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*RESEARCH ARTICLE*

# GEOTECHNICAL INVESTIGATION OF THE PROPOSED IFE DAM SITE AT KAJOLA VILLAGE, ILE-IFE, SOUTHWESTERN NIGERIA

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**ABSTRACT**

Geological and geophysical investigations were conducted to assess the competence and structural integrity of the foundation site of the proposed Ife-dam at Kajola Village, Ile-Ife, Southwestern Nigeria. Geological investigation along the two (2) proposed dam axes revealed that the overburden material is loose to dense with angular shearing resistance (ɸ) of 27° to 41°. The soils are predominantly elastic silts; cohesive with considerable strength and stability. Geophysical investigation involving the Schlumberger Vertical Electrical Sounding delineated four (4) lithologies namely: topsoil with resistivity of 69 – 558 Ωm and thickness between 1.5 and 4.0 m; weathered sandy layer with resistivity from 123 – 586 Ωm and thickness between 6.5 and 20.4 m; partially weathered/ fractured basement with resistivity from 60 – 220 Ωm and thickness between 6.5 and 14.0 m; and the fresh basement rock with resistivity from 1337 – 10683 Ωm. There are indications of fractures at a depth of 32 m beneath Axis B extending to Axis A at a depth of 35 m. The subsurface materials are suitable to host a dam. Axis B is more appropriate for the dam axis, although the fracture zone should be factored into the design of the dam to prevent water seepage.

**KEYWORDS**

geological mapping, geotechnical investigation, geophysical investigation, Kajola dam site, Osun State

## 1. INTRODUCTION

Water supply to a community can either be from surface or groundwater sources or both. Surface water sources such as rivers, lakes and oceans occur on the surface of the earth. Surface water sources have the advantage of being easily accessible, although they are relatively more expensive to develop and are more prone to pollution than groundwater sources.

Surface water exploitation for community use involves the extraction of large volumes of water from a river or lake. In the case of a river, a barrier or dam needs to be constructed across the river to hold back the flow of water, thereby creating a large body of water called dam reservoir, that can be used for single or multiple purposes (Chen et al., 2002). Various types of dams, such as earth fill dam, rockfill dam and concrete gravity dam, can be constructed across a river. The earth fill dam has earth materials such as clay as the major foundation material. The rockfill dam has rock materials as the major foundation material, while the foundation of a concrete gravity dam is made of concrete material. The basic dam foundation requirements which include the proposed dam load, deformation and permeability of the site material are based on the type of dam to be constructed. In some cases, the topsoil material may not be suitable as foundation material hence, the topsoil has to be excavated in order to achieve an adequate foundation. The depth of excavation can be determined through boring and test pits, field testing of soil or rock and laboratory analysis of representative soil samples.

In Nigeria, the several needs for the construction of small dams have been identified, including supply of water for irrigation, municipal water supply, industrial uses and for flood control.

An earth fill dam can supply water for human and animal consumption and irrigation purposes. In a small earth fill dam, the water impounded by the construction of an earth embankment could be between 3 m and 5 m high and several tens or hundreds of m long across the river channel. The integrity of a dam embankment can be undermined by the existence of geological features such as faults, joints, fissures or shear zones beneath the dam axis, seepage zones in the bedrock or discontinuities in the structure itself (Olorunfemi et al., 2000). An assessment of the geologic and geotechnical conditions at the proposed construction site is one of the most important aspects of dam design and safety. The evaluation of the safety of a new or an existing dam requires, among other things, that its foundation be adequately examined, explored, and investigated so that potential environmental problems are fully understood as much as possible.

An earth dam capable of impounding approximately ten million $m^3$ of water for domestic water supply and probably hydropower generation was proposed by the Federal Ministry of Water Resources (FMWR), for Kajola (near Ile-Ife) primarily to supply water to Ile-Ife town in Osun State. It is imperative that the dam structure be hosted on soils and rocks that have been tested and found competent. The procedure among most geotechnical engineers is to study the subsurface by means of numerous boreholes and rock corings on which the design parameters will be based. It is however standard practice in geotechnical studies that dam site investigations are accompanied by a combination of geophysical and engineering geological testing (Ajayi et al., 2005). Geophysical techniques are employed to reduce the duration and cost of the investigation and a small number of boreholes can then be drilled to yield subsurface information that could serve as control on geophysical interpretation

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(Ako, 1976; Ojo et al., 1990; Aina et al., 1996; Ajayi et al., 2005).

Therefore, this study aims at combining geological and geophysical investigations to assess the competence of the Kajola soils and rocks to host the proposed dam. The objectives of this study include:

i. Investigating the occurrence of any geological and structural features that can undermine the integrity of the dam;

ii. Determining soil properties that could affect the performance of the dam, the reservoir and appurtenant structures;

iii. Delineating the subsurface layers and depth to sound bedrock on which the dam could be safely anchored; and

iv. Making recommendations on the dam safety based on (i) to (iii).

## 2. Geological Setting

The study area is located at Kajola Village, near Ile-Ife, Osun State, Nigeria. The study area lies within Latitudes 7° 24' N and 7° 26' N and Longitudes 4° 35' E and 4° 38' E; covering approximately 10 km² (Fig. 1). The location of the dam site is roughly at 2 km from the Orita Obalara Junction along the Ita-Abiye – Alabameta Road. The site is accessible via the Kajola – Afasagboye Road, which is linked to the Orita Obalara Junction. Two alternate dam axes were considered by the Consultants and the Contractor (Fig. 2). Axis A was recommended by the Consultant to the Client, while Axis B was preferred by the Contractor. Both axes were investigated since a final choice of the dam axis had not been agreed between the Client and the Contractor. Axis A is located at an asymmetrical valley with fairly steep flanks and runs approximately NE-SW across R. Owena. Axis B, on the other hand, is located at a symmetrical valley with gentle slopes on either side of the river. Axis B runs in an approximately N-S direction across R. Owena.

The climate of the study area satisfies the definition of a humid tropical environment of the AF climate of Koppen, with a mean annual rainfall of about 1500 mm (Ogunkoya et al., 2014). The area is characterized by wet and dry seasons. The wet season usually runs from April to October and is dominated by heavy rainfall, while the dry season runs from November to March. Temperatures are constantly high with a minimum of about 22 °C in August and a maximum exceeding 32 °C in February and March. Relative humidity is consistently high ranging from about 70 % in January to about 95 % in July (Fosberg et al., 1961). The vegetation of the area is the secondary rain forest type. The forest consists of trees up to 30 m tall with few branches. Various species of trees are intermingled with palm trees, thick undergrowth and relatively tall grasses. Human activities, such as construction work, logging and farming, have modified the vegetation of some areas resulting in bare land. The topography of the study area is gently undulating with topographic elevation from 800 m to 990 m above mean sea level.

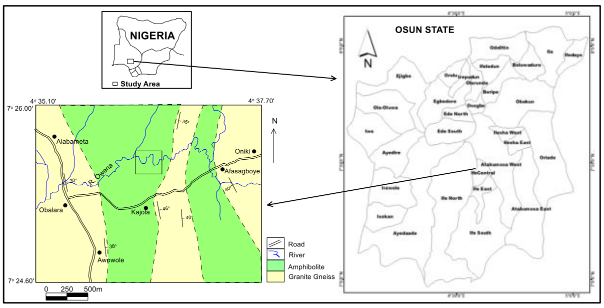


**Figure 1:** Geologic Map of Kajola and its Environs (Adekoya, 2008; Egwuatu, 2006)

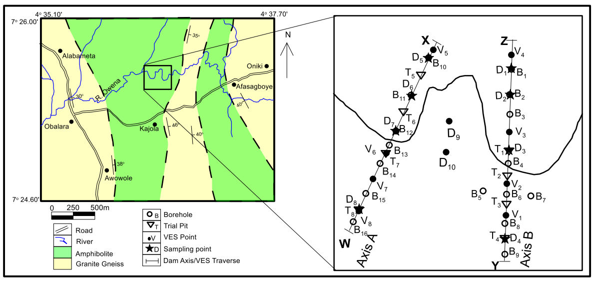


**Figure 2:** Proposed Kajola Dam Axes (Adekoya, 2008; Egwuatu, 2006)

Kajola area is drained mainly by R. Owena and its numerous tributaries. The area is characterized by dendritic drainage pattern. R. Owena flows generally from east to west at this location, receiving almost all stream waters in the area (Fig. 2). R. Owena is perennial. This indicates that the river is sustained by groundwater baseflow during the dry season. Rainwater is the major source of water within the study area. The frequency of the rainstorms has not been documented. The mean rainfall is about 1500 mm (Ogunkoya et al., 2014). The potential evapotranspiration of the area around Ile-Ife, including the study area, varies between 978 mm to 3016 mm (Ogunkoya, 2000). The Kajola catchment covers south-eastern section of the study area. The catchment area is delineated by drainage characteristics and watershed boundaries. Discharge in the catchment is regulated by water impounding structures and storage reservoirs. The mode of occurrence of the groundwater in the Kajola area is governed by the presence of structural features such as the fracture systems of the crystalline rocks and the thickness and characteristics of the unconsolidated materials overlying the bedrock. The catchment area is estimated to be 142 km² with stream order of 3. The drainage density of the Owena River basin is 4.40 x $10^{-8}$ km/m² with capacity to impound 10 million m³ of water with spillway capacity of 8600 m³ (Adekoya, 2008). The water table is inferred to be fairly deep judging from the trial pits and boreholes drilled by the Contractor. The water table is found at depths between 7 m and 15 m from the land surface.

## 3. Materials and Methods

This study employed the use of geological and geophysical methods of investigation. Geological investigation involved the use of the Global Positioning System (GPS), hammer, compass clinometer and hand lens to sample and identify the different rocks around the study area.

Geotechnical investigation was carried out along the two proposed dam axes A and B (Fig. 2), for both in-situ and laboratory tests of the foundation materials. Major aspects of the investigation involved drilling exploratory boreholes and excavating trial pits. DANDO 150 and DANDO 250 types of Cable tool (percussion) drilling machines were used for the boreholes with Shell and Auger tools and blind casings down the hole. Sixteen (16) boreholes were drilled from the topsoil to the weathered rock along the proposed dam axes. The depths of the boreholes varied from 10.5 m to 33.5 m depending on the topography of the dam site. The standard penetration tests (SPT) and rock coring operations were carried out. The rock coring were carried out using LONGYEAR model IDW00660 and model F6K912 rotary drilling machines and LONGYEAR model PTA 5615 (trailer mounted) and model PTA 56 regulated pumping machines. Digging by hand (hand dug method) was used for the trial pit excavations. The dimensions of the trial pit bored are 1.0 m x 1.0 m with maximum depth of 4.0 m. Eight (8) trial pits were dug along the proposed dam axes. Ten (10) disturbed soil samples of 70 g each were collected at various locations within the boreholes and trial pits and stored using sample bags. The samples were collected at depths ranging from 0.5 m to 2.0 m beneath the ground surface for the reconstruction of the subsurface lithologies. This depth range represents areas where the soil is well developed and is representative of the residual soil formed. From visual observation, the soils obtained from the dam site are representative of approximately 70 % of the study area. The soil samples were air-dried for two weeks after which they were tested for moisture content, grain size distribution, Atterberg limits and compaction at the Soil Laboratory of the Department of Civil Engineering, Obafemi Awolowo University. Both the mechanical sieve analysis and the hydrometer analysis were utilized to determine the distribution of particle sizes for the soil samples. The coefficient of permeability of each of the soil samples was estimated using the Hazen's equation (Equation 1).

$$k = Cd_{10}^2 \quad (1)$$

where: k = Coefficient of permeability (cm. $s^{-1}$)

$d_{10}$ = Effective size (cm)

C = Constant, which may be taken as 100 $cm^{-1}s^{-1}$.

The geophysical investigation involved the use of the Vertical Electrical Sounding (VES) technique of the electrical resistivity method to probe the subsurface. The Schlumberger electrode configuration where the current and potential electrodes have a common mid-point was employed. Eight (8) depth sounding stations were occupied (Fig. 2). These are, $V_1$ to $V_4$ located along Axis B, to the south and north of R. Owena respectively, at least 50 m apart; and $V_5$ to $V_8$ located along Axis A, also to the north and south of R. Owena. The electrode spacing (AB/2) varied from 1 m to 150 m. The VES array was oriented centred on the dam axes (perpendicular to the river channel). The data obtained were analysed manually and using the WINRESIST software.

## 4. Results and Discussions

### 4.1 Geological Mapping

The geological mapping of the study area revealed that the dam site and its environs are underlain by amphibolite and granite gneiss (Fig. 1). The amphibolite is weakly foliated, comprises hornblende, quartz and plagioclase. The granite gneiss is dark grey with medium grained minerals possessing well-defined foliation. The granite gneiss consists mainly of light and dark mineralogical bandings. The light minerals are mainly quartz and plagioclase feldspar, while the dark minerals consist of biotite and muscovite. The granite gneiss strikes approximately N-S, between 003° and 170°. The outcrops exhibit a general eastward dipping trend, ranging from 30° E to 40° E (Fig. 1).

The major structural elements observed in the rocks are foliation and fracturing. The fractures constitute two major sets. The first set, prominent within the amphibolite trends N-S with varying dips, ranging from 75° SW to 87° SW. The second set of fractures located within the amphibolite and granite gneiss, is randomly oriented with infilling of quartz in some localities. Within the granite gneiss, the foliation trends N-S approximately, with vertical dip. Micro folding was observed in the granite gneiss, consisting of several parallel similar folds that are tight to isoclinal (Adekoya, 2008; Egwuatu, 2006).

### 4.2 Soil Geotechnical Properties

Based on physical observation of the ditch cuttings from the boreholes and trial pits, the subsurface lithologies underlying the dam axis were reconstructed. Correlation of the subsurface lithologies across the boreholes showed four subsurface layers (Figs. 3 and 4). These include the topsoil with thickness ranging from 0.8 m beneath Borehole 10 to 3.5 m beneath Borehole 3; clayey weathered layer with thickness ranging from 4.0 m beneath Borehole 4 to 19.5 m beneath Borehole 16; partially weathered layer with thickness ranging from 3.5 m beneath Boreholes 13 and 16 to 15.0 m beneath Borehole 1; and the fresh basement rock. The soil permeability ranged from 0.07 x $10^{-6}$ cm. $s^{-1}$ to 13.09 x $10^{-6}$ cm. $s^{-1}$ (Figs. 5 and 6). The permeability of the topsoil was not estimated. The permeability of the clayey weathered layer was 2.45 x $10^{-6}$ cm. $s^{-1}$, while that of the partially weathered layer was between 0.07 x $10^{-6}$ cm. $s^{-1}$ and 13.09 x $10^{-6}$ cm. $s^{-1}$. There is a general decrease in soil permeability from the second to the third layer. This decrease in soil permeability could be attributed to the increase in soil compaction with depth, resulting in reduced porosity and interconnectivity of pore spaces. The exceptionally high permeability of the partially weathered layer at a depth of 32 m beneath Borehole 1 is attributed to the occurrence of fractures, which could serve as flow paths for groundwater. The occurrence of the fractures is responsible for the high degree of weathering observed in Borehole 1 (Fig. 5).

SPT carried out in the boreholes revealed increasing numbers of blows with depth (Figs. 3 and 4). The increase in numbers of blows with depth indicates an increasing soil density arising from increased soil compaction with depth. Based on the SPT the soils underlying the dam axes are classified as loose to dense soils, with angular shearing resistance (ϕ) between 27° and 41° (Fig. 7). The moisture content obtained for the soil samples ranged between 11.79 % and 42.00 % (Table 1). The moderate values of moisture content indicate that the soil samples are slightly moist to moist. Six (6) out of the ten (10) soil samples had moisture content between 11. 79 % and 29.90 %, while the remaining four (4) soil samples had moisture content between 39.99 % and 42.00 %. The large number of soil samples that are slightly moist is an indication of the clayey nature of the soils and the presence of relatively moderate levels of groundwater in the study area. The water table obtained from trial drill pits and boreholes range between 7 m and 15 m (Das, 2010).

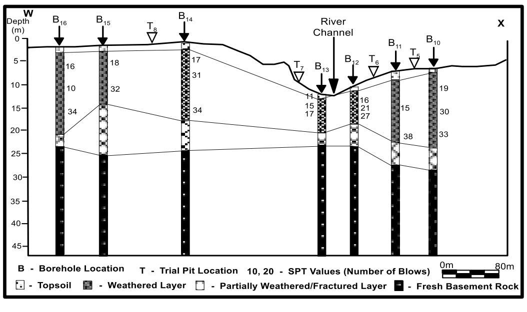


**Figure 3:** Lithological Section along Dam Axis A

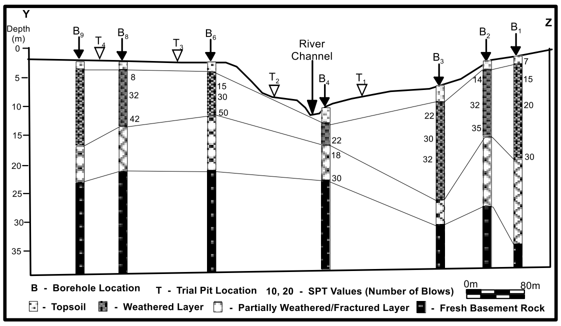


**Figure 4:** Lithological Section along Dam Axis B

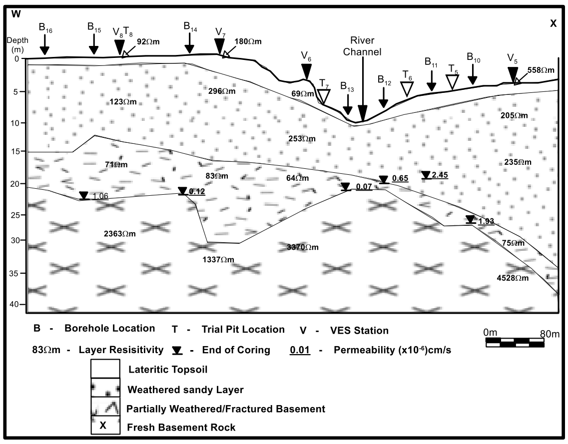


**Figure 5:** Geoelectric Section along Dam Axis A

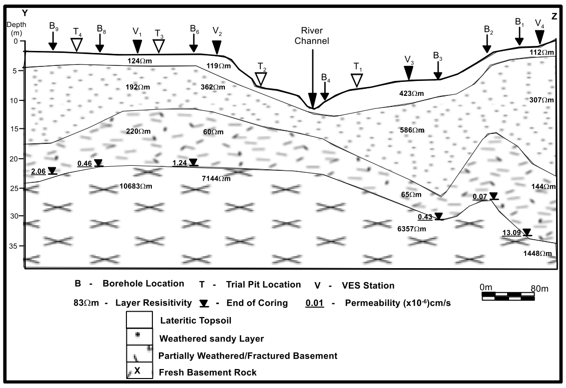


**Figure 6:** Geoelectric Section along Dam Axis B

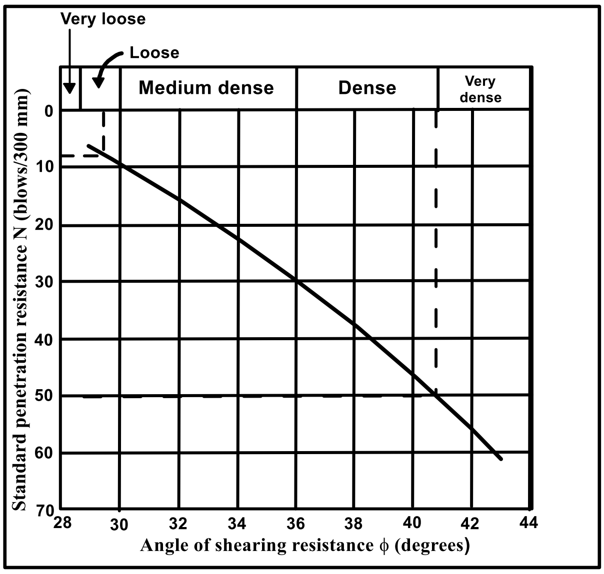


**Figure 7:** Relationship between SPT Values and Angle of Shearing Resistance (Peck et al., 1967)

| **Table 1:** Results of Grain Size Analysis | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample No** | **GPS Coordinate** | **Sampled Depth (m)** | **Moisture Content (%)** | **$d_{10}$ (mm)** | **$d_{30}$ (mm)** | **$d_{60}$ (mm)** | $C_u = \frac{d_{60}}{d_{10}}$ | $C_c = \frac{d_{30}^2}{d_{10}d_{60}}$ | **K ($\times 10^{-10} cm.s^{-1}$)** |
| **1** | N7° 25.340' E4° 36.570' | 0.5 | 11.79 | 0.0001 | 0.00027 | 0.0098 | 98 | 0.1 | 1.00 |
| **2** | N7° 25.420' E4° 36.570' | 1.2 | 40.94 | 0.00014 | 0.0015 | 0.037 | 264 | 0.4 | 1.96 |
| **3** | N7° 25.490' E4° 36.580' | 2.5 | 42.05 | 0.00015 | 0.0017 | 0.038 | 253 | 0.5 | 2.25 |
| **4** | N7° 25.580' E4° 36.580' | 2.1 | 20.42 | 0.0002 | 0.005 | 0.05 | 250 | 2.5 | 4.00 |
| **5** | N7° 25.530' E4° 36.550' | 2 | 17.2 | 0.0018 | 0.036 | 0.055 | 31 | 13.1 | 3.24 |
| **6** | N7° 25.420' E4° 36.500' | 1.9 | 27.12 | 0.00015 | 0.002 | 0.047 | 313 | 0.6 | 2.25 |
| **7** | N7° 25.470' E4° 36.450' | 2.4 | 28.33 | 0.00016 | 0.0016 | 0.036 | 225 | 0.4 | 2.56 |
| **8** | N7° 25.370' E4° 36.390' | 1.8 | 29.9 | 0.00015 | 0.0013 | 0.038 | 253 | 0.3 | 2.25 |
| **9** | N7° 25.430' E4° 36.500' | 2.5 | 37.66 | 0.00018 | 0.0018 | 0.0076 | 42 | 2.3 | 3.24 |
| **10** | N7° 25.350' E4° 36.460' | 1.7 | 39.99 | 0.0006 | 0.015 | 0.05 | 83 | 7.5 | 3.60 |

Using the Unified Soil Classification System (USCS), the soils generally classify as elastic silts. The effective grain sizes ($d_{10}$) ranged from 0.00010 mm to 0.0018 mm (Table 1). The uniformity coefficient ($C_u$) obtained for the various soil samples showed exceptionally large values ranging between 31 and 313 (Table 1). The large $C_u$ reflect the very flat grain size distribution, indicating that the soil samples are all well graded; hence, suitable for construction purposes where drainage might be problematic. The coefficient of curvature ($C_c$) obtained for the soil samples ranged between 0.1 and 13.1 (Table 1). Soils with smooth curves have $C_c$ between 1 and 3, while irregular curves have higher or lower values (Das, 2010). The $C_c$ for the different soil samples indicate that only Samples 4 and 9 have smooth curves while the remaining soil samples have irregular curves. The results obtained for the Atterberg limits indicate that the Liquid Limit (LL) of the soil samples ranged between 42.60 % and 72.95 %, while the Plasticity Index (PI) ranged between 20.19 % and 34.87 % (Table 2). All the soil samples had high LL indicating that the soils are silt to clayey silt. The LL showed close values for soil samples collected from both axes A and B. The results of the PL indicate that all the soil samples are plastic. The PI ranged between 20.19 % and 34.87 %. The classification of soils on the basis of PI (Burmister, 1949), indicates that all the soil samples are clayey with high plasticity and are cohesive (Table 3). Using the soil classification scheme (Sowers, 1979), Samples 2, 3, 4, 5, 6, 8 and 10 have medium plasticity, medium dry strength and exhibit the characteristics of being difficult to crush with the fingers; while Samples 1, 7 and 9 have high plasticity, high dry strength and are impossible to crush with the fingers (Table 4). The plasticity chart (Cassagrande, 1948) shows that Samples 1, 2, 3, 5, 7, 8, 9 and 10 all plot below the A-line and are thus, predominantly silt; while Samples 4 and 5 plot above the A-line and are thus, predominantly clayey soils (Fig. 8). The plasticity chart also shows that Samples 1, 2, 3, 6, 7, 8, 9 and 10 classify as MH, which is predominantly silt, high plasticity soil. Sample 4 classifies as CH, which is predominantly clay, high plasticity soil. Sample 5 classifies as CL, which is predominantly clay, low plasticity soil. Using the USCS classification scheme, MH soils are elastic silts, while CL soils are known as lean clays. Using Sower assessment of soil properties based on group symbols, Samples 1, 2, 3, 6, 7, 9 and 10, which are MH soils, have fair to poor compaction characteristics, high compressibility and expansion, poor drainage, fair stability and would require good compaction for use as fill material (Sowers, 1979). Sample 4 which is classified as CH has fair to poor compaction, very high compressibility and expansion, no drainage and it is unstable, thus, not suitable as a fill material. Sample 5, classified as CL has good compaction, slight to medium compressibility and expansion, no drainage and has good stability, thus it is suitable for use as fill material.

| **Table 2:** Atterberg Limits of Soil Samples | | | | | | |
|---|---|---|---|---|---|---|
| **Sample No** | **Liquid Limit (%)** | **Plastic Limit (%)** | **Plasticity Index (%)** | **MDD (kg/m³)** | **OMC (%)** | **Porosity (%)** |
| **1** | 65.50 | 33.05 | 32.45 | 1850 | 18.6 | 7.8 |
| **2** | 71.49 | 46.76 | 24.73 | 1870 | 16.0 | 1.2 |
| **3** | 70.00 | 48.79 | 21.21 | 1790 | 19.6 | 10.7 |
| **4** | 52.15 | 25.53 | 26.62 | 1840 | 15.2 | 7.7 |
| **5** | 42.60 | 22.41 | 20.19 | 1820 | 19.6 | 10.8 |
| **6** | 58.00 | 34.34 | 23.66 | 1760 | 15.8 | 8.2 |
| **7** | 72.95 | 38.08 | 34.87 | 1740 | 20.4 | 9.8 |
| **8** | 70.20 | 41.84 | 28.36 | 1770 | 17.2 | 15.5 |
| **9** | 67.00 | 35.34 | 31.66 | 1720 | 18.2 | 9.6 |
| **10** | 61.25 | 35.12 | 26.13 | 1745 | 16.4 | 6.9 |

| **Table 3:** Classification of Soil Based on Plasticity Index (Burmister, 1949) | | | |
|---|---|---|---|
| **Plasticity Index (%)** | **Soil Property** | **Soil Type** | **Cohesiveness** |
| **0** | Non-plastic | Sand | Non-cohesive |
| **1 – 5** | Slightly plastic | Silt | Partly cohesive |
| **5 – 10** | Low plasticity | Silt | Partly cohesive |
| **10 – 20** | Medium plasticity | Silty clay | Fairly cohesive |
| **20 – 40** | High plasticity | Clay | Cohesive |
| **>40** | Very high plasticity | Clay | Very cohesive |

| **Table 4:** Characteristics of Soils with Different Plasticity Index (Sowers, 1979) | | | |
|---|---|---|---|
| **Plasticity Index (%)** | **Classification** | **Dry Strength** | **Visual-Manual Identification of Dry Sample** |
| **0 - 3** | Non-plastic | Very Low | Falls apart easily |
| **3 - 15** | Slightly plastic | Slight | Easily crushed with fingers |
| **15 – 30** | Medium plastic | Medium | Difficult to crush with fingers |
| **>30** | Highly plastic | High | Impossible to crush with fingers |

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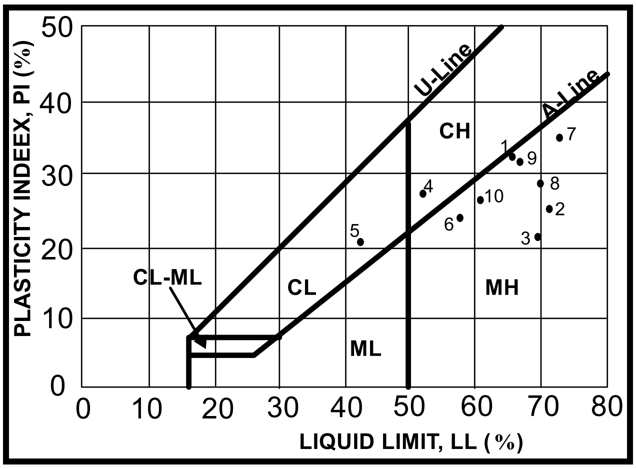


**Figure 8:** Plasticity Chart of Soil Samples

The results of the compaction tests show that the soil samples all have generally high values of maximum dry densities (MDD) at corresponding optimum moisture contents (OMC), Table 2. The results also indicate that Samples 1, 2, 3 and 4 collected along Axis B had higher MDD values than Samples 6, 7 and 8 collected along Axis A. The soil samples all have low values of porosity with Sample 2 having the lowest value of 1.2 % and Sample 8 having the highest value of 15.5 % (Table 2). The results confirm that all the soil samples have poor drainage characteristics. The permeability characteristics of the soil samples based on the particle size analysis using the Hazen's formula at a constant of 100 $cm^{-1}s^{-1}$ were obtained, although the formula is most appropriate for sandy material where $d_{10}$ is between approximately 0.1 and 3.0 mm (Fetter, 2001). The $d_{10}$ obtained for the soil samples is between 0.0001 mm and 0.0018 mm (Table 1). The results showed that the soil samples have coefficient of permeability between 3.24 x $10^{-8}$ $cm.s^{-1}$ and 1.00 x $10^{-10}$ $cm.s^{-1}$ (Table 1), hence are highly impervious (Chen et al., 2002). The poor permeability characteristic of the soil samples is attributed to the high clay content of the soil samples with high plasticity index.

### 4.3 Geophysical Investigation

Based on the results of geophysical investigation (Table 5), and physical observations from boreholes and trial pits, up to four subsurface layers were delineated. The first layer is the lateritic topsoil with resistivity between 69 Ωm and 558 Ωm with thickness ranging from 1.5 m beneath VES 4 and VES 8 to 4.0 m beneath VES 5. The second layer is the weathered sandy layer with resistivity between 123 Ωm and 586 Ωm and thickness ranging from 6.5 m beneath VES 2 to 20.4 m beneath VES 5. The third layer is the partially weathered/fractured bedrock with resistivity between 60 Ωm and 220 Ωm and thickness ranging from 6.5 m beneath VES 5 to 14.0 m beneath VES 7. The fourth layer is the fresh bedrock, having resistivity between 1337 Ωm and 10683 Ωm. The bedrock topography is gently undulating away from the river channel but dip steeply into the river channel (Figs. 5 and 6). The occurrence of thick weathered/fractured layer beneath VES 7 at shallow depths along Axis A is capable of causing water seepage beneath the dam axis.

**Table 5:** Summary of VES Interpretation

| VES No | GPS Coordinate | Depth (m) $D_1/D_2/D_3.../D_n$ | Layer Resistivity $\rho_1/\rho_2/\rho_3.../\rho_n$ | Curve Type |
|---|---|---|---|---|
| **1** | N7° 25.382' E4° 36.465' | 3.0/13.3/23.5 | 124/192/220/10683 | AA |
| **2** | N7° 25.438' E4° 36.475' | 3.5/13.7/21.1 | 119/362/60/7144 | KH |
| **3** | N7° 25.512' E4° 36.480' | 3.5/16.5/23.8 | 423/586/65/6357 | KH |
| **4** | N7° 25.532' E4° 36.496' | 1.5/20.4/32.5 | 112/307/144/1448 | KH |
| **5** | N7° 25.546' E4° 36.434' | 4.0/12.9/19.4/24.4 | 558/205/235/75/4528 | HKH |
| **6** | N7° 25.453' E4° 36.394' | 3.5/14.5/20.3 | 69/253/64/3370 | KH |
| **7** | N7° 25.409' E4° 36.321' | 0.4/2.2/16.5/31.6 | 266/146/286/83/1337 | HKH |
| **8** | N7° 25.368' E4° 36.285' | 1.5/14.2/33.9 | 92/123/71/2363 | KH |

## 5. Conclusions

Geological and geophysical investigations were carried out at a proposed dam site in Kajola Village, near Ile-Ife. The geological investigation revealed that the study area is underlain by weakly foliated amphibolite and well foliated granite gneiss. Geological and geophysical investigations revealed four subsurface layers of topsoil, weathered clayey-silt/sandy-silt, partially weathered/ fractured basement and the fresh basement. The engineering properties of the soil revealed that the soils beneath the study area are loose to dense soils, with angular shearing resistance (ϕ) between 27° and 41°. Most of the soil samples (80%) have fair to poor compaction characteristics, high compressibility and expansion, poor drainage, fair stability and would require good compaction for use as fill material; while the remaining 20% of the soil samples have good compaction, slight to medium compressibility and expansion, no drainage and has good stability, thus it is suitable for use as fill material.

Although all the soil samples had low values of porosity, soil samples collected along Axis B had higher MDD values than soil samples collected along Axis A. The low porosity (and poor infiltration characteristics) of the soil samples account for the flooding recorded at the study area during heavy rainfall. The soil samples have coefficient of permeability between 3.24 x $10^{-8}$ $cm.s^{-1}$ and 1.00 x $10^{-10}$ $cm.s^{-1}$, hence are highly impervious.

The general characteristics of the soil materials at the site indicate that the soils are cohesive, stable and possess considerable strength, hence the soil materials are suitable as construction materials. However, the slight to medium compressibility and expansion characteristics of the soil may result in settlement. The soil material at the site is suitable for use as fill material for the embankment, if compacted to optimum dry density. The bedrock is suitable to host the dam. Axis A is asymmetrical, and will require longer length dam axis and large quantity of earth material to fill the deep valleys at its flanks. Axis B is symmetrical, and will require shorter length dam axis and lacks deep valleys at its flanks. There is a risk of water seepage beneath the dam axes especially beneath Axis A through the delineated weathered/fractured basement and may require deep excavation or grouting of the weak material beneath the dam axis at these weathered/fractured locations. The design of the proposed dam should factor these identified features in the design in order to guarantee its integrity and safety.

## 6. Recommendations

Based on the findings in this study, the following recommendations are suggested to safeguard the integrity and safety of the proposed dam:

i. A relative compaction of 90 – 100 % should be attained prior to the placement of the foundation on the soil to be used as fill materials;

ii. Due to the silty nature of the soil, filter and drain zones should be provided to control seepage and prevent soil migration through the embankment;

iii. Axis B should be used for the construction of the dam because of the relatively shallower depth which range from 20 m to 33 m to basement when compared with Axis A which range from 21 m to 38 m depth to bedrock. The deep valleys at the flanks of Axis A will require large quantities of earth materials to fill. The presence of prominent fracture zones beneath Axes A and B may also act as conduits for anomalous groundwater seepage which may undermine the integrity of the dam;

iv. Post construction geophysical investigation should be carried out to examine the integrity of the embankment; and

v. Routine performance monitoring of the dam and embankment should be carried out after construction, periodically and throughout the life cycle of the dam.

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