Ife Journal of Science vol. 8, no. 1 (2006)

APPLICATION OF GEOPHYSICS TO FOUNDATION STUDIES ALONG THE AXIS OF LIKARBU EARTH DAM ZUNTU IN KADUNA STATE, NIGERIA

B.D. AKO[1,+]; J.F. ADEYEMI[2]; T.R. AJAYI[1]; A.O. ADEPOJU[4] and J.B. ARUBAYI[3]

[1]Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria.
[2]Jabrildep. (Nig.) LTD, Plot 1240, Samuel Akintola Boulevard, Garki-Abuja
[3]Department of Physics, Obafemi Awolowo University, Ile-Ife, Nigeria.
[4]Petro Soga Haggai Ltd, 163, Bamgbose Street, Lagos.

(*Submitted*: 31 May 2005; *Accepted*: 18 May 2006)

Abstract

The Government of Nigeria through the Federal Ministry of Water Resources (FMWR) and the UNRBDA commissioned the construction of the Likarbu Earth Dam, across the Likarbu River (a tributary of the Galwa River) in Kaduna State, for the purpose of irrigation. It is imperative that the subsurface geology along the dam axis, must be well known to prevent subsequent hazards. The electrical resistivity method was chosen for cost effectiveness and its accuracy in evaluating subsurface geology. A total of Thirty (30) vertical electrical sounding (VES) stations were occupied (eight in the rainy season and twenty two in the dry season) with twenty-one stations located on the dam axis. The composite geoelectrical section for both seasons shows three geoelectrical layers: laterite topsoil (ρ= 141-448 ohm-m) with an average thickness of 2 m, underlain by a clay layer (ρ= 17-49 ohm-m) about 15m thick and bedrock of sand (ρ = 207-342 ohm-m) at some stations. Partly weathered/fresh basement rocks (ρ = 1046-1737 ohm-m) occur at some other stations. Correlation between geoelectrical data for both seasons and available drill-hole data was very good, confirming that the geology derived from the geoelectrical data is reliable. The lateritic topsoil (ρ=141-485Ohm-m) is competent and has appropriate thickness (5m) at CH 100-300 and CH 850-1050 to support a good foundation. There is need for cut and fill between CH 300-750 to improve the bearing capacity of the soil and thus enhance it as a good foundation base.

Keywords: dam axis, electrical resistivity, geoelectric layers, foundation.

1. Introduction

Lack of reliable and adequate water supply is a major constraint in tropical agriculture with the area of land under irrigation increasing considerably only during the last few decades. However, the increase is stagnating, partly because the water resources in many countries are now being used almost to the maximum, and partly because problems have arisen with respect to rising costs of maintaining the infrastructure, salination (about 20% of the total irrigated area), falling water tables and other ecological problems. Construction of big dams led to several social problems when many people had to be resettled causing psychological shock as a result of enforced removal from traditional homes with cultural, religious, and trading focal points and ancestral burial grounds. Also the inefficiency often recorded in water use on large-scale irrigation schemes has now led to the small-scale alternatives such as lift irrigation, small earth dams and water harvesting tanks which use water more efficiently and give farmers the possibility to participate in layout and management. The Likarbu Earth Dam in Kubau Local Government Area of Kaduna State, as proposed by the Upper Niger River Basin Development Authority (UNRBDA) is designed to meet these objectives.

The Government of Nigeria through the Federal Ministry of Water Resources (FMWR) and the UNRBDA commissioned the construction of the Likarbu Earth Dam, across the Likarbu River (a tributary of the Galwa River) close to Zuntu in Kaduna State. The Likarbu Dam is specifically for the purpose of irrigation in the farms at Zuntu and environs. It is an earth fill embankment dam with crest length of about 1175m, maximum height above river bed of 10m, a channel spillway of capacity of about 70 m^3/s, an irrigation water outlet structure and a bottom outlet for flushing sediments for ecological releases.

The unique nature of the dam makes it imperative that the subsurface geology along the dam axis must be well known to prevent subsequent hazards (e.g. failure, seepage etc). As a result preliminary investigations must be carried out along the dam axis to ascertain the suitability of the axis, and also the need for further detailed investigations at specific

+ *corresponding author*

portions along the axis. For cost effectiveness geophysical methods of investigation had to be carried out. The use of geophysical methods in dam site investigation has been on the increase (Artsybashev, 1973; Ako, 1976; Artsybashev and Asseez, 1977; Kilty *et al.*, 1986; Annor *et al.*, 1989; Okwueze *et al.*, 1994). The electrical resistivity method was chosen for the investigation because of the cost effectiveness and accuracy of the method in evaluating subsurface geology.

Zuntu and environs grow and produce maize, millet, cowpeas, tomatoes, onions vegetables etc. in large quantities. However, the climate and available water resources support only a one-season harvesting. The construction and subsequent operation of the Likarbu earth dam will greatly enhance agricultural output (crops and fisheries), improve water supply, bring about the development of the tourism industry and improve the general conditions of the local inhabitants, and if not properly managed, may have adverse effect on the lives of the inhabitants.

2. Study Area Description

Likarbu is one of the minor tributaries of the Kaduna River at its upper reach northeast of Kaduna town. It is part of the Upper Niger River Basin (Fig. 1). It is a third order stream and its dentritic pattern suggests that the drainage network is associated with underlying rock of rather uniform resistance. The proposed Likarbu Dam axis is approximately along 140° azimuth with a reference location of 10° 43.663'N, 08° 12.835E. It is approximately 40 km SE of Zaria (Kaduna State), 65 km NE of Jos (Plateau State), and 160 km NW of Abuja (The Federal Capital, Nigeria) all within the Central high plains of Northern Nigeria. The climate is of the moist-dry

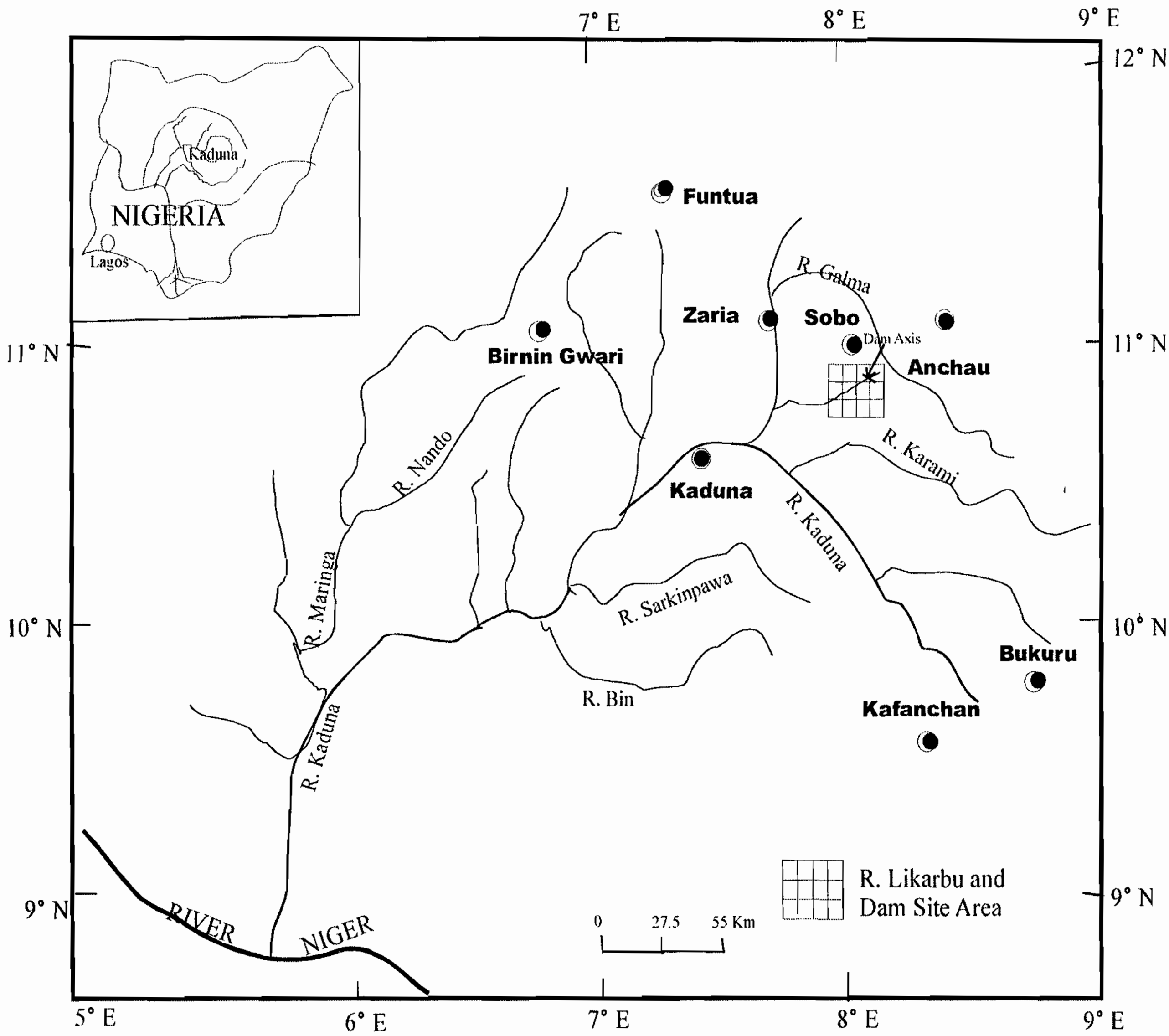

Fig. 1: Map of Kaduna River Network Showing the Likarbu Dam Site Zuntu Location.

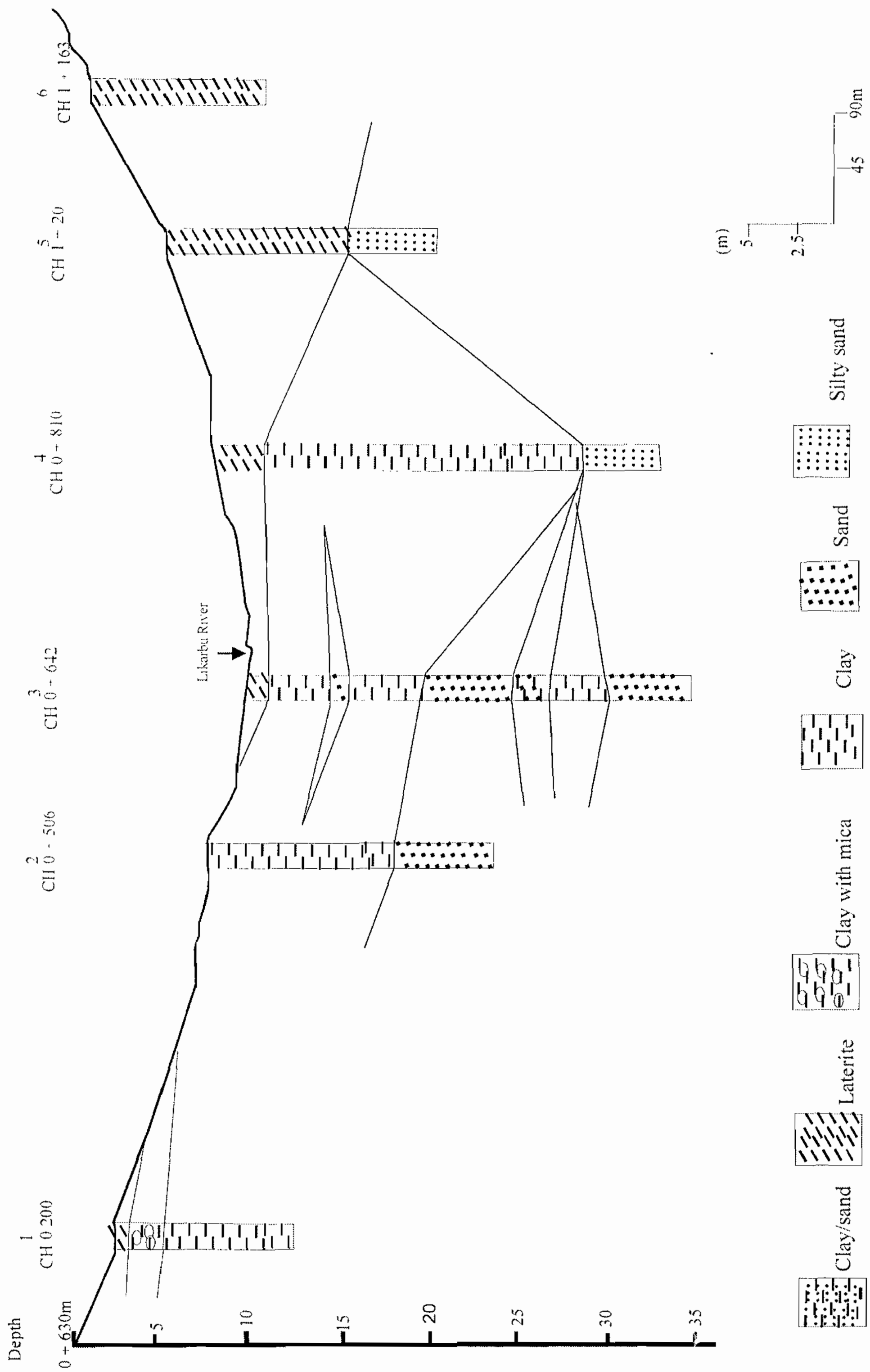

Fig. 2: Drilling Results along Likarbu Dam Axis Zuntu (After Damtech Nig. Ltd. 2002)

Table 1: Vertical Electrical Sounding (VES) Interpretation Results Likarbu Dam Site, Zuntu.

S/N	VES Nos	SITE DESCRIPTION	GPS GEOGRAPHIC COORDINATES	LAYER RESISTIVITY $\|\rho_1\|\rho_2\|\rho_3\|\rho_4$	DEPTH (m) $\|Z_1\|Z_2\|Z_3$	REMARKS
1	---	CH 100 Ref. Point	10° 43.663?N, 08°12.835?E			
2	1	80m S. of CH 100	10° 43.628?N, 08°12.863?E	84/475/37/1442	0.3/13.3/24.7	RAINY SEASON DATA (OCT 2002)
3	2	30m S. of VES 1	10° 43.614?N, 08°12.873?E	142/433/56/12215	0.6/13.7/46.2	
4	3	100m S. of VES 2	10° 43.574?N, 08°12.909?E	172/89/724	2.0/59.1	
5	4	285m S. of VES 3	10° 43.555?N, 08°13.006?E	30/45/31/224	1.3/5.0/21.5	
6	5	210m S. of VES 4	10° 43.344?N, 08°13.097?E	360/64/40/96	0.6/2.5/15.7	
7	6	60m N. of VES 5	10° 43.364?N, 08°13.053?E	115/90/31/106	0.6/4.3/13.3	
8	7	130m S. of VES 5	10° 43.288?N, 08°13.140?E	744/90/27/3685	1.4/4.9/44.4	
9	8	70m S. of VES 7	10° 43.258?N, 08°13.165?E	450/193/29/405	2.2/13.2/31.2	
10	9	In River Channel	10° 43.424?N, 08°12.562?E	33/33/165	2.2/18.2	
11	10	30m S. of VES 9	10° 43.346?N, 08°12.980?E	43/102/31/140	0.3/1.1/15.4	
12	11	30m S. of VES 10	10° 43.332?N, 08°12.986?E	90/34/145	1.5/15.5	
13	12	20m S. of VES 11	10° 43.319?N, 08°12.993?E	90/110/33/144	0.5/1.9/11.5	
14	13	20m N. of VES 9	10° 43.346?N, 08°12.977?E	54/100/32/193	0.6/1.5/17.7	
15	14	20m N. of VES 13	10° 43.376?N, 08°12.940?E	62/42/220	0.6/20.8	
16	15	40m N. of VES 14	10° 43.388?N, 08°12.937?E	161/42/200	0.4/21.5	DRY SEASON DATA MAR/APR. 2003
17	16	60m N. of VES 15	10° 43.413?N, 08°12.905?E	30/90/36/324	0.8/2.1/24.5	
18	17	100m N. of VES 16	10° 43.439?N, 08°12.899?E	120/75/27/758	0.6/2.5/22.7	
19	18	60m N. of VES 17	10° 43.475?N, 08°12.881?E	137/104/41/499	0.5/2.7/25.4	
20	19	50m E. of VES 18	10° 43.472?N, 08°12.901?E	398/100/40/1958	0.7/3.8/22.0	
21	20	100m S. of VES 19	10° 43.419?N, 08°12.942?E	134/33/1423	0.9/21.8	
22	21	100m S. of VES 20	10° 43.392?N, 08°12.977?E	300/204/46/241	0.4/22.6	
23	22	50m E. of VES 21 then N. 50m	10° 43.430?N, 08°12.987?E	220/39/342	1.3/18.2	
24	23	80m N. of VES 22	10° 43.462?N, 08°12.967?E	371/74/31/1046	0.5/2.0/20.3	
25	24	100m S. of VES 12 then 50m E.	10° 43.297?N, 08°13.048?E	397/96/17/1737	0.7/10.2/21.8	
26	25	60m N. of VES 24	10° 43.323?N, 08°13.032?E	648/141/46/207	0.5/2.8/14.0	
27	26	60m N. of VES 25	10° 43.350?N, 08°13.014?E	440/49/250	0.9/19.8	
28	27	100m E. of VES 26	10° 43.380?N, 08°13.057?E	288/37/1740	0.4/25.7	
29	28	50m S. of VES 27	10° 43.630?N, 08°13.074?E	340/70/32/4480	0.6/2.9/27.0	
30	29	250m S. of Camp-Zuntu Rd. then 100mE.	10° 43.542?N, 08°12.875?E	450/182/64/627	1.3/5.2/25.0	
31	30	97m E. of VES 29	10° 43.572?N, 08°12.926?E	368/176/42/7856	0.4/4.4/21.4	

monsoon type with humid period of about five months. The area is characterized by a single peak rainfall pattern, as applicable in most parts of Northern Nigeria. Long-term annual record has revealed that the estimated upper limit of annual rainfall is 1256 mm and the lower limit is 780 mm over a period of three decades. The annual regime of temperature in the area (based on long data on Jos and Kaduna) shows that temperatures are generally high in the study area. The annual mean of daily, minimum and maximum temperatures is 19 °C and 32 °C, respectively. For both minimum and maximum values, daily amplitude of variation are higher than the annual values; a characteristic that is typical of the tropical areas of the world (Annual report of the Meteorological Services, Nigeria data).

3. Geological Setting

The regional geology of the study area is best represented by the geology of Dutse Wai Sheet 125. The rock types in the area can be sub-divided into two main subgroups. These are the older granite suite and the younger granite suite. The younger granite suite consists of minor intrusives, biotite granite, riebeckkite granite, pyroxene-fayalite granite, fayalite-quartz-porphyry, ryolites and relics of gneisses and feldsparthic older granite. These are found mainly in the eastern part of Sheet 125 and they intrude into the older granite suit.

The older granite suite, include the following rock types: leucogranite, medium grained biotite granite, porphyritic biotite and biotite hornblende-granite, amphibolites and migmatites. All these rocks belong to the Pre-Cambrian Basement Complex of Nigeria

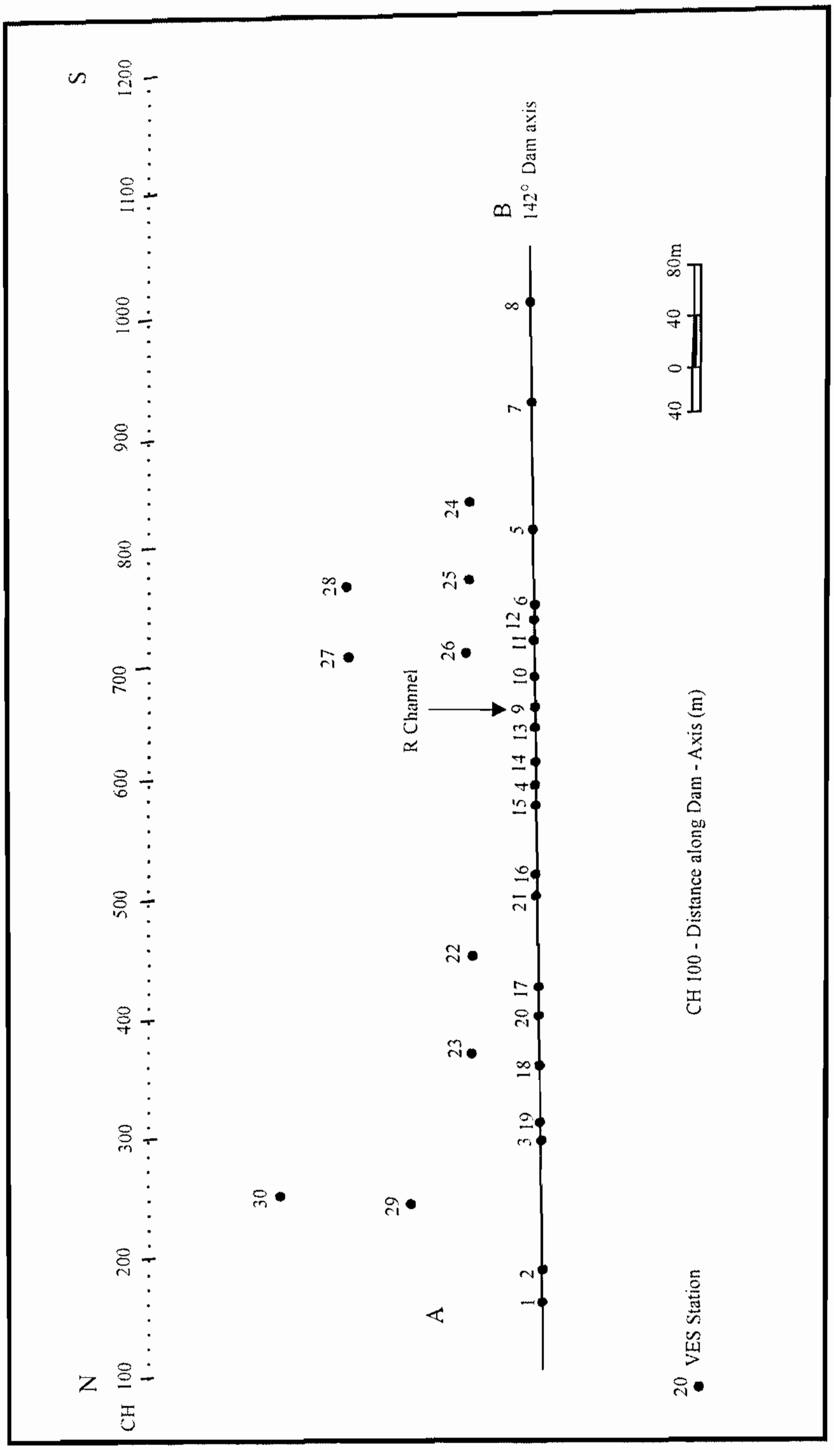

Fig. 3: Sketch location of VES Stations, Likarbu Dam Site Zuntu (Rainy Dry Seasons)

(Rahaman, 1976). The younger granites are mainly of Jurassic age. Rocks of the older granite suite dominate the regional geology of the study area.

The Likarbu dam site is located within the area underlain by the migmatite-gneiss complex. The Likarbu/Zuntu and immediate environ lack rock outcrops but there is considerable evidence of superficial laterites, and alluvium in the stream channels and flood planes. The area is generally flat lying with sparse vegetation. Outcrops of porphyritic older granites are common at Pambegua about 9km SE of Zuntu. The residual soil around the dam site, described by Damtech Nig. Ltd. (2002) is as shown in Fig. 2 and consists of:

(i) An upper lateritic clay at the surface with layer thickness ranging from 10m at the left abutment and about 2m on the right abutment.

(ii) Close to the river, alluvial deposits (sand) are observed with about 2m thickness.

(iii) Below the lateritic clay layer is found, silty clay with mica at the drill hole 1 (CH 0 + 200) Fig 2. Mica is not observed in any other drill hole.

(iv) Thick layers of sand have been observed in some holes.

The result of the Damtech Nig. Ltd. (2002) study according to UNRBDA could not explain the origin and characteristics of the thick sand layers in (*ii*), hence further study was recommended to be carried out during construction to confirm the characteristics and origin of the sand layers observed under the dam axis and also to determine the effects of these layers on the water tightness of the reservoir. Conseqently geophysical investigation was carried out using the electrical resistivity method.

4. Method

An initial geological reconnaissance survey was carried out using compass and ground positioning system (GPS) mapping. This was followed with geophysical investigation using essentially the electrical resistivity method. A total of Thirty (30) vertical electrical sounding (VES) stations were occupied. Eight (8) of them were occupied in the rainy season (October 2002) and twenty two (22) in the dry season (Mar/April 2003). Of the thirty stations, twenty-one were located on the dam axis with a line azimuth of 142°, that is, approximately NW-SE and Nine (9) others strategically located to the east of the dam axis. CH 100 with GPS geographic coordinates of 10° 43.663'N, 08° 12.835'E (Table 1, Fig. 3), was chosen as the reference point for sitting the VES stations. The ABEM 300C SAS TERRAMETER was used for data acquisition. The Schlumberger electrode configuration was used throughout the survey with half-current electrode separation (AB/2m) varying from 1m to 100m

Figure 3 shows the vertical electrical sounding stations of both the rainy (VES 1-8) and dry seasons (VES 9-30). Table 1 is the distribution of the VES stations within the site and their GPS geographic coordinates. The VES data were presented as VES curves, that is, the plot of apparent resistivity (Á$_a$) values in Ohm-m against half-current electrode separation (AB/2m) on bi-log graph papers. The resulting VES curves are composed of H, QH and KH type. The typical VES curve is shown in Figure 4. The interpretation of the VES curves was quantitative. This involved manual partial curve matching (Zohdy, 1965; Orellana and Mooney, 1966; Keller and Frisckneckt, 1966) and computer iteration technique using the Interpex Resix Plus Software. The interpretation results are listed in Table 1.

5. Results and Discussion

Figure 5 shows the composite geoelectrical section for the rainy and dry season data. Figure 5 (a) shows data collected east of the dam axis which is, part of the expected lake or reservoir whilst Fig. 5 (b) is the geoelectrical section along the dam axis. Three geoelectrical layers are shown in Fig.5 (a) viz. laterite topsoil (Á= 141-448 ohm-m) underlain by a clay layer (Á= 17-49 ohm-m) which is in turn underlain by the bedrock of sand (Á = 207-342 ohm) at stations 22, 25 and 26 and partly weathered/fresh basement rock (Á = 1046-1737 ohm-m) at stations 23 and 27. The lateritic layer has an average thickness of 2.0m whilst the mean thickness of the underlying clay layer is 15.0m. In Fig. 5 (b), three geoelectrical layers are shown. The first layer is the lateritic layer (Á = 100-475 ohm-m). The thickness varies from 2.0m to 5.0m between CH 300 to CH 950; and increases to a mean of 10.0m between CH 100-300 and CH 950-1050 respectively. The second layer is composed of mainly clay (Á= 27 –56 0hm-m). It has an average thickness of 15.0m except at between CH 200-240 and CH 920-980 where the value is about 30m. The third layer is variable in lithology being weathered/fresh basement rock (Á > 324 ohm-m) along the entire length of the dam axis, except at CH 500, CH 580-820 where the resistivity values (ρ < 324 ohm-m) suggest sand. Figure 6 which show a geoelectrical fence diagram using data along the dam axis and to the east, confirm our observation that channel type clastic sediments exists between CH 450-750.

Figure 7 shows the correlation of geoelectrical data for the rainy and dry seasons with available drill-hole data. The drill hole data show three main subsurface layers viz: a first layer of laterite (BH 1, 2,3,4,5 & 6) underlain by clay (BH 1, 4 and 5) on alternating sequence of clay and sand (BH 2 and 3). The third layer, into which BH 3 and 4 were terminated, is sand/silt. The drill holes did not get to the weathered basement rock as the last geoelectric interface in deepest boreholes (BH 3 and 4) which indicate sand and silty sand respectively (ρ < 165 Ohm-m). Although there is some correlation of the geoelectrical and geological data along the dam axis,

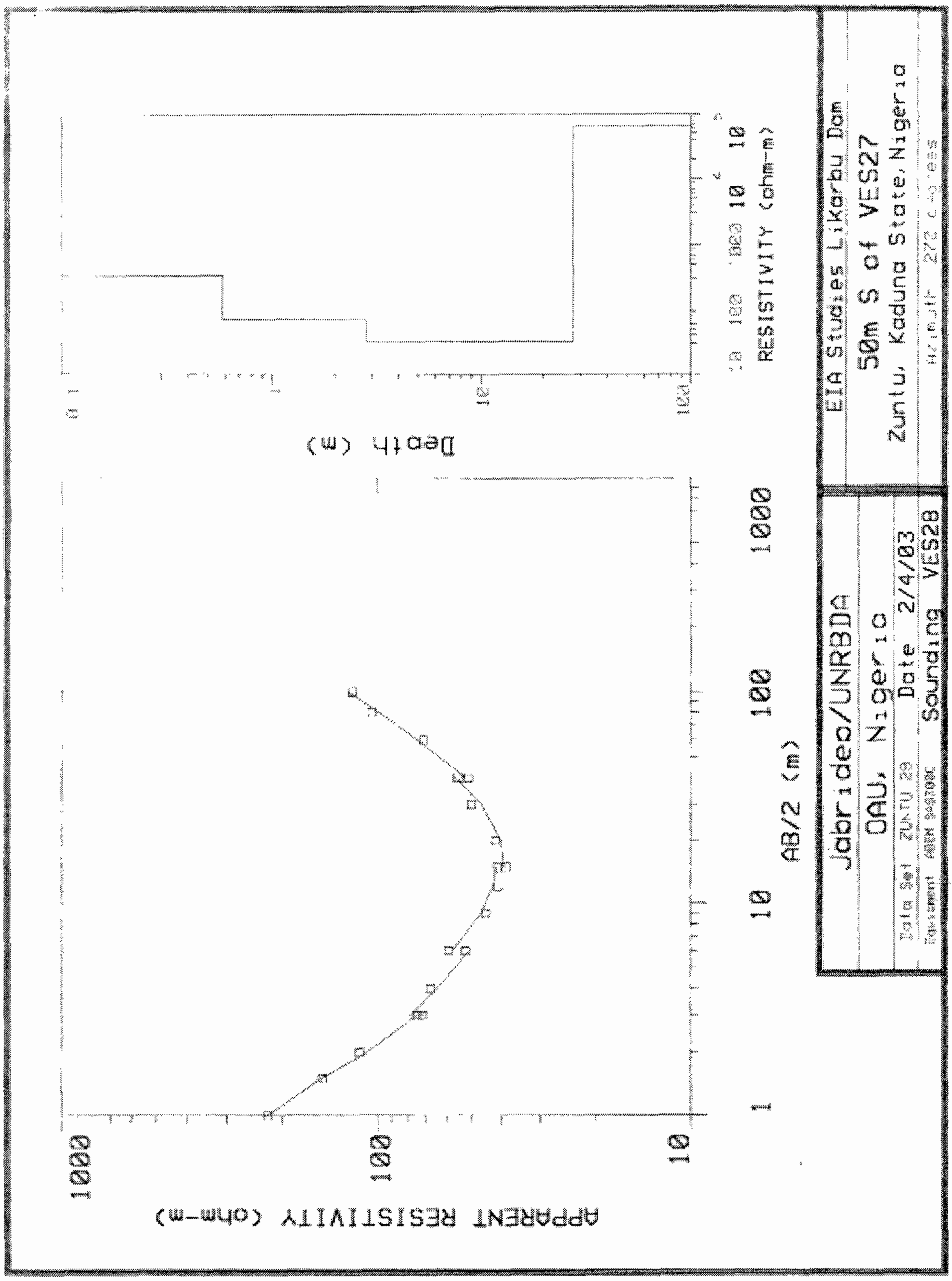

Fig. 4: A typical VES curve

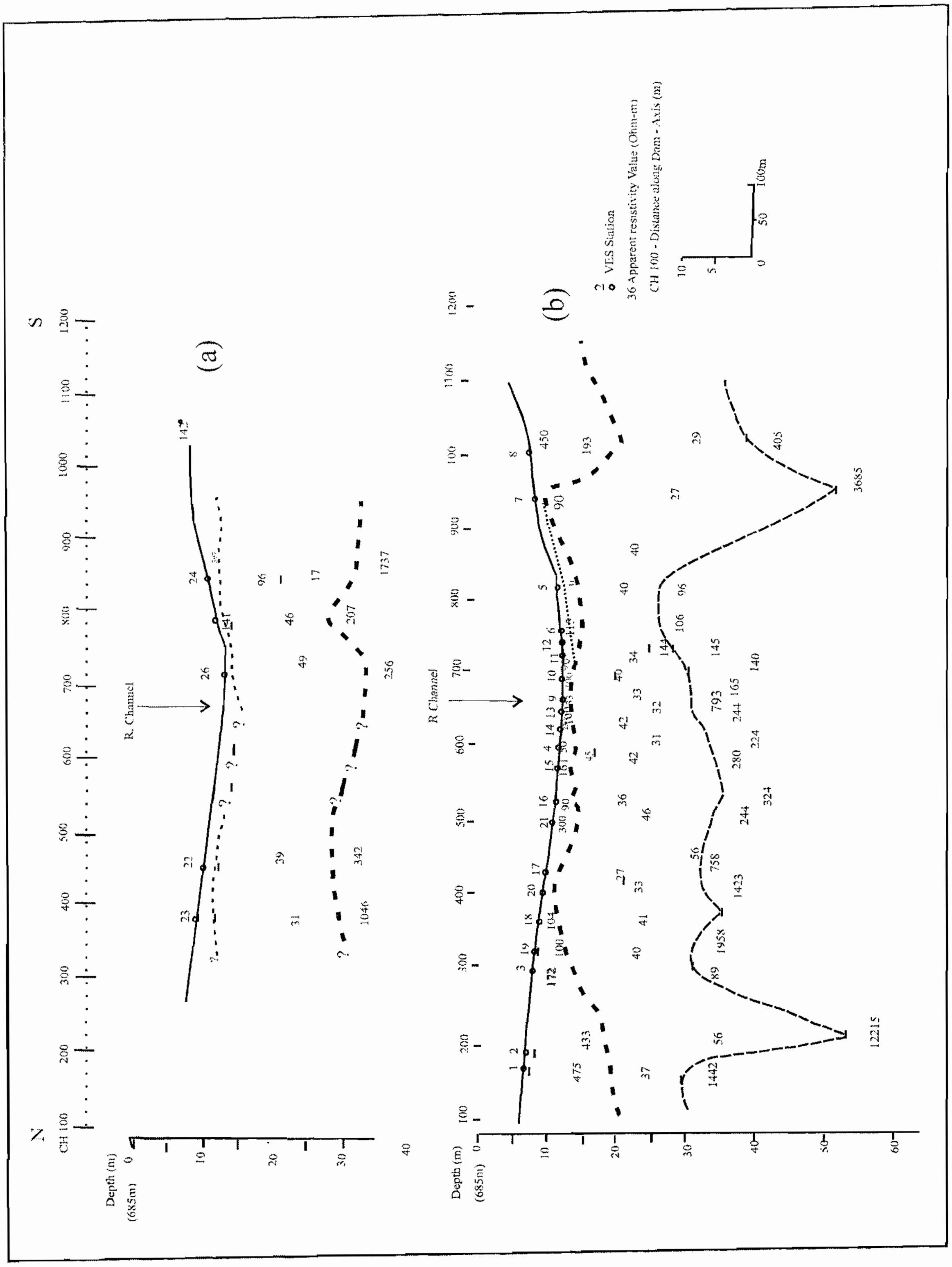

Fig. 5: Geoelectrical section along Upstream and Main Dam axes, Likarbu Dam Project, Zuntu.

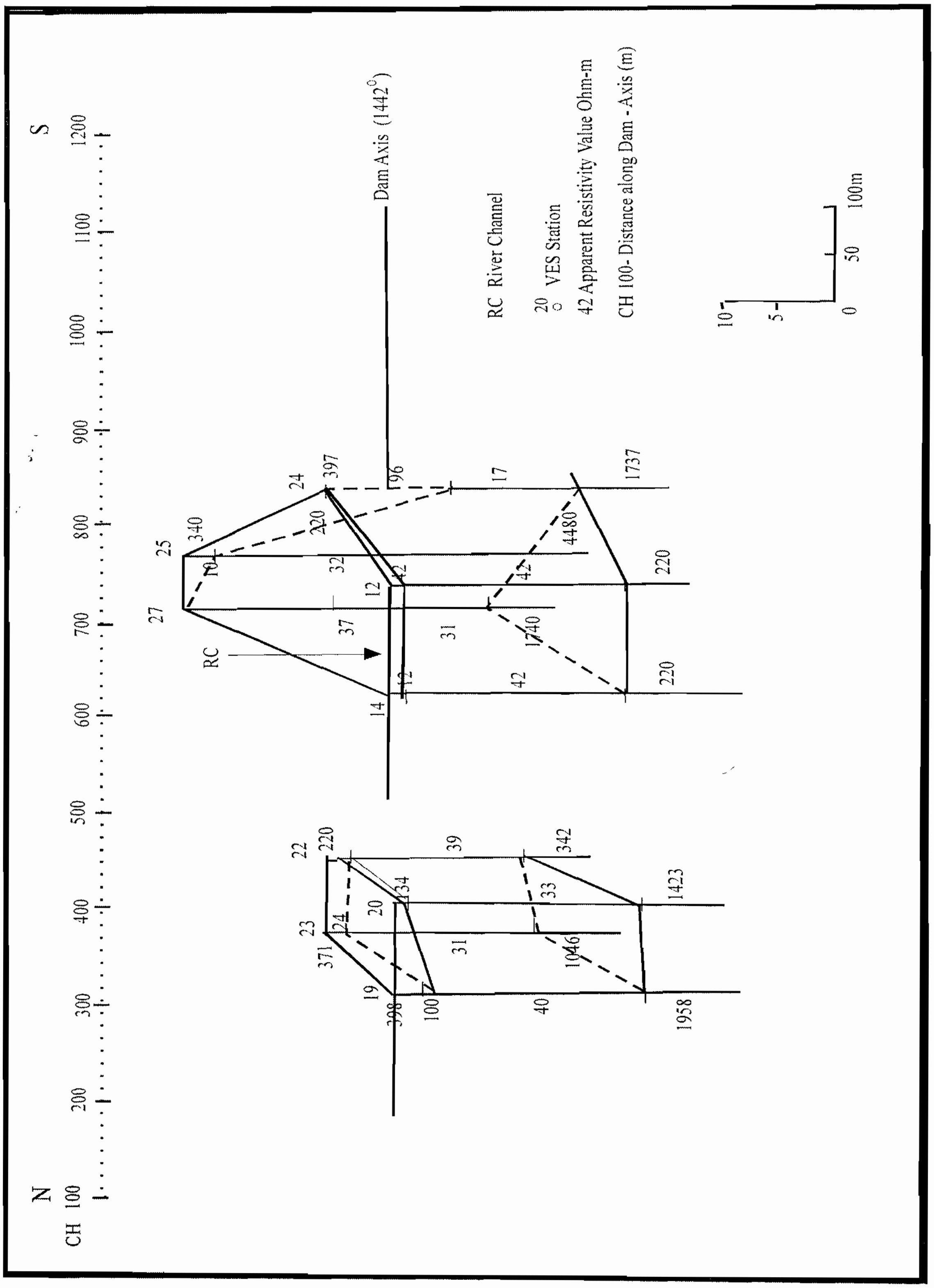

Fig. 6: Geoelectrical Fence Diagram, Likarbu Dam Site, Zuntu

the geoelectric data give a better definition of the resistivity values of the subsurface. The lateritic top soil (ρ >100 Ohm-m), the clay layer (ρ = 27-90 ohm-m) and the basement (ρ > 324 ohm-m) are better delineated from geoelectrical data compared to borehole data.

Consequently, there is better confidence in the subsurface geology derived from the geoelectrical data than from the geological data. We can therefore look at the subsurface geology as similar at the abutments (CH 100-450 and CH 850-1050). Here, the lateritic top layer is fairly thick (2.0-10.0m). It is underlain by the clay layer, which in turn is underlain by the weathered basement rock. However between CH 450-850, the top-soil is more of lateritic clay, often less than 2.0 m thick and is underlain by alternating sequence of clay and sand terminating in bedrock of sand.

The lateritic topsoil thickness is adequate for the dam foundation at the abutments but with clay as the first layer from CH 550 to CH 750 requires further engineering design consideration. Clays are porous, but have low permeability and high shrinkage characteristics that may affect the stability of the dam axis. The depth to the fresh basement rock is everywhere greater than 20m. This also has implication for the design characteristics of the dam. There is therefore the need to drill at least four test holes to reach the bedrock at CH 300, 400, 800 and 900 for further soil analysis.

The occurrence of sand units within the clay layer and as the bedrock in part of the dam site suggests availability of fairly good quantity of groundwater. A well of 20m deep located at 10°44. 272'N, 08°13.885'E, with a standing water column of 0.40m at the time of the field-work; (April, the peak of dry season), confirms the occurrence of adequate groundwater.

The groundwater aquifers can serve as base flow recharge source for the lake or reservoir after impoundment particularly during the dry season as the river is not a perennial one, it could also be sites for seepage if grouting is not adequate.

6. Conclusion

Result from both rainy and dry season data show that the composite geoelectrical section east of the dam axis (Fig. 5a) consists of three geoelectrical layers. These are: laterite topsoil (Á = 141-448 ohm-m) with an average thickness of 2.0 m, underlain by a clay layer (Á= 17-49 ohm-m) with a mean thickness of 15.0 m, which is in turn underlain by the bedrock of sand (Á = 207-342 ohm) at stations 22, 25 and 26 and basement rock (Á = 1046 – 1737 ohm-m) at stations 23 and 27. Along the dam axis the geoelectrical section consists of three geoelectrical layers also. The first layer is the lateritic layer (Á = 100-475 ohm-m) with a thickness which varies from 2.0m to 5.0m between CH 300 to CH 950; and increases to a mean of 10.0 m between CH 100-300 and CH 950-1050 respectively. This is underlain by a second layer composed mainly of clay with some sand. (Á = 27-56 0hm-m). It has an average thickness of 15.0 m except at between CH 200-240 and CH 920-980 where the value is about 30 m. The third layer is composed of sand/silt (Á = 96-324 ohm-m) at CH 460- 820 and basement rock (ρ >324 ohm-m) at CH 100-420 and CH 850-1120 respectively.

The lateritic topsoil is competent and has adequate thickness (2-10 m) to take the load of the dam axis at the abutments CH 100 – 300 and CH 850 – 1050. Between CH 300-CH 750 there is the need for cut and fill to improve the bearing capacity of the soil and thus enhance it as a good foundation material. Although fractures are not prevalent, suspected fault/ fracture mapped in the basement at CH 200-220 and CH 850-1000 are rather deep and are not likely to affect the stability of the structure.

Acknowledgment

The authors wish to acknowledge the release of data by the Upper Niger River Basin Development Authority (UNRBDA), Minna and the support and contribution of our field crew and other support staff.

REFERENCES

ABEM, 1990. WADI Instrument Manual, ABEM Printed matter No. 90282 pp. 29-33.

Ako, B.D., 1976. An integration of Geophysical and Geological data in Dam site Investigation. The Case of Opa Dam. *Journ. Min. Geol.*, Vol. 13 No. 1 pp. 1-6.

Annor, E.A., Olasehinde, P.L. and Pal, P.C., 1989. A geological evaluation of a Prospective site for a Weir in the River Oyin, Ilorin, Nigeria. *Zangew: Geowiss,* Delft 8, pp. 83-90.

Artsybashev, V.A., 1973. Geophysical Investigation of Oyimo dam site, Ikare, Western Nigeria. (unpublished report) Department of Geology. University of Ife.

Artsybashev, V.A., and Aseeze, L.O., 1977. Geophysical Investigation of Oyile dam site, Ilesha. *Journ. of Min and Geol.,* vol. 14, No. 2, pp. 44-46.

DAMTECH (Nig) Ltd., 2000. Design Report - Likarbu Earth Dam Project, Upper Niger River Basin Development Authority, 61pp.

Keller, G.V. and Frischknecht, F.C., 1966. Electrical Methods in Geophysical Prospecting. Pegamon Press, New York. 520pp.

Kilty, K.T., Norris, R.A., McLamore, W.R., Hennon, K.P. and Euge, K., 1986. Seismic refraction at Horse Mesa dam: An application of the generalized reciprocal method. *Geophysics,* vol. 51, No. 2. pp. 266-275.

Okwueze, E.E., Ebeniro, J.O. and Mbongning, M., 1994. The geoelectric structure of the Lake Nyos dam, Cameroon and its geologic implications. *Journ. Min. Geol.* vol. 30, No. 2 pp. 247-250.

Orellana, E. and Mooney, H.M., 1966. Master Tables and Curves for Vertical electrical Sounding over layered Structures. Interciencia, Madrid.

Rahaman, M.A., 1976. Review of Basement Geology of South-Western Nigeria in Geology of Nigeria, Kogbe, C.A. (Ed.). Elizabethan Publ. Co., Lagos Nigeria, pp. 41-58.

Zohdy, A.A.R., 1965. The auxillary point method of electrical sounding interpretation and the relationship to the Dar Zarrouk parameters, *Geophysics*, 30, pp. 644-660.

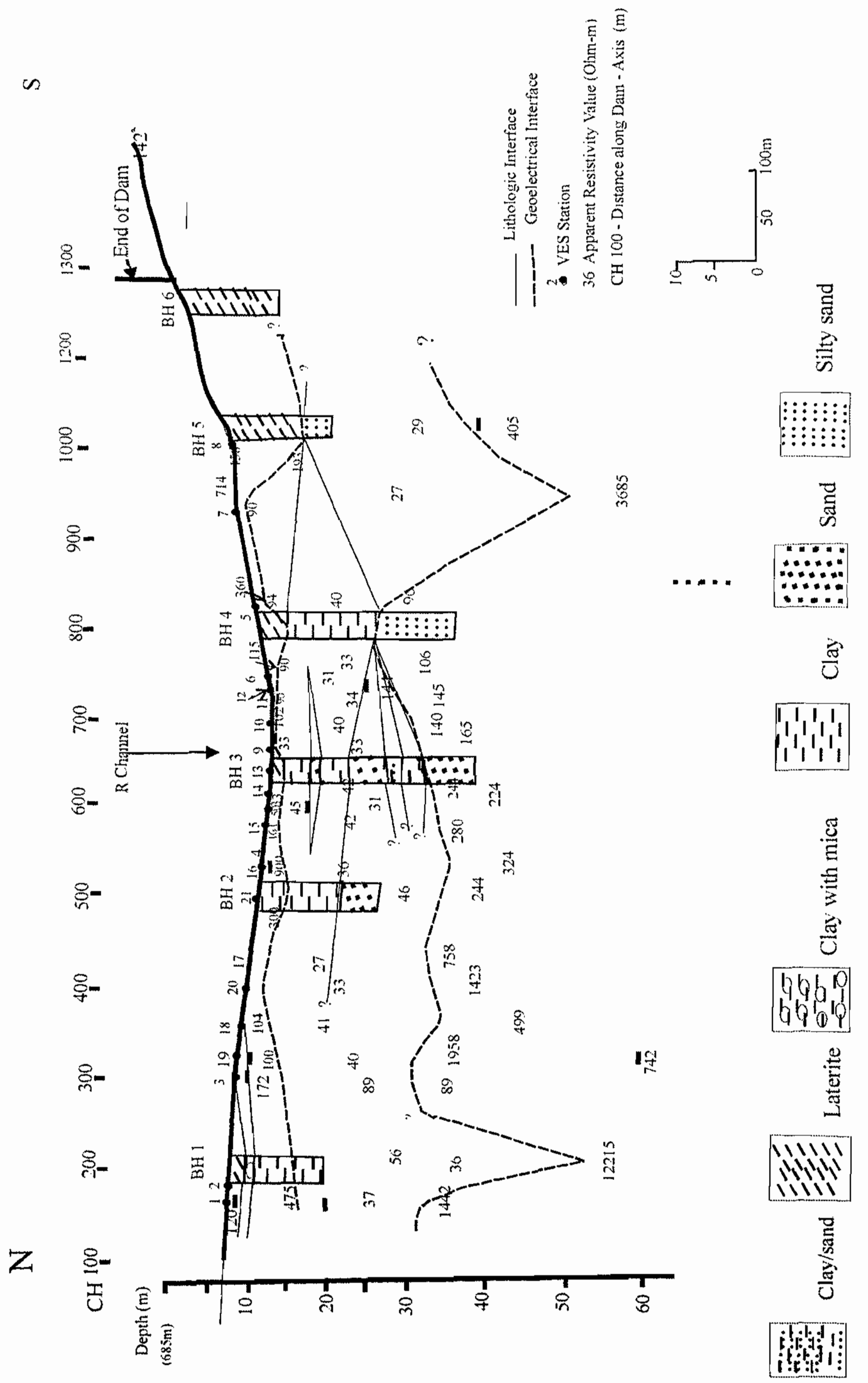

Fig. 7: Geoelectrical/Geological section along Likarbu Dam Axis, Zuntu