Professional paper

Received: February 27, 2014
Accepted: September 25, 2014

Integrated geophysical and geotechnical investigations of a proposed dam site, Southwestern Nigeria

Kombinirane geofizikalne in geotehniške raziskave predlagane lokacije za pregrado v jugozahodni Nigeriji

Michael Adeyinka Oladunjoye[1], Isaac Oluwatosin Babatunde[1,*], Adebisi O. Oshoko[2]
[1]University of Ibadan, Department of Geology, Ibadan, Nigeria
[2]Integrated Geosciences Services, Ibadan, Nigeria
*Corresponding author. E-mail: isaac.oluwatosin10@gmail.com

Abstract

Earth and rock-fill dams are designed to operate under steady state but geological defects may lead to failure of the dam, especially in unconsolidated or fractured terrains. Integrated geophysical and geotechnical investigations were undertaken to assess the vulnerability of a proposed dam site, South-western Nigeria. The study area is underlain by undifferentiated schist.

The field investigations involved use of Very Low Frequency (VLF) electromagnetic and Vertical Electrical Sounding (VES) using the Schlumberger array to generate curves and 2D-imaging lines. Geotechnical investigation entailed establishing points for Standard Penetrometer Test (SPT).

The VLF-EM result revealed localized regions of anomalous conductivity/resistivity. The VES result delineated topsoil, weathered basement and fractured/fresh bedrock. The geotechnical results revealed low stability for the proposed dam axis.

The uneven nature of the basement topography is a potential threat to the stability of engineering structures. As a result, the site was considered unsuitable for concrete dam but suitable for earth dam. If the dam will however be constructed, proactive measures, such as deep excavation and grouting must be taken against the structural and geological defects.

Key words: Geophysical and geotechnical, Damsite, Clayey overburden, Poorly drained, Proactive measures.

Izvleček

Zemljinske in nasute kamninske pregrade so projektirane za obratovanje v normalnih okoliščinah, toda neugodne geološke lastnosti, zlasti nekonsolidiranost in razpokanost kamnine, utegnejo privesti do okvar. S kombiniranimi geofizikalnimi in geotehniškimi raziskavami smo ocenili ranljivost neke predlagane lokacije pregrade v jugozahodni Nigeriji. Podlago raziskovanega območja tvorijo nerazčlenjene skrilave kamnine.

Uporabljene terenske metode so obsegale zelo nizkofrekvenčno (VLF) elektromagnetno in vertikalno električno sondiranje (VES) po Schlumbergerjevem razporedu z izdelavo krivulj in 2D-linij. V okviru geotehniških raziskav so opravili v izbrani mreži standarni penetrometrični preizkus (SPT).

Glede na rezultate preiskav VLF-EM smo omejili območja anomalne prevodnosti/upornosti. Z VES smo ločili v podlagi tla, preperelo kamnino in razpokano svežo kamnino. Geotehniški preizkusi so nakazali pomanjkljivo stabilnost v osi predlagane pregrade. Neravna oblikovanost podlage je potencialna nevarnost za stabilnost predlaganih objektov. Kot rezultat raziskave smo ocenili, da lokacija ni ugodna za betonsko pregrado, vsekakor pa je primerna za zemljinsko pregrado. Če se bodo odločili za gradnjo, bo treba predhodno izvesti primerne ukrepe, kot so globoki vkopi in injekcijske zavese, da zavarujejo objekte pred strukturnimi in geološkimi nevarnostmi.

Ključne besede: geofizikalne in geotehniške preiskave, lokacija za pregrado, glinasta tla, slabo odvodnjavanje, predhodni ukrepi

Introduction

Dams are among the largest and most important projects in civil engineering[1]. They are major engineering structures that are designed and constructed with long life expectancy[2, 3]. Due to the fact that dam constructions serve tremendous purpose to the human community, the design and construction of a dam is expected to create a stable structure that will last for a very long period of time. Out of the various natural factors that directly influence the design of dams, none is more important than the geological, not only do they control the character of the foundation but they also govern the materials available for construction[4]. For geologic, hydrologic and topographic reasons, there are limited numbers of ideal sites for dams' placement[5]. It is therefore very important to intensely scrutinize any proposed dam site. There are many problems which give a broad variety of special tasks to the geophysicist, beginning with prospecting for geological near-surface structures and ending in the determination of the properties of soils and rocks by geophysical methods. Concealed fractures are structures which pose great difficulties in public works and their non-localization may lead to failure of otherwise well planned projects. The prospects of surface water development through the construction of a water dam in crystalline basement complex area are considerably enhanced by carefully planned and well executed preliminary geophysical investigations[6–10]. Pre-construction site study is a prerequisite for the construction of dams and other hydraulic structures in order to avoid locating such structures on undesirable subsurface features such as buried stream channels, near-surface fractures, joints, fissures etc.[2]. The unpredictability of the near-surface ground often complicates site investigations and budgetary constraints may limit the number of boreholes. Geophysics can provide powerful tools to complement other forms of site investigation. Geophysical studies carried out prior to the intrusive investigation in form of borings and trial pits may locate anomalous areas associated with significant subsurface features. The identification of anomalies allows borings and trial pits to be appropriately targeted. The appropriate location of borings on the basis of prior geophysical surveys may result in borehole data being more representative of site conditions. Essentially, geophysics may enhance the value of borehole data. On a complex site, geophysics may be utilized to determine the geology between boreholes, since interpolation between borehole logs may be ambiguous. Comparison of geophysical survey results with directly obtained geological information permits the extrapolation of geophysical results into areas where little or no borehole information is available[3, 11]. On large sites in particular, the design of the spatial location of direct sampling points may be contentious and important underground targets may be missed completely. However, in order to reduce the duration and cost of investigation, geophysical techniques are often employed and small number of boreholes are then drilled to yield subsurface information that could serve as control on the geophysical interpretation[6, 12–15]. Hence, an integrated geophysical (electrical resistivity and electromagnetic surveys) and geotechnical (borehole drilling/coring) investigations were carried out at the proposed Obafemi Awolowo University Teaching Hospital complex mini earth dam intended at supplying potable water to the College of Medicine community in OAU Ile-Ife Southwestern Nigeria. This study was aimed at evaluating the geo-structural setting of the concealed bedrock along the proposed dam axis and the flanks of the proposed dam site. Dam transmits and exerts tremendous forces on the foundation, including the thrust of the impounded water which can be of the order of millions of tons, in addition to weight of the biggest man-made structures. The stresses generated from these two main factors, water pressure and deadweight are further aggravated by dynamic forces and other influences. The interaction of dam and foundation is compounded by a third force, that of the impounded water acting both on the foundation and in the foundation, compressing the valley bottom and the flanks, producing uplift, seepage and percolation forces in voids and pores which can result in instabilities, erosion and leaching of supporting strata.

Site description and geologal setting of the proposed dam site

The proposed Dam site is to be erected across the Opa Stream that flows approximately east west of Ile-Ife town. It falls within the geographical coordinates of latitudes 07° 30′ 59.1″ N to 07° 31′ 13.0″ N and longitudes: 04° 33′ 03.7″ E to 04° 33′ 11.0″ E (Figures 1, 2 and 3). The study area is an area of undulating topography with elevation ranging from 250 m to 270 m above sea level with isolated outcrops. The drainage of the shallow valley is poor, with conspicuous presence of stagnant water bodies in the flood plain. The largest parts of the flood plain are essentially swampy. On average, the rainfall and temperature of the area respectively are 1 260.23 mm and 26.6 °C, this is in accordance with the tropical annual rainfall of 1 262.38 mm and temperature of range between 26.6 °C and 28.8 °C[16].

The area is underlain by the basement complex terrain of Nigeria. The main lithological units in the dam site environment are pegmatite and schist (Figure 4). The pegmatite and undifferentiated schist rocks are highly weathered and this result into the preponderance of clay horizons upon which the dam will be erected. The basement rocks are concealed in most parts of the site. However, very few isolated outcrop relics were encountered along the stream channels.

Materials and methods

The geophysical investigation involved the WADI VLF electromagnetic (EM) and the electrical resistivity methods. Horizontal profiling (Wenner) and Vertical Electrical Sounding (VES) techniques were employed.

EM measurements were made at every 10 m interval along the dam axis and 5 m interval along the left and right abutements.

The VES measurements were made at 15 locations along the dam axis, the two abutements and the upstream using the Schlumberger array with electrode spacing, AB/2, varying from 1 m to 75 m. VES were carried out at 50 m interval along the dam axis and the two abutements. The Wenner profiling utilised a fixed electrode spacing of 5 m and an expansion factor (n) varies from 1 to 5.

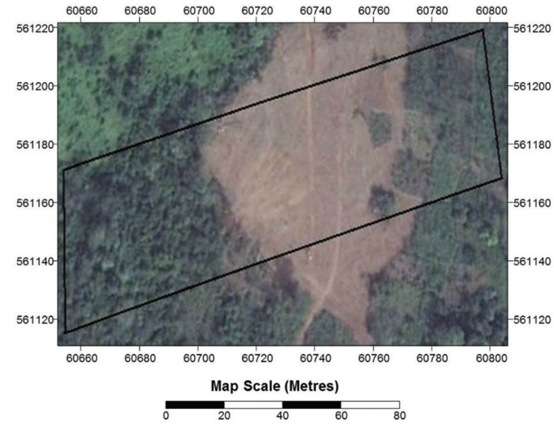

Figure 1: *Location map of the study area showing the boundary of proposed OAUTHC dam site (Google Earth 2014).*

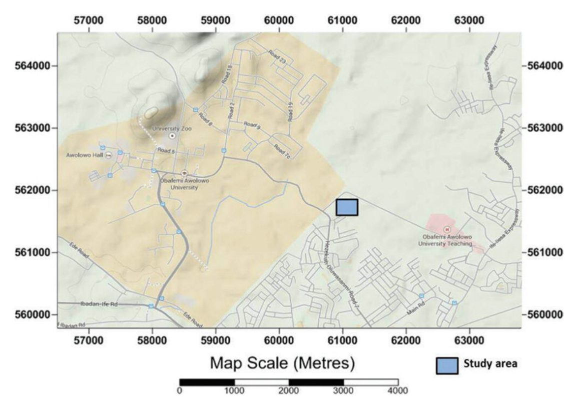

Figure 2: *Location map of OAU and the study area showing the proposed OAUTHC dam site (Google Earth 2014).*

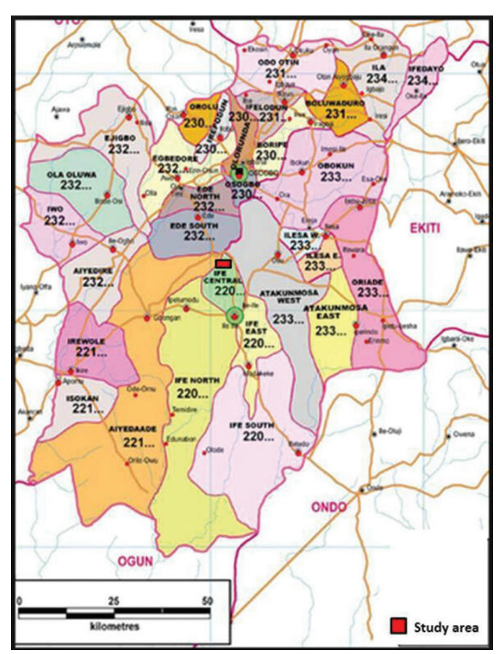

Figure 3: *Administrative map of Osun state showing the local Government and the study area.*

The geotechnical investigation involved soft rock boring and hard rock coring. The Standard Penetrometer Test (SPT) was conducted in four boreholes along the dam axis. The field layout of the geophysical and geotechnical traverses and measurement stations are shown in Figure 5.

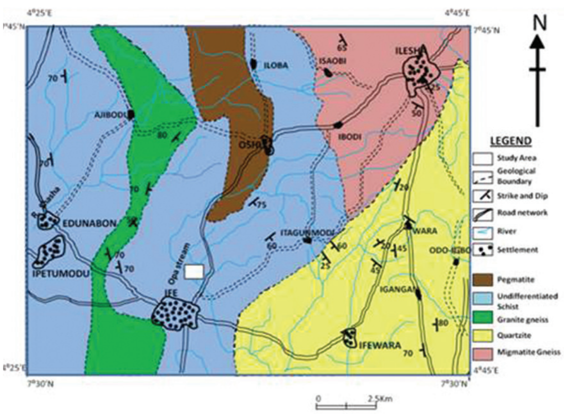

Figure 4: *Geological map of the area around Ile-Ife showing the study Area.*

The Very low frequency Electromagnetic Method (EM) data are displayed as profiles while the Vertical Electrical Sounding (VES) data are presented as depth sounding curves. Geo-electric sections, isopach, bedrock and resistivity contour maps were prepared from the VES data.

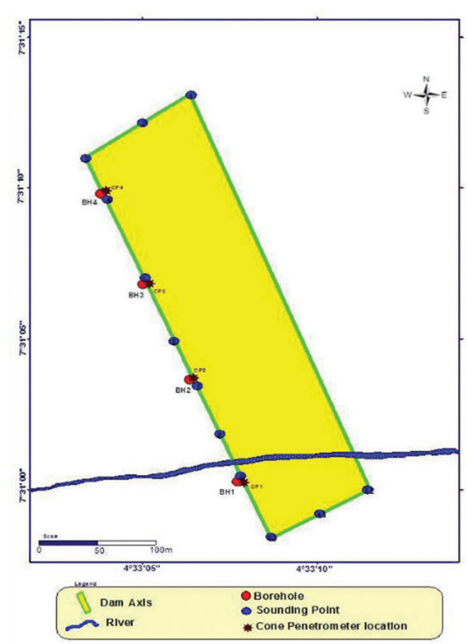

Figure 5: *Spacial distribution of VES points, SPT Test locations and Boreholes in the study area.*

2D-resistivity model for deeper depths of up to 13.5 m were prepared from the Wenner data for the dam axis and the two abutments. Quantitative (1D) interpretation of the VES curve involved partial curve matching and computer iteration techniques. The VES modelling was aided by the availability of borehole lithological logs.

Results and discussion

The EM profiles, Schlumberger and Wenner inverted sections showed the inhomogeneity in the subsurface. Very Low Frequency electromagnetic survey of the dam site revealed the conductive and the resistive nature of the subsurface, the resistive materials predominate the subsurface while the subsurface materials are generally of low average conductivity. There are however, localized regions of anomalous conductivity/resistivity, distributed along the profiles. The Karous-Hjelt contour for the dam axis (Figure 6a) shows a varying resistive sections, pockets of highly resistive unit and highly conductive unit were embedded within the low resistive background, the conductive (Siemen/metres) pockets occur between 320 m to 340 m and 360 m to 400 m up to 40 m deep, similar pockets of high conductive unit occur along a veinlet like structure, dipping approximately 45° N and cutting across the section at offset 220 m at the base and 280 m at the top of the profile. The abutments (Figures 6b and c) are characterized by alternation of conductive and resistive materials from left to right.

The VES curves are mostly the H and A-types, characterized by three geoelectric/lithologic layers consisting of topsoil (sand or sandy clay) weathered layer and fractured/fresh bedrock. The summary of the layer model interpretation and the inferred lithologies are presented in Table 1 while representative VES curves are presented in Figures (7a, b). The electrical resistivity contrasts existing between geoelectric layers in the area enabled the delineation of lithologic units, occurring at varying depths with variable thicknesses. The results of the interpretation were used to construct three sections on the dam axis, the left and the right abutments, taken in the north-south, and east-

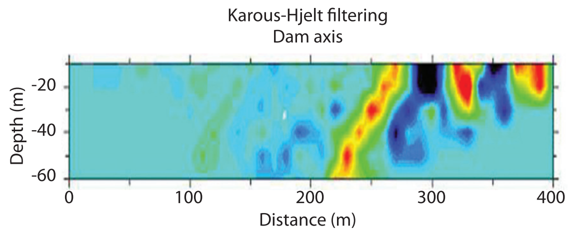

Figure 6a: *Frazer Graph and Karous-Hjelt Contour for the Dam axis.*

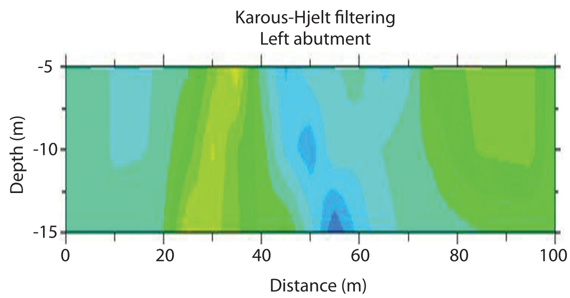

Figure 6b: *Frazer Graph and Karous-Hjelt Contour for the Left Abutment.*

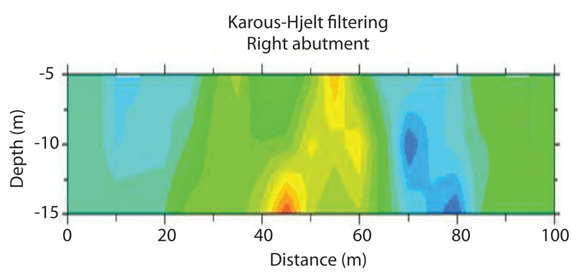

Figure 6c: *Frazer Graph and Karous-Hjelt Contour for the Right Abutment.*

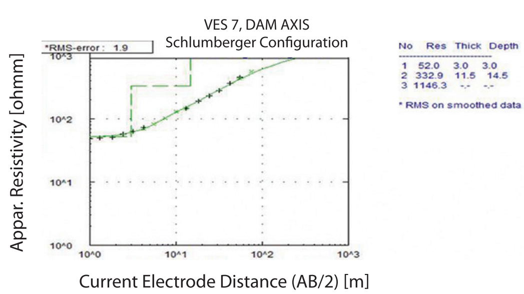

Figure 7a: *Computer Iterated Graph for VES 7.*

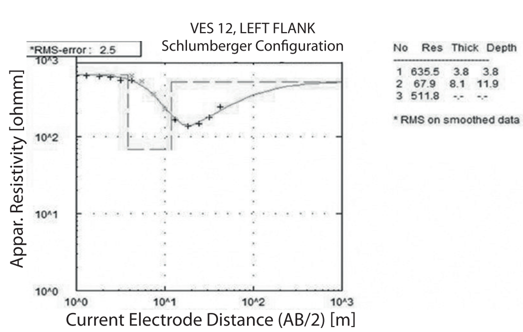

Figure 7b: *Computer Iterated Graph for VES 12.*

west directions (Figures 8a, c). The sections show three geoelectric/lithologic layers.

Geoelectric sections

Dam axis

The resistivity of the dam axis ranges from 18 Ω m to 32 Ω m (Figure 8a) while thickness varies from 0.4 m to 4.8 m in the first layer (topsoil). In the second and third layers, resistivity varies from 11 Ω m to 333 Ω m and 447 Ω m to 1 386 Ω m respectively while the weathered basement thickness ranges between 0.3 m to 12.1 m. The topography of the dam axis is uneven the basement with competent bedrock is closer to the surface at the central part of the dam axis and deepening towards the two abutments.

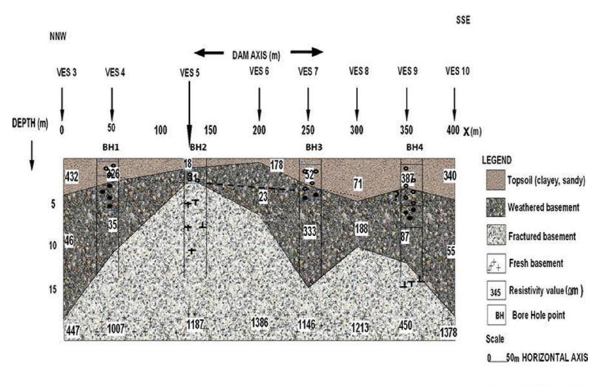

Figure 8a: *Geo-electric section for the Dam axis.*

Left Abutment

The left flank is underlain by three layers representing the topsoil, the weathered basement and the bedrock (Figure 8b). The first two units is the overburden comprising the topsoil and the weathered basement with resistivity and thickness values ranging from 340 Ω m to 635 Ω m / 3.7 m to 4.6 m and 55 Ω m to 81 Ω m / 8.1 m to 16.2 m respectively. The topsoil and weathered basement interface have a near horizontal geometry. The basement resistivity is relatively high, ranging from 512 Ω m to 1 378 Ω m. Its thickness increases progressively towards the centre of the profile from both ends.

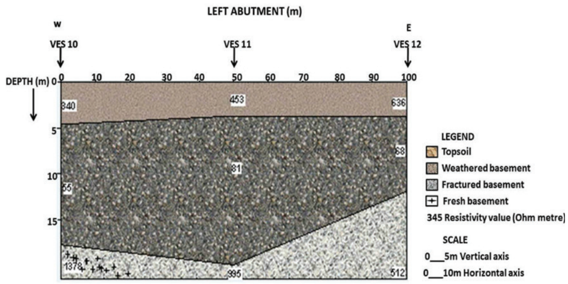

Figure 8b: *Geo-electric section for the Left abutment.*

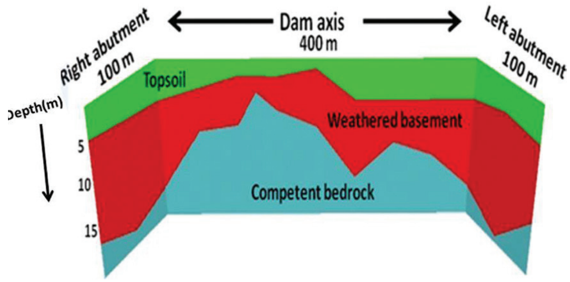

Figure 8d: *Fence diagram of the study area showing the dam axis and the abutments.*

Right Abutment

The right abutment is underlain by three geologic layers comprising the topsoil, the weathered basement and the bedrock (Figure 8c). The layer parameters from the VES interpretation show that the topsoil and the weathered basement have resistivity and thickness values ranging from 432 Ω m to 804 Ω m /3.3 m to 4.1 m and 45 Ω m to 58 Ω m /13 m to 14.9 m respectively. The topsoil and weathered basement interface have a near horizontal geometry. The basement resistivity is relatively low, ranging from 268 Ω m to 673 Ω m, with gently undulating topography.

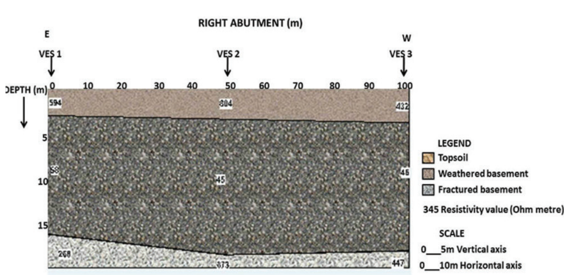

Figure 8c: *Geo-electric section for the Right abutment.*

Fence diagram

This represents two dimensional views of the geo-electric sections. The basement relief as revealed from the fence diagram (Figure 8d) slopes from the dam axis to the abutments. This aids groundwater flow as it was not encountered at boreholes BH1 and BH4 but was seen at borehole BH2 and BH3. The bedrock is closer to the surface along the dam axis with thin overburden. However, at the abutments, the overburden is relatively thick.

Isopach map of the overburden

Figure 9a shows the contoured map of the overburden thicknesses for the proposed dam site. This encompasses all materials above the presumably fractured/fresh bedrock. The overburden is relatively thick around the northern and southern part of the dam axis (abutments), with thickness values ranging from 16 m to 19.9 m while the overburden of the remaining part (middle part of the proposed dam axis) is relatively shallow (2.3 m to 14.5 m). Generally, the overburden of the study area is relatively shallow when compared to the range given by some authors,[17–19] for the southwest basement overburden thickness. They ranged overburden thickness less than 30 m as thin overburden and overburden greater than 30 m as thick overburden.

Bedrock relief map

The bedrock relief map (Figure 9b) is a contour map of the bedrock elevation beneath all the VES stations of the survey area. The significance of this is the reflection of the bedrock topography and its structural disposition. Depressions are characterized by thick overburden while ridges are noted for thin overburden cover. Ridges are characterized at the middle portion of the dam axis due to the closeness of the bedrock to the surface at this portion. Hence, there is poor drainage along the dam axis. The left and the right abutments are characterized by depression.

Resistivity of the bedrock

The resistivity values of the bedrock vary from 268 Ω m to 1 483 Ω m. According to[2, 3, 20], the resistivity values that exceed 1 000 Ω m is fresh

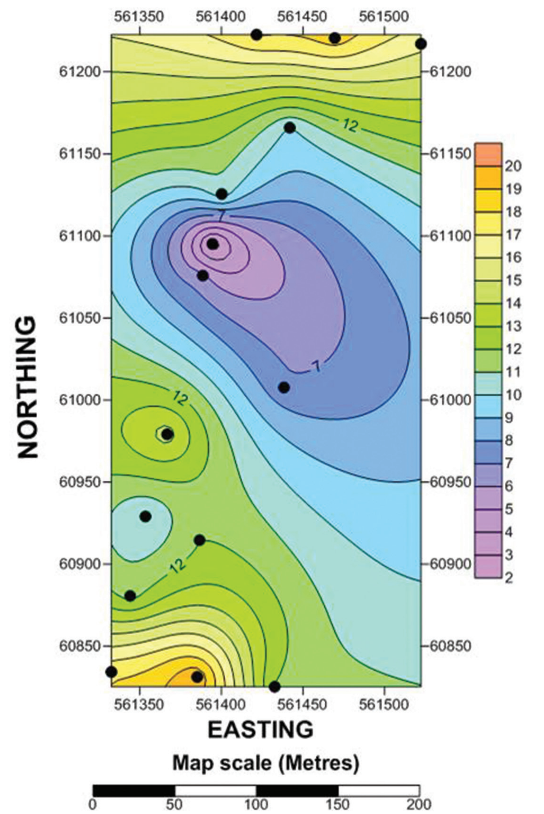

Figure 9a: *Isopach map of the study area.*

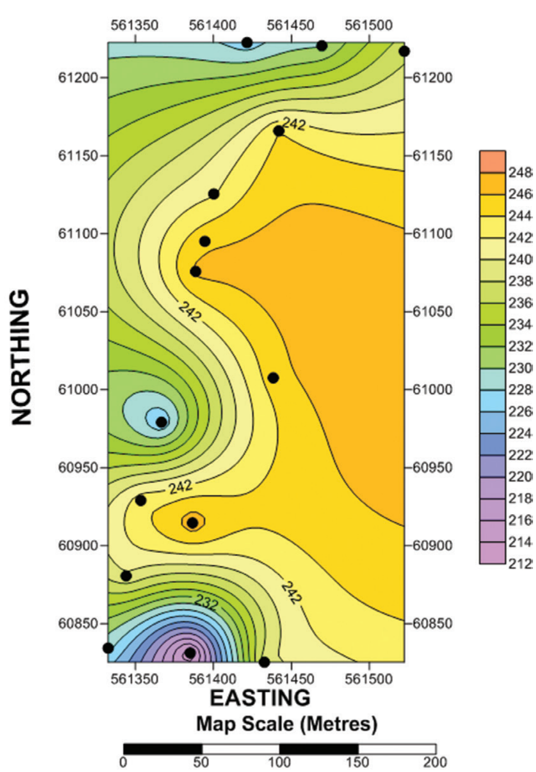

Figure 9b: *Bedrock relief map of the study area.*

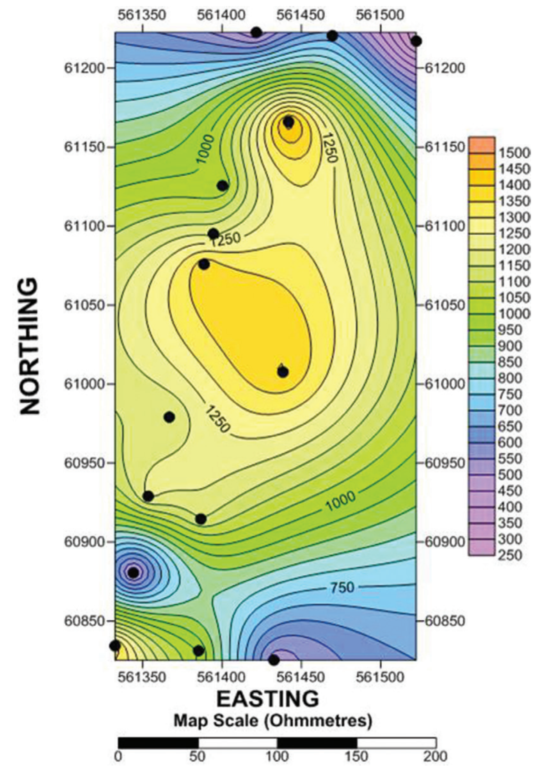

Figure 9c: *Resistivity contour map of the study area.*

bedrock and for a value below 1 000 Ω m, the bedrock is fractured and saturated. From the resistivity contour map (Figure 9c), higher resistivity values (1 007 Ω m to 1 483 Ω m) are typical of the dam axis while the abutments are characterized with low values indicating fractured bedrock. It can be deduced from (Figures 8a, c) that the dam axis with thin overburden thickness corresponds to area with high resistivity values which invariably correspond to area with bedrock ridges. Generally, the fresh bedrock along the dam axis can be said to be poorly saturated (low porosity and permeability) while the overburden is highly saturated (poor drainage).

2D-resistivity models

From the inversion of field data using RES 2DINV, the two-dimensional inverse resistivity models for the subsurface terrain underlying the dam axis, the left and right abutments generally indicate relative uniformity in the values of resistivity along the horizontal direction, especially beneath the two abutments.

2D-Resistivity model for the Dam axis

The complete resistivity inversion model along the dam axis is shown in Figure 10a. Low resistivity zones in the inversion sections are prevalent across the entire topmost layer of the dam axis, however the resistivity increase with depth. The thickness of this very low resistive (high conductive) region decreases from about 7.4 m at the extreme left down to about 2.4 m at 160 m offset. Similar phenomenon was noticed towards the extreme right of the dam axis. The second horizon, interpreted as a weathered water-saturated layer with resistivity ranging from 50 Ω m to 300 Ω m has an average thickness of about 3.5 m. The value of resistivity increases with depth. The regions with high values of resistivity, which is an indication of the basement rock, are closer to the surface at (160, 280 and 330) m offsets. This is indicative of the variation in thickness of the overburden as revealed by the isopach map of overburden and the basement relief map in which the thickness of the overburden is much reduced at 160 m offset. The thickness of the overburden is however, much higher around the left extreme at zero offset (abutment), around the central region at 200 m offset and around the right extreme at 400 m offset (abutment). The resistivity of the third layer is over 3 000 Ω m interpreted as competent basement.

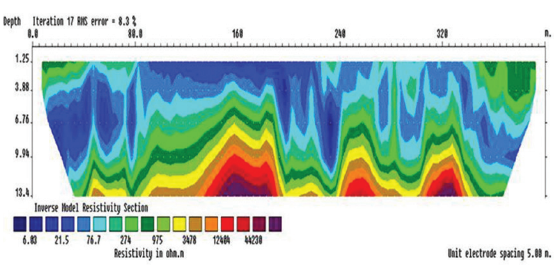

Figure 10a: *Inverse resistivity model for the Dam axis.*

2D-Resistivity model for the Left abutment

The model resistivity values generally decrease with depth (Figure 10b). The uppermost layer that is relatively dry and sandy on the left abutment shows consistently high resistivity values of between 472 Ω m and 780 Ω m, the downward decrease in resistivity result in the occurrence of a thicker layer when compared to the uppermost horizon with very low resistivity values from a depth of about 6.8 m down to the base of the section at a depth of 13.4 m around 57 m to 60 m offset. This horizon corresponds to the water saturated region of the clayey weathered basement material. High resistive (780 Ω m) basement rock was found gradually intruding the second layer at distance 25–35 m and 65–70 m. This was not conspicuously revealed in this section because the overburden is very thick.

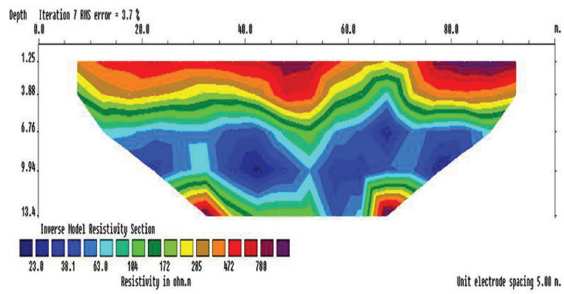

Figure 10b: *Inverse resistivity model for the left abutment.*

2D-Resistivity model for the Right abutment

Resistivity image interpretation shown in Figure 10c indicates that the resistivity values are decreasing gradually downward in the section from surface to bottom of the section and are uniform in nature. A highly (769 Ω m) resistive lithology (dry and sandy) was revealed at the uppermost layer to a depth of 5 m on the right flank of the proposed dam site. The downward decrease in resistivity, result in the occurrence of a layer with very low resistivity values (18 Ω m to 50 Ω m) from a depth of about 6.5 m down to the base of the section within a depth of 13.4 m, at 45 m offset. This horizon corresponds to a region with water saturation, within the clayey weathered basement material.
High resistivity value is evident at the bottom of the section with offset distance 60–75 m beyond 13 m depth.

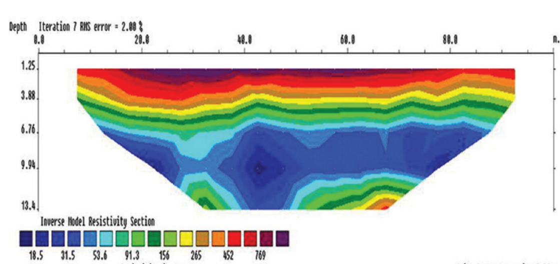

Figure 10c: *Inverse resistivity model for the Right abutment.*

Geotechnical characterization

The stability of any engineering structure is primarily dependent on their supporting foundation which is largely a function of the nature and condition of the underlying soil materials[21]. A correlation of the lithologic section penetrated at position of BH1, BH2, BH3 and BH4 (Figure 11) suggests that the depth to bedrock vary between 3 m to 6 m with an increase in depth at the two extreme boreholes (BH1 and BH4) along the dam axis. Groundwater was not encountered at boreholes BH1 and BH4, but it was encountered at depth of 3.5 m and 2.5 m in boreholes BH2 and BH3 respectively. The Standard Penetrometer Test (SPT) investigation was undertaken between 1.5 m and 6.0 m depth range (Figures 12). The SPT blows range between 12 and 50. At depth of 1.5 m, the

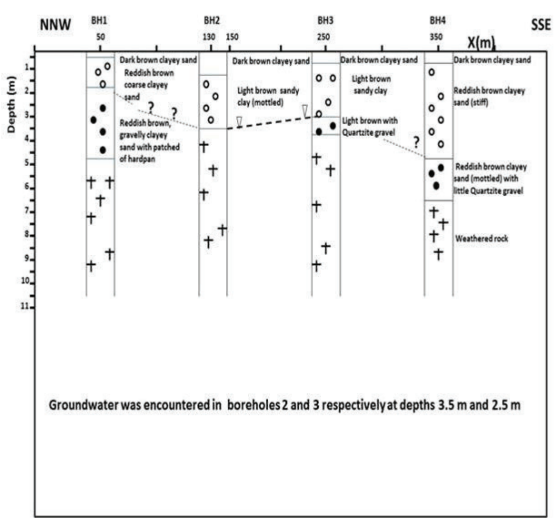

Figure 11: *Boreholes lithologic correlation along the dam axis.*

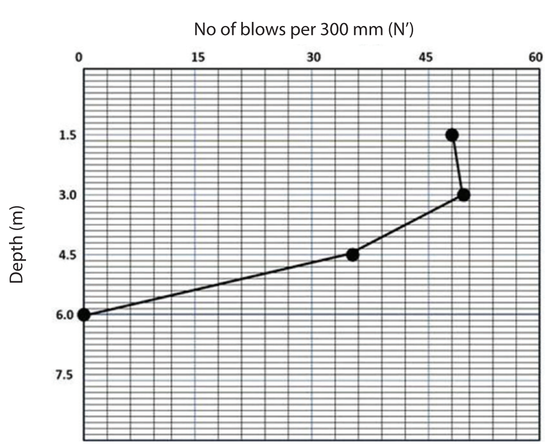

Figure 12: *SPT plot for BH4.*

SPT number of blows (*N*) for BH1 and BH4 was respectively 35 and 48 and decreases for BH2 and BH3 along the proposed dam axis. At depth of 3 m, the trend of the SPT number of blows are low at BH2 and BH3 indicating the type of clay present is very soft (easy penetration) and the region is marshy but the number of blows increases for BH1 and BH4 towards the edges of the proposed dam axis and showing a well drained portion. This shows proportional rate of penetration with the nature and hardness of rock encountered when correlated with borehole log and geoelectric parameters.

Conclusions

The results from Very Low Frequency electromagnetic method indicated that the host rock is generally of low conductivity with pockets of highly resistive and highly conductive units embedded within the low background. From the geoelectric sections, the thickness of the overburden is relatively thick at the dam abutments and shallow along the dam axis with the lowest thickness at the central part of the dam axis. It can be deduced from the Isopach, Bedrock relief and Resistivity contour maps that the dam axis with thin overburden thickness correspond to area with high resistivity values which invariably correspond to the area with bedrock ridges, more so, the bedrock (fresh) along the dam axis is poorly saturated (low porosity and permeability) and the overburden is highly saturated (poor drainage). However, at the abutments, the reversed was experienced and the bedrock is fractured. Uniformity in resistivity values along the horizontal direction and variation in resistivity values in the vertical direction was revealed from inverse resistivity 2-dimensional models. The geotechnical results revealed that the stability of the proposed dam axis is lowest at the central part of the axis and increases away to the two extremes.The uneven nature of the basement topography is a potential threat to the stability of engineering structures. As a result, the site was considered unsuitable for concrete dam but suitable for earth dam. If the dam will however be constructed, proactive measures, such as deep excavation and grouting must be taken against the structural and geological defects.

Table 1: *Summary of VES data interpretation*

S/N	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve Type	Reflection Coefficient	Probable Lithology
VES 1	I.	594	3.3	3.3	H type $\rho_1 > \rho_2 < \rho_3$	0.642	Topsoil
	II.	58	13.0	16.3			Weathered basement (clayey)
	III.	268	–	–			Fractured basement
VES 2	I.	804	3.7	3.7	H type $\rho_1 > \rho_2 < \rho_3$	0.874	Topsoil
	II.	45	14.9	18.6			Weathered basement (clayey)
	III.	673	–	–			Fresh basement
VES 3	I.	432	4.1	4.1	H type $\rho_1 > \rho_2 < \rho_3$	0.812	Topsoil
	II.	46	14.0	18.1			Weathered basement (clayey)
	III.	447	–	–			Fresh basement
VES 4	I.	326	2.6	2.6	H type $\rho_1 > \rho_2 < \rho_3$	0.933	Topsoil
	II.	35	8.0	10.6			Weathered basement (clayey)
	III.	1 007	–	–			Fresh basement
VES 5	I.	18	1.0	1.0	H type $\rho_1 > \rho_2 < \rho_3$	0.981	Topsoil
	II.	11	1.3	2.3			Weathered basement (clayey)
	III.	1 187	–	–			Fresh basement
VES 6	I.	178	0.4	0.4	H type $\rho_1 > \rho_2 < \rho_3$	0.967	Topsoil
	II.	23	5.9	6.3			Weathered basement (clayey)
	III.	1 385	–	–			Fresh basement
VES 7	I.	52	3.0	3.0	A-type $\rho_1 > \rho_2 < \rho_3$	0.549	Topsoil
	II.	333	11.5	14.5			Weathered basement (sandy clay)
	III.	1 146	–	–			Fresh basement
VES 8	I.	71	4.8	4.8	A-type $\rho_1 > \rho_2 < \rho_3$	0.731	Topsoil
	II.	188	5.1	9.9			Weathered basement (clayey)
	III.	1 213	–	–			Fresh basement
VES 9	I.	387	3.3	3.3	H type $\rho_1 > \rho_2 < \rho_3$	0.677	Topsoil
	II.	87	8.3	11.6			Weathered basement (sandy clay)
	III.	450	–	–			Fractured basement
VES 10	I.	340	4.6	4.6	H type $\rho_1 > \rho_2 < \rho_3$	0.923	Topsoil
	II.	55	13.1	17.7			Weathered basement (clayey)
	III.	1 378	–	–			Fresh basement
VES 11	I.	453	3.7	3.7	H type $\rho_1 > \rho_2 < \rho_3$	0.849	Topsoil
	II.	81	16.2	19.9			Weathered basement (clayey)
	III.	995	–	–			Fresh basement
VES 12	I.	636	3.8	3.8	H type $\rho_1 > \rho_2 < \rho_3$	0.766	Topsoil
	II.	68	8.1	11.9			Weathered basement (clayey)
	III.	512	–	–			Fractured basement

Acknowledgement

Special thanks to Prof. M. O. Olorunfemi and Prof. J. O. Ajayi of the Department of Geology, Obafemi Awolowo University Ile-Ife for critically reviewing the manuscript.

References

[1] Coduto, D. P. (1999): *Geotechnical Engineering*: *Principles and Practice*. Prentice Hal Inc. Upper Saddle River, New Jersey 07458.

[2] Olorunfemi, M. O., Ojo, J. S., Sonuga, F. A., Ajayi, O., Oladapo, M. I. (2000): Geoelectric and electromagnetic investigation of the failed Koza and Nassarawa earth dams, around Katsina, Northern Nigeria. *Journal of Mining and Geology*, 36(1), pp. 51–65.

[3] Olorunfemi, M. O., Ojo, J. S., Sonuga, F. A., Ajayi, O. and Oladapo, M. I. (2000): Geophysical investigation of Karkarku earth dam embankment. *Global Journal of Pure and Applied Sciences,* 6(1), pp. 117–124.

[4] Bell, F. G. (2007): *Engineering Geology*. Butterworth-Heinimann Publishers, Oxford, UK, 524p.

[5] Price, D. G., Frectas, M. H. (2009): *Engineering geology, principles and practise.* Springer-Verlag Berlin Heidelburg, Germany, pp. 103–384.

[6] Ako, B. D. (1976): An integration of geological and geophysical data in dam site investigation, a case study of Opa dam, Ile-Ife, Osun state, Southwestern Nigeria. *Journal of Mining and Geology,* 13(1), pp. 1–6.

[7] Drake, C. L. (1962): Geophysics and Engineering. *Geophysics,* 27(2), pp. 193–197.

[8] Dutta, N. P. (1984): Seismic Refraction Method to study the foundation rock of a dam. *Geophysical Prospecting,* 32, pp. 1103–1110.

[9] Early, K. R., Dyer, K. R. (1964): The use of resistivity survey in a foundation site underlain by Karst Dolomite. *Geotechniques,* 4, 341–348.

[10] Moore, R. W. (1952): Geophysical method adapted to Highway Engineering Problems. *Geophysics,* 17(3), p. 530.

[11] Olorunfemi, M. O., Mesida, E. A. (1987): Engineering Geophysics and its application in Engineering site Investigations (Case study from Ile-Ife area). *The Nigerian Engineers,* 22(2), pp. 57–66.

[12] Ojo, J. S., Ayangbesan, T. A., Olorunfemi, M. O. (1990): Geophysical survey of a dam site. *Journal of Mining and Geology,* 26(2), pp. 201–296.

[13] Aina, A, Olorunfemi, M. O., Ojo, J. S. (1996): An integration of aeromagnetic and electrical resistivity methods in dam site investigation. *Geophysics,* 61(2), pp. 349–356.

[14] Olorunfemi, M. O., Idoringie, A. I., Fagunloye, H. O., Ogun, O. A. (2003): Assessment of anomalous seepage conditions in the Opa dam embankment, Ile-Ife, southwestern Nigeria. *Global Journal of Geological Sciences*, 2, pp. 23–31

[15] Olorunfemi, M. O., Idoringie, A. I., Coker, A. T., Babadiya, G. E. (2004): The application of the electrical resistivity method in foundation failure investigation. *Global Journal of Geological Sciences*, 2, pp. 39–51.

[16] Faniran, A. (1971): *Water supply to rural communities. A case of the Ibarapa water scheme.* Paper presented at the Geographical Association Conference held at the University of Ife, Ile-Ife, Nigeria, March 20–25, 1971.

[17] Olorunfemi, M. O., Okhue, E. I. (1991): Electrical Resistivity investigation of a typical basement complex area. The Obafemi Awolowo University Campus case study. *Journal of Mining and Geology*, 27(2), pp. 63–69

[18] Dan-Hassan, M. A., Olorunfemi, M. O. (1999): Hydrogeophysical investigation of a basement terrain in the north-central part of Kaduna State Nigeria. *Journal of Mining and Geology,* 35(2), pp. 189–205.

[19] Omosuyi, G. O., Ojo, J. S., Enikanselu, P. A. (2003): Geophysical investigation for Groundwater around Obanla-Obakekere in Akure Area within the basement complex of Southwestern Nigeria. *Journal of Mining and Geology,* 39(2), pp. 109–116.

[20] Olayinka, A. I., Mbachi, C. N. (1992): A technique for the interpretation of electrical soundings from crystalline basement areas of Nigeria. *Journal of Mining Geology,* 37, pp. 163–175.

[21] Faleye, E. T., Omosuyi, G. O. (2011): Geophysical and Geotechnical characterization of foundation beds at Kuchiyaku, Kuje area, Abuja, Nigeria. *Journal of emerging trends in Engineering and Applied Sciences*, 2(5), pp. 864–870.