil samples; while other factors such as climate, sesquioxide enrichment and topography, etc., which may affect the resulting properties of the soils, are practically held constant. Sample S2 was found to have higher specific gravity; this shows that soil at downstream section of the dam has experienced higher degree of lateritisation.

I. FIGURES AND TABLES

Figure 1: Location map of OAU campus [12]

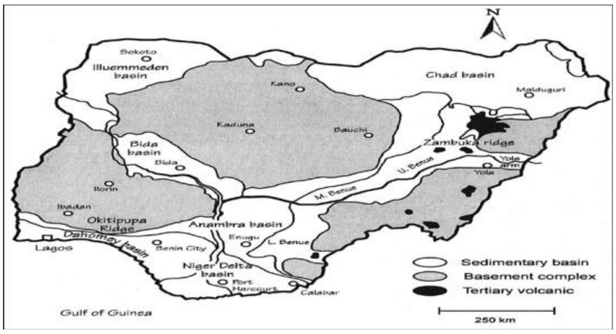
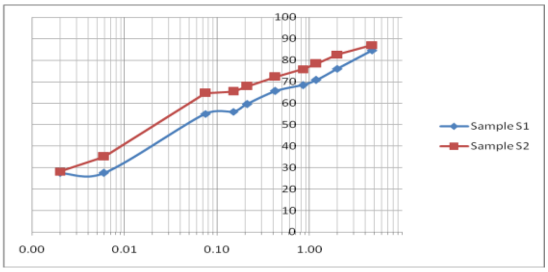
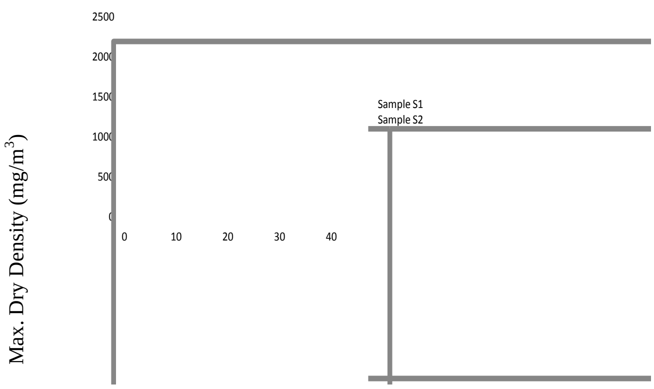


Figure 2: Map of the major geological formations of Nigeria [20]



Equivalent particle size (mm)

Figure 3: Particle size distribution of soil samples



Moisture content (%)

Figure 4: Compaction values for soil samples

Table1: Physical Properties of Soil Samples

Samples	S1	S2
Natural moisture content (%)	16.90	19.75
% passing 0.075µm	55.00	64.60
Liquid Limit (%)	41.00	31.00
Plastic Limit (%)	30.73	24.84
Plasticity Index (%)	10.27	6.16
Maximum dry density(mg/m^3)	1.92	1.95
Optimum moisture content (%)	20	15
AASHTO classification	A-7	A-7
USCS classification	SC	SC
Specific gravity	2.86	2.94
Activity	13.42	13.92
Void ratio	0.493	0.503
Porosity	0.330	0.335
Permeability	0.36	0.36

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