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Geoelectrical Assessment of a Proposed Dam Site around Ehuhe area of Oji River, Southeastern Nigeria.

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Abstract
The current study involves applying the Vertical Electrical Sounding (VES) by using the symmetrical Schlumberger configuration to evaluate the suitability of the soil underlying Ehuhe area of Oji River Southeastern Nigeria for dam construction. The survey was conducted along the proposed dam axis (about 477 m long) and its vicinity with the view to determining the presence or otherwise of deleterious matter along the dam axis down to a depth of 35m below the surface, evaluate the geo-structural setting of the concealed bedrock, the fracture pattern and possible dam seepage along the dam axis and its banks as well as give suggestions on any other measures/studies that may be needed for a proper engineering design. Twelve (VES) sounding stations at between 40m (VES 1 – VES 10) and 60m (VES 10 – VES 12 and VES 2 – VES 11) were located and fully occupied along the dam axis. The data obtained were subjected to 1-D inversion algorithm to determine the layer parameters. The results show that the subsurface is remarkably inhomogeneous in geological composition. The geoelectric section revealed three (3) lithologic units defined by top loose dry sandstone, hard but jointed iron oxide-cemented sandstone and porous sandstone, with shales being totally absent. Resistivity values range from 9200-66100, 1440-161000 and 555-21300 ohm-m in the topsoil, ironstone and porous sandstone respectively. Depth to each layer varies from 0.5-12.0 m in the topsoil, 3.6-22.1m in the ironstone rich zone and greater than 40m in the porous sandstone region. No structures that will be of deleterious effect were observed in all the VES points down to about 40m. From the results and field observations it is concluded that the proposed dam axis is underlain by high sandy/ arenaceous matter usually brought in from both Ehuhe and Udi areas with high porosity and potentially rife for great infiltration. It is expected that high bearing capacity shall characterize the rock units. However the absence of shales means high infiltration in a sandy environment. Efforts should be made to provide some suitable blanket materials for the dam and mechanism for desilting when the dam is put in place.
Keywords: Geoelectric Section, Geometric factor, Lithology, Oji River, Seepage.

1. Introduction

A dam is a barrier of concrete or Earth that is built across a river or stream to obstruct or control the flow of water thereby creating a reservoir upstream. Benefits provided by dams include water supplies for drinking, irrigation and industrial uses; flood control; hydroelectric power; recreation; and navigation. At the same time, dams also represent a risk to public safety. Despite series of geotechnical studies preceding the construction of dams, there are still number of problems that dams are prone to. Such problems can be caused by existence of concealed fracture/faults, fissures, joints or shears which can greatly reduce the reservoir capacity of the dam (Akanmu *et al*., 2007). The statistics of failures of structures such as road, buildings, dam and bridges throughout the nation has increased geometrically. The need for pre-foundation studies has therefore become very imperative so as to prevent loss of valuable lives and properties that always accompany such failures. Foundation study usually provides subsurface information that normally assists civil engineers in the design of foundation of civil engineering structures. Geophysical methods have been used extensively in dam site investigations (Artsybashev, 1973; Ako, 1976; Artsybashev and Azeez, 1977; Kilty et al., 1986; Annor et al., 1989; Ojo and Olorunfemi, 1995; Olasehinde and Adelana, 1999). Geoelectric surveys, particularly resistivity measurements, still account for a large amount of work in using geophysical methods for surveys of shallow depths. The advantage is that they are not so demanding for instrumentation. This study involves a pre-design geophysical survey carried out along a 477m proposed dam axis across the Oji River near Ehuhe, Southeastern Nigeria. The objectives of the study are to determine the presence or otherwise of deleterious matter along the dam axis down to a depth of 35m below the surface, evaluate the geo-structural setting of the concealed bedrock, the fracture pattern and possible dam seepage along the dam axis and its banks as well as give suggestions on any other measures/studies that may be needed for a proper engineering design.

1. Location and Accessibility of the study area.

Ehuhe is located at about 18km Southeast of Oji River Local Government Secretariat, through Adu Achi. The dam site, across Oji River is however 2.5km northeast of Ehuhe town (figure 1). The Dam site is located at Latitudes $6^o12.240$'N – $6^O12.605$'N and at longitudes $7^o21.968$'E – $7^o22.570$'E. The Dam axis is about 350m and the studied length including the axis is 470m with the centre symmetrically at the river (235m on either side of the river (figure 2). The Dam site is accessible through Achi, Agu Achi and Oji River towns.

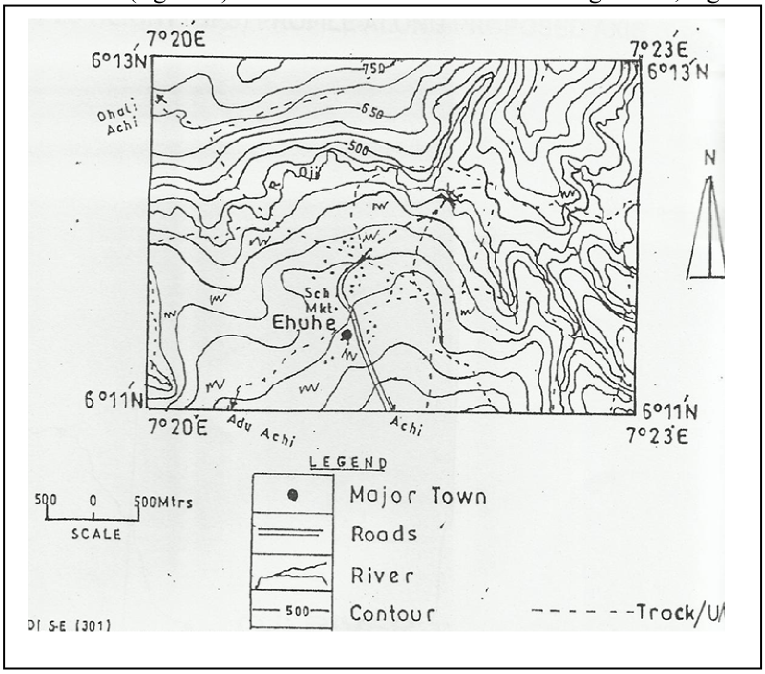

Figure 1. Location map of study area Showing Oji River to be dammed.

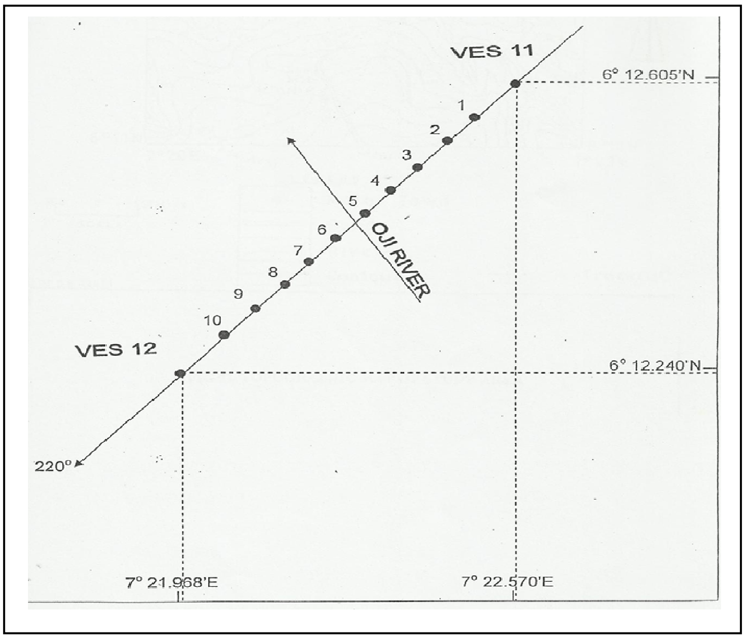

Figure 2. Symmetry map of the study area

2. Climate, Vegetation, Relief and Drainage of the study area.

Essentially Ehuhe area falls under the Guinea Savannah forest with scattered trees and grassy under-growth. Visibility is fair and people can see and talk up to 200m apart. Sheer butter tree is common with very few Iroko trees, confined mainly towards Ehuhe area. The River in the area supports dense vegetation along the banks typical of the rain forest regions of southeast and south-south Nigeria (Iloeje, 1991). Ehuhe and Achi areas are the dip slope sections of the famous Enugu Escarpment, which runs from Okigwe through Enugu to Ayangba in the middle Benue area. While the Ehuhe area has subdued topography, the area around the Dam site displays rugged and uneven topography. At the River valley the slopes are quite prominent. The area is prone to erosion as huge gullies have nearly cut off the old Ehuhe-Oji river roads. As at the moment of this study the road was no more motorable due to gullying. Oji River is the only river in the area. Most run-off from the hilly Ehuhe area are naturally channeled into the River which flows northwest from southeast. Drainage pattern is dendritic with tributaries of very short flow regimes. In most areas along the river, huge and high angle gorges are seen along the River banks.

3. Geological Setting

Oji River area is underlain by rock units of the Danian Nsukka Formation. This in turn, is underlain by the Maastrichtian Ajali Formation. Rock units of these Formations include (a) Shales, limestones, coal beds, sandstones and resistant iron-oxide-bearing sandstone for the younger Nsukka Formation (b) Sandstone and ferruginous sandstone for the older Ajali Formation. Because of the overriding sandy units in the area, soil erosion is common, carving huge gullies that are parallel to one another and running into the Oji River. The outcrops of both the hard ironstone of Nsukka Formation and the iron-stained Ajali counterpart are observed along the River bank. These strike NW-SE and dip at 17^o to the 245^o direction (plates 1-3).

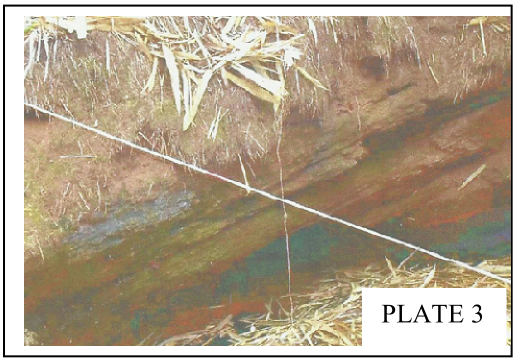

Plate 1: Bailey bridge, Plate 2: SW dipping Ferrugenised Sandstone, Plate 3: Profile Direction.

One of the most remarkable structural features is that the river appears to be stratigraphically controlled, flowing 335^o which is the strike direction; from observation made on rock outcrops at the river bank, joints trend NE-SW (along dip direction). Thus it is very possible that the net groundwater movement is SW from NE. As in Okigwe area, the hilly areas are sites for ironstone quarries while the River bed areas are sites for sand and gravel quarries.

4. Materials and Methods

The methods utilized in this study involve both Geological and Geophysical approaches. The Geological method includes the identification of rock units along the Dam axis taking their attitudes and relating these to regional geology. Such outcrops helped in inferring the signals on the geophysical records. In other to evaluate the geo-structural setting of the concealed bedrock, the fracture pattern and possible dam seepage along the dam axis and its banks, a geophysical survey involving the use of electrical resistivity was employed.

4.1 Theory

The electrical resistivity method is an active geophysical method. It employs an artificial source which is introduced into the ground though a pair of electrodes. The procedure involves measurement of potential difference between other two electrodes in the vicinity of current flow. Apparent resistivity is calculated by using the potential difference for the interpretation. The electrodes by which current is introduced into the ground are called Current electrodes and electrodes between which the potential difference is measured are called Potential electrodes.

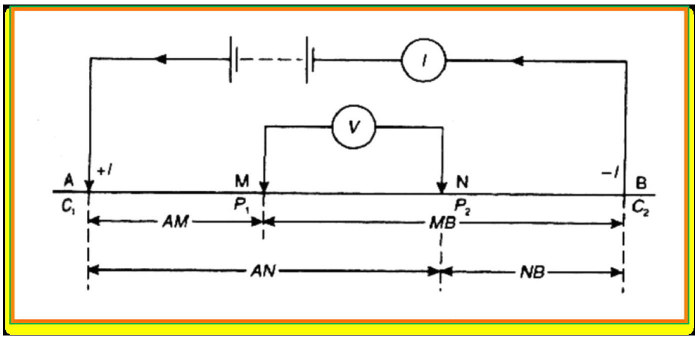

Figure 3. Generalized Electrode configuration for Electrical Resistivity surveying.

A and B are current electrodes; M and N are potential electrodes.
In Schlumberger configuration, MN<<AB.

Potential at M,

$$V_1 = \frac{\rho_a I}{2\pi} \left(\left(\frac{1}{AM}\right) - \left(\frac{1}{MB}\right) \right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Potential at N,

$$V_2 = \frac{\rho_a I}{2\pi} \left(\left(\frac{1}{AN}\right) - \left(\frac{1}{NB}\right) \right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Potential Difference

$$\text{Potential Difference } \Delta V = \frac{\rho_a I}{2} \left\{ \left(\left(\frac{1}{AM}\right) - \left(\frac{1}{MB}\right) \right) - \left(\left(\frac{1}{AN}\right) - \left(\frac{1}{NB}\right) \right) \right\} \quad \ldots\ldots\ldots\ldots(3)$$

Basically we use direct currents but we can also use low frequency alternating currents to investigate the electrical properties (resistivity) of the subsurface. Current is injected into the ground using two electrodes (from A and B) and the resulting voltage is measured using the remaining two electrodes (from M and N) (figure 3). The fundamental equation is derivable from Ohm's laws. The electric potential, Vr at any point, P distance, r from a point electrode emitting an electric current, I in an infinite homogenous and isotropic medium of Resistivity, ρ is given by

$$V_r = \frac{\rho I}{2\pi r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

For a semi-finite medium, this is the simplest Earth model, and with both current and potential point-electrodes placed at the Earth's surface.

$$\rho = \frac{V(2\pi r)}{I} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Irrespective of surface location and electrode spread, the resistivity is constant in a homogenous and isotropic ground. However, it does vary with the relative positions of electrodes when there is presence of subsurface inhomogeneities and any computed value is known as apparent resistivity

$$\rho_a = \frac{\Delta v(2\pi r)}{I} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

For schlumberger arrangement

$$G = \frac{\pi \left(\left(\frac{AB}{2}\right) - \left(\frac{MN}{2}\right) \right)^2}{2 \left(\frac{MN}{2}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$$\rho_a = \frac{\Delta VG}{I} = R.G \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

This can generally be written as

ρ_a = $\pi(a^2/b - b/4)$ R …………………(9)

where

ρ_a = apparent resistivity in Ohm-m
a = AB/2, the Half Current Electrode Separation in metres
b = MN, Potential electrode separation in metres
R = Instrument reading in Ohms

G is the Geometric Constant which is a function of the electrode configuration employed during the survey. The data collected on the field were presented by plotting the apparent resistivity (ρ_a) values against the electrode spacing (AB/2) on bi-log graph. Quantitative interpretation of the VES curves involved partial curve matching and computer iteration technique. As a good fit, (up to 95% correlation) was obtained between field and model curves, interpretation was considered as right. The AB/2 for this study ranged from 1.5 to 55m ensuring a depth penetration of approximately 36m. A profile of 470m across the river, parallel to the Dam axis was made. The profile was taken at about 137m upstream southeast of the Bailey bridge (figure 4).

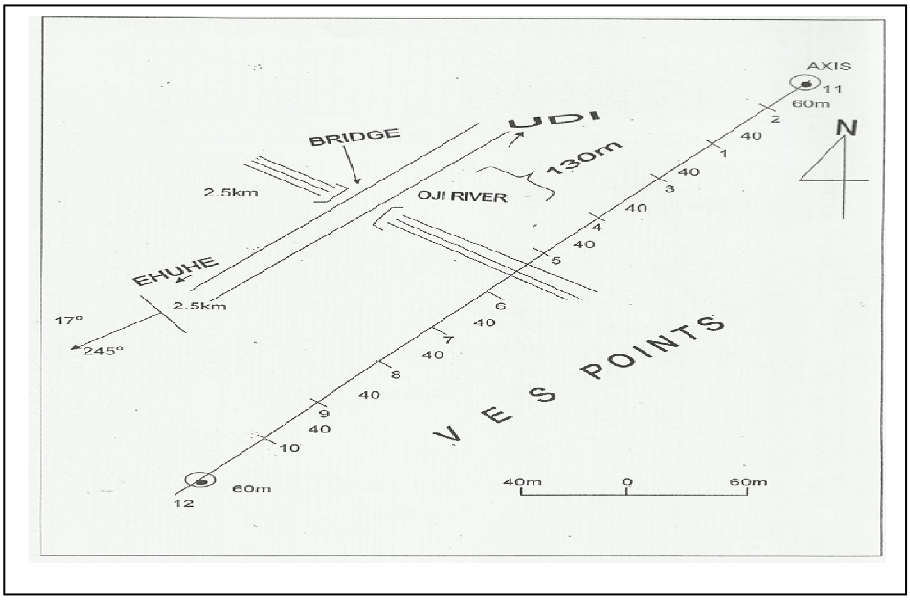

Figure 4. VES Points layout along the proposed Dam axis

The ABEM Terrameter model SAS 4000 (figure 5) was used in the field reading operation. Field readings in Ohms were reduced to apparent resistivity values using equation 9.

The field layout is shown in figure 4. Twelve vertical electrical sounding stations at between 40m (VES 1 – VES 10) and 60m (VES 10 – VES 12 and VES 2 – VES 11) (figure 4), were made. The geophysical profile across the river trends 220^o (NE-SW), nearly parallel to the dip direction.

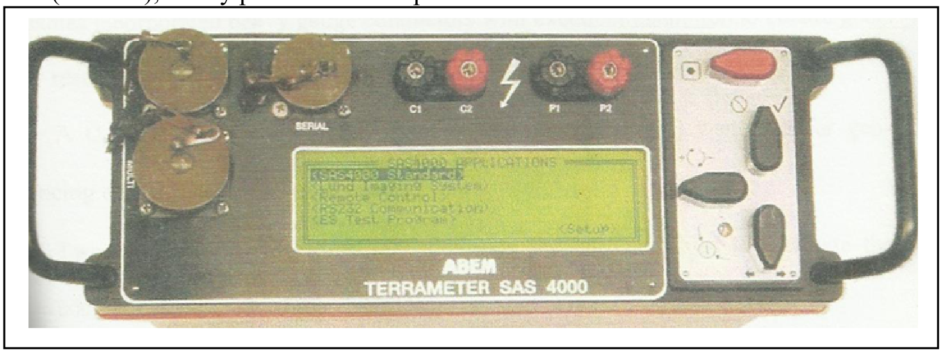

Figure 5. ABEM Terrameter SAS 4000.

5. Results and Discussion

For the multilayer sounding curves obtained after curve matching and computer iteration, various types of curves were determined by the relationship existing between the layer resistivity values ρ1, ρ2, ρ3 ... ρn. It was discovered that the curves are mostly k-type and Q-type. Curve shapes and not necessarily the resistivity values are employed in resistivity sounding data interpretations. This is because the values of resistivity may change due to wetness or dryness as during wet and dry seasons, but the real depths to geoelectric layers remain constant. Thus curve shapes were used to infer the number of geoelectric layers prior to quantitative treatment. Preliminary field data were fed into Zohdy software to generate real depths and layer resistivities in the twelve sounding points. Model interpretations of the results of the Vertical Electrical Soundings in the twelve stations are shown in table 1 and a typical modeled curve shown in figure 6.

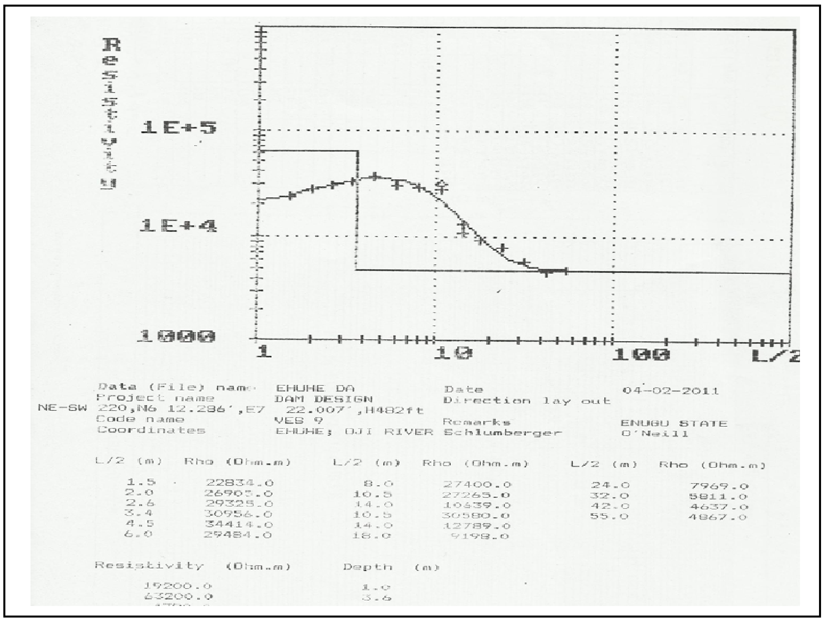

Figure 6. Typical modeled curve of the study area.

Table 1. Model Interpretations of the VES results.

VES Stations	Layer Parameters Layer1			Layer 2			Layer 3		
	Depth (m)	ρ(Ohm-m)	Lithology	Depth(m)	ρ(Ohm-m)	Lithology	Depth(m)	ρ(Ohm-m)	Lithology
VES 1	5.0	23200	Sandy top soil	12.3	52300	Hard ironstone	40.0	1560	Porous sandstone
VES 2	1.0	18300	Sandy top soil	11.8	41100	Hard ironstone	40.0	3150	Porous sandstone
VES 3	12.0	21300	Dry top soil	22.1	1440	Iron stained sandstone	40.0	3340	Porous sandstone
VES 4	3.3	18800	Dry top soil	7.4	13300	Hard ironstone	40.0	3620	Porous sandstone
VES 5	1.9	9200	Wet sandy soil	12.2	2140	Saturated ironstone	40.0	555	Saturated sand stone
VES 6	1.6	14400	Dry top soil	6.4	14200	Wet ironstone	40.0	5860	Porous sandstone
VES 7	4.4	66100	Dry top soil	20.2	17900	Hard ironstone	40.0	8400	Porous sandstone
VES 8	7.0	31900	Dry sandy soil	17.7	2460	Iron stained sandstone	40.0	6640	Porous sandstone
VES 9	1.0	19200	Dry sandy soil	3.6	63200	Hard ironstone	40.0	4790	Porous sandstone
VES 10	2.7	38400	Dry sandy soil	7.1	91000	Hard ironstone	40.0	19800	Porous sandstone
VES 11	0.5	17000	Dry sandy top soil	21.1	53500	Hard ironstone	40.0	4450	Porous sandstone
VES 12	0.8	33900	Dry sandy top soil	7.3	161000	Hard ironstone	40.0	21300	Porous sandstone

The topographic section with the GPS readings are shown in figure 7 while the geoelectric section correlated with all twelve VES points is shown in figure 8.

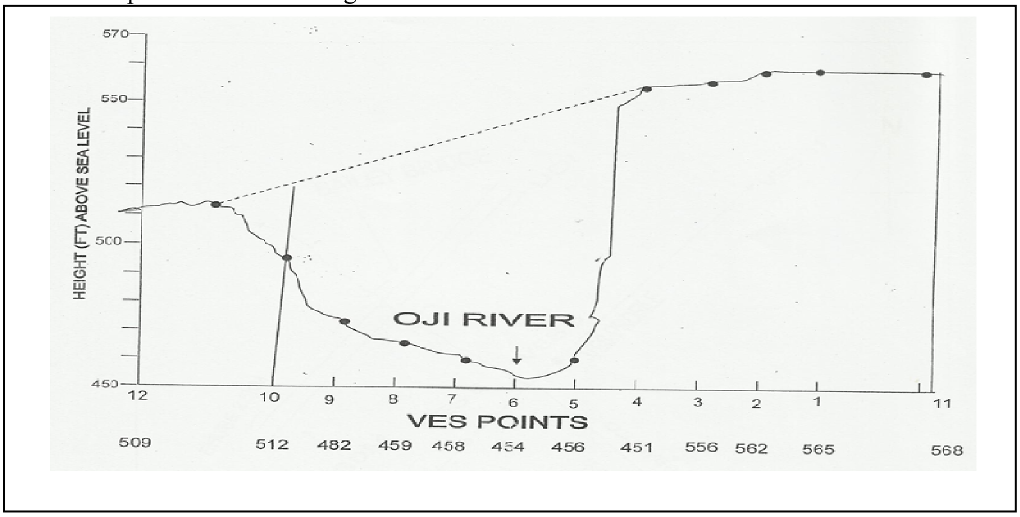

Figure 7. Height (GPS) Profile along the proposed axis (in feet).

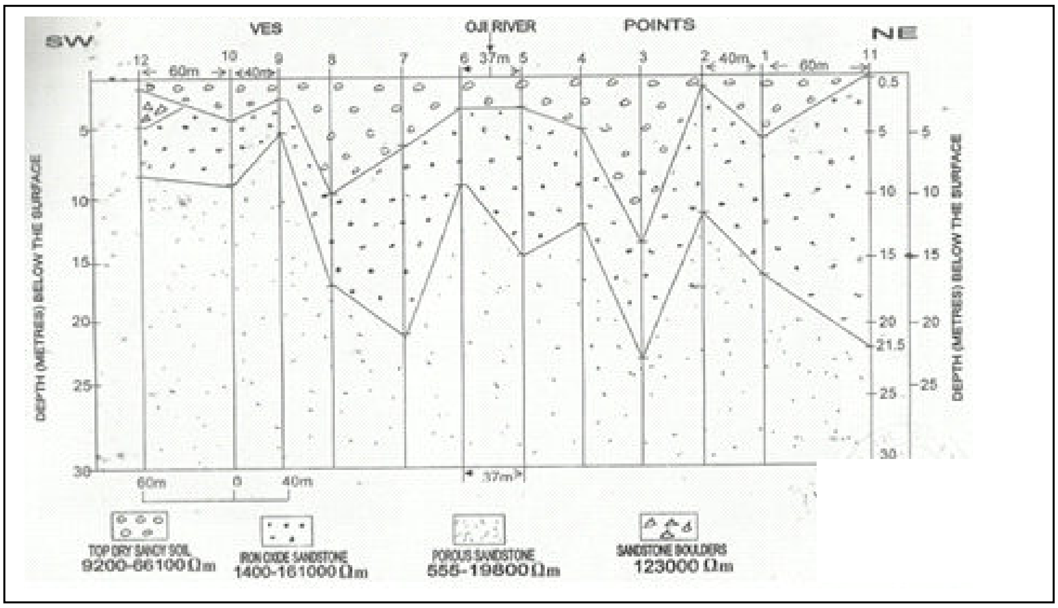

Figure 8. Geoelectric Section correlated for the VES Points along the Proposed axis.

From the results presented in the forms of resistivity and depth values of various layers, outcrops observed along the dam axis and adjoining areas, stratigraphic relations, a number of facts come out very clearly: height differentials of up to 150 feet occur between the highest point along geophysical profile (VES 2) and the river bed (VES 5 and VES 6). Overriding sandy units dominate the area. No shales were observed. The sandstone ranges from top loose dry sandstone, through very hard but jointed iron oxide-cemented sandstone to porous sandstone. The river flows along the strike and through the porous layer, thus being stratigraphically controlled. No structures that will be of deleterious effect were observed in all the VES points. However results show high degree of porosity, cross-bedding and dips of 15-20^{o} in the 245^{o} direction. The river flows along bedding planes and does not leave any fine matter at the banks. So much sand is generated from the upstream area. Thus much arenaceous matter shall come in from the sandy units upstream. No faults were detected down to 40m.

6. Conclusion

From the results and field observations it is concluded that the proposed dam axis is underlain by highly sandy matter with high porosity and potentially rife for great infiltration. Also great sandy matter is bound to be brought in from upstream equally rich in arenaceous matter.

It is expected that high bearing capacity shall characterize the rock units. However the absence of shales means high infiltration in a sandy environment. Efforts should be made to provide some suitable blanket materials for the dam. Soil test from points along the proposed axis shall confirm our conclusion on high competence of the rock units along the axis. Great sandy matter is brought in from both Ehuhe and Udi areas. This must be checked and mechanism for desilting put in place.

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