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Geophysical and Geotechnical Investigation of River Ero, Ajuba, Southwestern Nigeria for Dam Development

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ABSTRACT

Dams are among common large engineering structures and a major amenity that enhances quality life. Thus, design and construction should be preceded by adequate investigation to prevent collapse and its consequences.
Geophysical and geotechnical investigations have been carried out around River Ero Ajuba-Osi area, Southwestern Nigeria. This was aimed at harnessing the potential of the river for the purpose of earth or rock-filled dam development to meet high water demand by neighboring communities.

The satellite image together with the geological map of the area was analyzed and interpreted with ArcGIS version 10.0. Reconnaissance survey shows that construction materials are available at economic hauling distance while total of 7 Vertical Electrical Sounding carried out across the river course using Schlumberger array revealed minor fractures. Also, geotechnical assessment of soil samples revealed that they are generally well graded with moderate internal friction angle and suitable bearing capacity.

The study concluded that material availability, perennial discharge of the river in addition to suitable geology and engineering properties around River Ero will enhance development of either earth or rock filled dam.

Keywords: *Geotechnical, Geophysical, Ajuba, Permeability, VES.*

1. INTRODUCTION

Dams are among the largest and most important projects in civil engineering. For geologic, hydrologic and topographic reasons, there are limited numbers of ideal sites for dams. However, demand for dam for the purpose of water supply especially in areas with good potential is constantly on the increase. Ajuba area in the southwestern Nigeria is an exception in terms of high water demand, where seasonal rainfall and hand-dug well have always failed. It is therefore very important to carry out adequate pre-construction investigations on the perennial flowing Ero River around the town to meet high demand for water by the populace. Studies on Dams investigation have always been in simulation of the Probable Maximum Flood (PMF) and uplift pressures under dam (Guy and Lund, 2006), depth to bedrock, stratigraphic, structural and stability mapping (Hunter *et al.*, 2011). The information provided by these studies is expected to aid dam site investigation. Dams intended for water supply require a low tolerance of seepage losses. Besides, the design of dam structures must be adapted to the existing site conditions (Ajayi *et al*., 2005) to minimize the losses. Failure to do any of these may invariably result in unplanned seepage and/or total collapse of the structure (Olorunfemi *et al*., 2000). Biswas and Charttergee (1971) examined causes of dam failures worldwide and discovered that 25% of the failures were due to geotechnical problems associated with seepage, inadequate seepage cut-off, faults, settlements and landslides.

An integrated geotechnical and geophysical survey is often the most cost-effective and rapid means of obtaining subsurface information especially over large study areas (Sirles, 2006). This was employed for the Ero river was done in order to establish the depth to bed rock, depth to water table, geo-electric sections from the layered parameters, concealed basement morphology, fractures /seepage channels(s) (where they exist) in the subsurface thus, enabling the evaluation of the feasibility of the area for establishing a dam and reservoir.

2. STUDY AREA DESCRIPTION

The location of the studied area is Ajuba town, Osi area, Southwestern Nigeria; it lies approximately 4km west of Osi on Long. 5°23'E and 5°30'E; Lat. 8° 05'N and 8°13'N, It covers an area of $9km^2$ (Fig. 1). The major village in the area is Ajuba settlement (Fig.1) which is located within two rock suites of different lithologies that is, Osi migmatite-gneiss complex to the west and Egbe schist belt to the east. (Bamigboye and Adekeye, 2011). The climate of the study area usually alternates with dry and rainy season. The area lies within the southwestern Nigeria but close to central part of Nigeria with a total annual rainfall between 1270 mm and 1524 mm, spread over the month of April to October. The highest amount of rainfall is observed around June/July and October. Monthly temperature is highest in March at about 30°C and lowest in August at about 25^{0}C (Olasehinde, 1999).

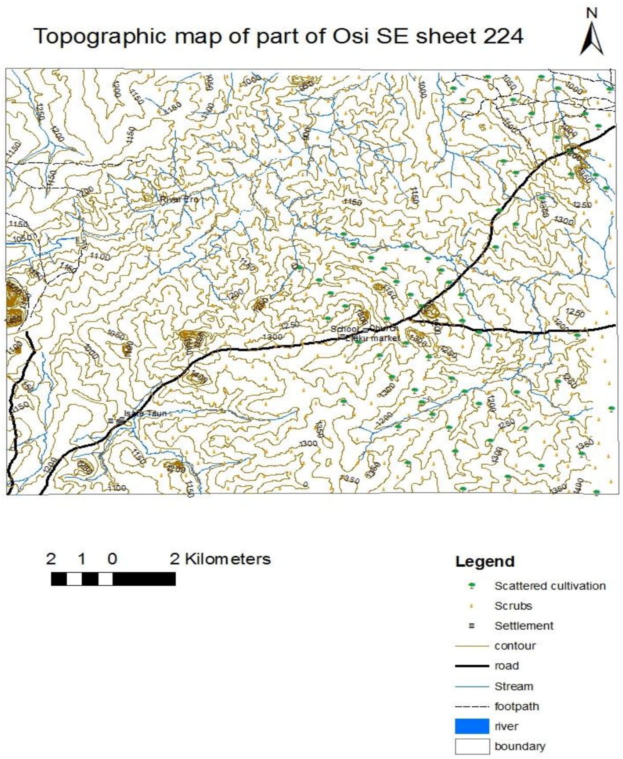


Fig. 1: Topographical map of Ajuba area

3. GEOLOGY AND HYDROGEOLOGY

Ajuba and its environs lie close to Osi migmatite-gneiss complex in the west (Fig. 2).

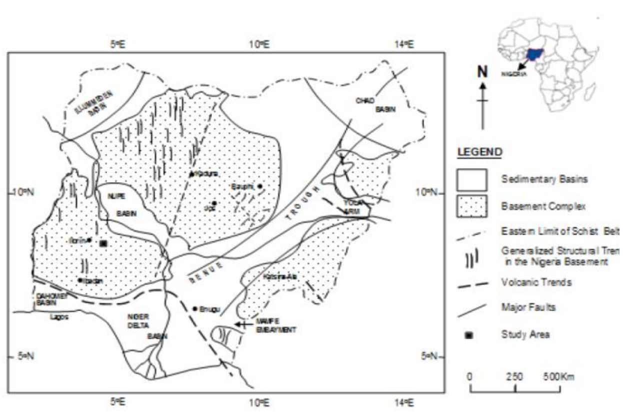


Fig. 2: Geological map of Nigeria showing the study area (After Kogbe, 1976)

The geology of Nigeria has been described to consist of older and younger metasediments, older and younger Granites and volcanic intrusive which are overlain unconformably by younger sedimentary basins of Illumeden, Niger-Delta, Bida, Benue and Dahomey (Grant, 1970; McCurry and Wright, 1971; Cooray, 1972; Oyawoye, 1972 and Rahaman, 1976). The rocks that dominate the study area include gneiss, granite, gabbro, migmatite, amphibolite and pegmatite (Fig.3). The granites are porphyritic and occur as boulders along the river channel.

Massive outcrop of porphyritic granite is situated about 800 m south of the site. A characteristic feature of the Basement Complex tectonics is the widespread occurrence of fractures (Oluyide, 1988). Thus, varieties of surface structural features such as foliations, folds, faults, joints, fractures and fissures in the area were documented. The superficial deposit on the higher elevation of the river consists of alluvia sand.

The major type of aquifer in the study area is that of consolidated (hard) rock. They have secondary porosity which might have been affected by tectonic or cooling phenomenon, the thickness of encountered. Adequate climatic conditions could be said to exist for groundwater recharge purpose. Also, the occurrence of joints, faults and fractures in the subsurface are indications of good aquifer in the study area (Olasehinde, 1999). Weathered/fractured zone shows a high water yield and few hand-dug wells exist at different parts of village. The hydrology of the mapped area was studied under close observation. It was noticed that the rivers is always flooded by water at the peak of raining season and flow rate reduces to average 2.7m/s during dry season from 7.4m/s in raining season.

4. METHODS OF STUDY

A three-phase approach was used in this study; the geological, geophysical and geotechnical investigations. These were preceded by desktop and reconnaissance studies for the purpose of site identification and familiarization. Geologic study involves location of outcrops identification, description of featured characteristics, collection and labeling and of samples.

Geotechnical investigation involves collection of disturbed representative samples from trial pit. Properties tested include the particle size distribution, Atterberg limits, strength, consolidation and permeability potential.

Electrical resistivity technique was employed in studying the general geological sub-surface structure and bedrock topography across the 500 x 200meter length of the dam axis. The geophysical investigation was carried out using the Vertical Electrical Sounding (VES) with Schlumbeger types of electrode configuration. VES investigation was conducted at seven points (VES 01-07) across the river (Fig. 4) at 50m intervals. DDR1 Resistivity meter equipped with an SAS 2000 booster was used for field measurement of resistance (R) from which apparent resistivity (pa) was calculated by the relation, the curves were interpreted with ipi2win (2008) software. The spread of electrodes was 100m (maximum) due to closeness of bedrock to the surface. Field data were plotted on the log-log paper manually and the curves obtained were used as models for the computer aided iteration.

River discharge calculation was done according to the formular and assumption proposed by Sagadah *et al*. (1997).

$$\text{Stream flow rate} = \frac{\text{Length of river traverse}}{\text{Time taken}}$$

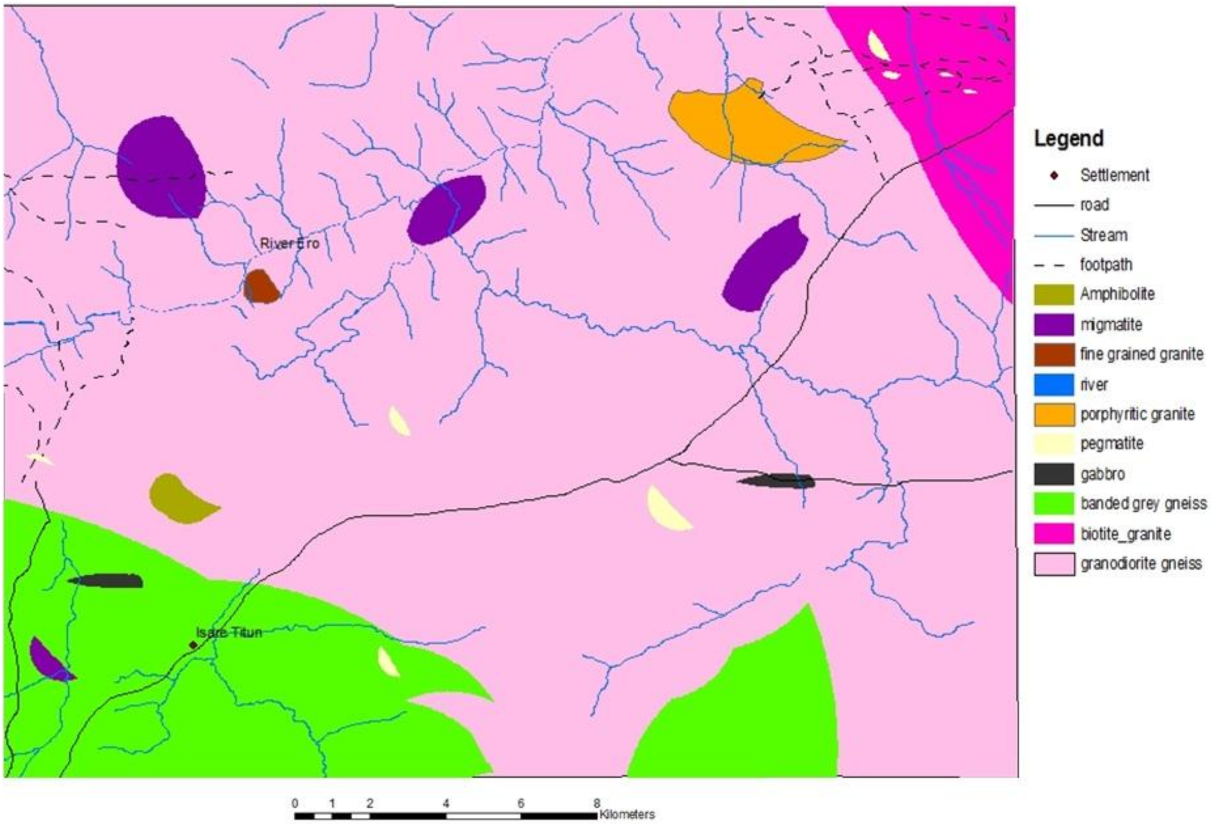


Fig. 3: Geology Map of the Study Area

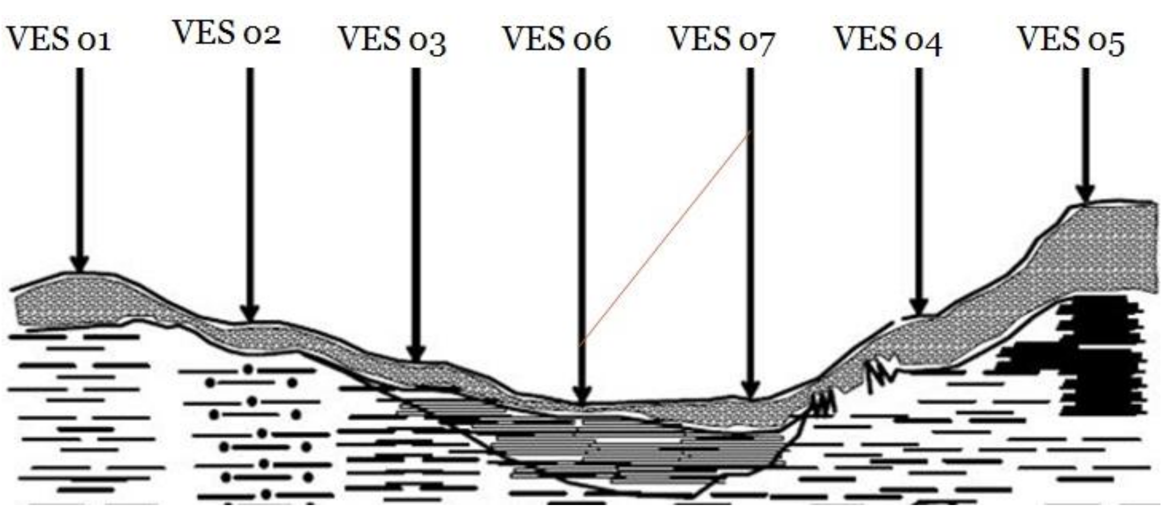


Fig. 4: VES positions across dam axis

Six trial pits were excavated, three at the right, two left side of the river bank and one at Ekiti clay deposit, these were done to obtain soil as possible core materials. The samples were collected into a plastic bag and transported to the soil laboratory, the soil was air dried and lightly crushed into smaller pieces for classification, strength and specialized tests according to the British Standard (BS 1377:1990).

5. RESULT AND DISCUSSION

5.1 Geophysical Investigation

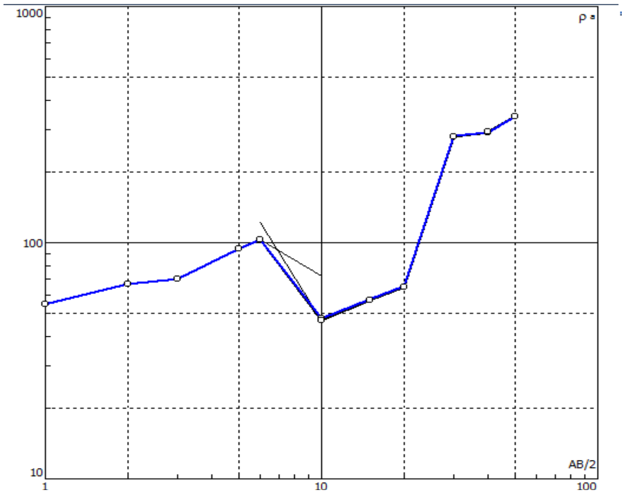
Table 1 and Fig. 4 give the summary of the interpretation of VES 1 to VES 7 curves in terms of the apparent resistivity and the thickness of each soil layer, the VES are typical of the basement terrain being H, A-type curves. In general, the subsurface of the dam axis consists of the following three layers: The first layer which extends from the surface down to a depth of 6m significantly composes of top soil and sand at VES 1 to VES 5 with apparent resistivity values ranges from 50 to 133 Ohm-meter. The second layer which extends from depth of about 6 meter to 30meter with apparent resistivity values ranging from 28 to 200 Ohm-meter suggest that these layers composed of wet-fairly weathered basement.

The first layer in VES 6 and VES 7 with apparent resistivity values of 170 to 450 Ohm-meter suggested moderately to fairly hard basement. The second layer with high value (>500 Ωm) of apparent resistivity suggests very hard fresh crystalline rocks. However, VES 2 and VES 7 show evidence of fracture both from depths of 25m-30m, which is about 5m in length for each of them while VES 4 has a pronounced fracture from 15m-25m, which is about 10m in length, these will require grouting. Although, the tectonically inactive nature of the terrain allays the fear of possible reactivation of the fractures which would be inimical to the safety of the Dam. Correlation of the VES data shows that basement is closest to the surface at VES 6 and deepest at 2 (Fig. 5).

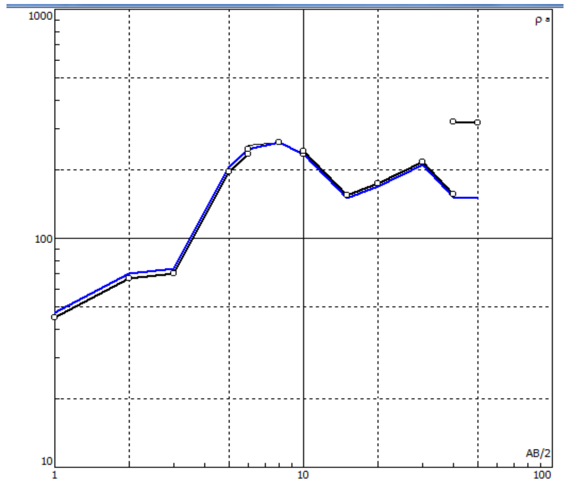
Table 1: Typical Interpretation of VES curves along dam axis

	VES1		VES 2		VES 3	
Description	**Resistivity (Ohms)**	**Thickness (m)**	**Resistivity (Ohms)**	**Thickness (m)**	**Resistivity (Ohms)**	**Thickness (m)**
Top soil	55	0-1	45	0-1	145	0-1
Sand/Sandy clay	72	1-6	95	1-6	*******	******
Weathered basement	280	6-20	245	6-15	230	1-8
Fairly Hard basement	*******	********	190	15-40	205	10-20
Very hard basement	400	30-Above	350	40-Above	300	30-Above

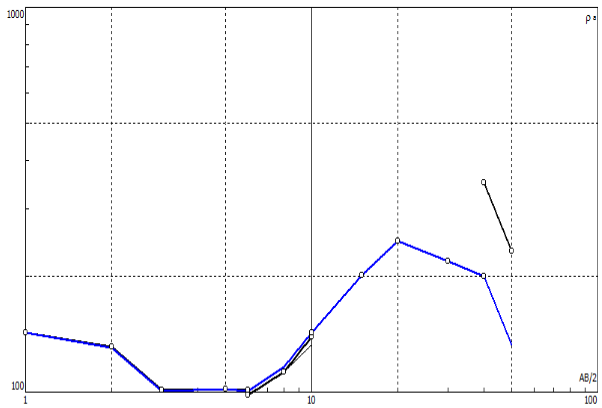
	VES 7	
Description	**Resistivity (Ohms)**	**Thickness (m)**
Top soil	**********	*********
Sandy/Sandy clay	**********	**********
Weathered basement	**********	**********
Fairly Hard basement	170	0-10
Very hard basement	400	15-Above



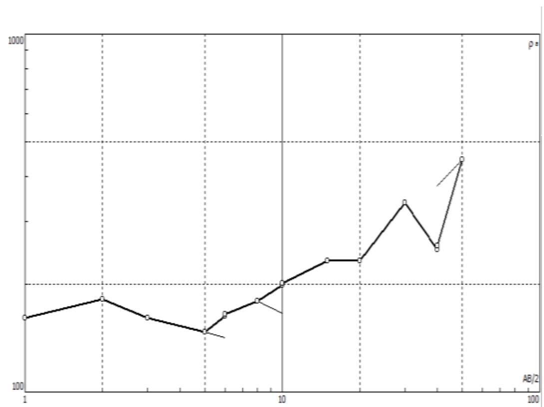
VES 1River Area



VES 2 River Area



VES 4 River Area



VES 7 River Area

Fig. 4: Typical VES curves obtained across the River Axis for VES 1 to VES 7

*Legend

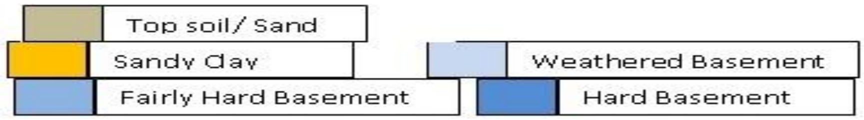


Fig. 5: Correlation of VES 1 to VES 7 Lithologic Cross Section along Ero River

5.2 Geotechnical Analyses

5.2.1 Borrowed Pits

Five borrowed pits were dug to a depth of about 3m for sample A, B, C, D, E and F. The top soil at 0-1m is mainly darkish and humus in nature. At 1.5m, it changes into reddish brown color. At 3m, bulk of sand and thick layer of clay was collected for analysis for embarkment/ foundation investigation. The three main categories covered under the laboratory testing include soil classification tests, strength tests and specialized tests.

All laboratory tests were carried out in accordance with BS 1377:190.

5.2.2 Grain Distribution

The particle size distribution curve are represented in figures 6 and 7 while the values obtained is give in Table 2

Table 2: Particle size distribution curve are represented

Samples	Grain Size Distribution				Soil Group
	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	
Sample A	16	84	0		Gravelly SAND (GP/SP)
Sample B	27	71	2		Gravelly SAND (GP/SP)
Sample C	50	50	0		Gravelly SAND (GP/SP)
Sample D	89	10	1		Gravelly SAND (GP/SP)
Sample E	44	55	1		Gravelly SAND (GP/SP)
Sample F	0	22	78		Sandy CLAY (SC/CH)

5.2.3 Atterberg Limit Test

With reference to the Plasticity index Standard Range (Clayton and Juckes, 1978) and Plasticity Indices and Corresponding States of Plasticity (Burmister, 1997), sample F (from Ekiti) have high plasticity with a value of 31% fig. 9, this indicates that the soil is actually cohesive, and non-friable, therefore very suitable for embankment materials.

5.2.4 Direct Shear Box Result

Direct shear box test was conducted on sample A, B, C, D and E in order to determine the shear strength parameter so as to be able to calculate the allowable bearing capacity for the dam foundation. The angle of internal friction parameter obtained from graph of Shear Stress vs Normal Stress for sample A , B, C, D , E are 25°, 28°, 34^0, 30^0, 30^0 respectively confirmed sandy material. For square footing, (Terzaghi, 1967) suggested this equation; $Q_u=1.3\ CN_c + \Upsilon D_f N_q + 0.4\Upsilon B N_{\Upsilon,}$ the equation was used to determine allowable capacity at differential depth for sample A, B, B, C, D and E, the average values are shown in Table 4. Recommending foundation depth for dam structures will depend on the total load that will be erected on the subsurface soil based on structural design, but from all indication shallow foundation may not be suitable for rock fill dam but good for earth fill dam.

Table 3: Average allowable bearing capacity for dam foundation from shear box for samples A to E

	Differential Depth (m)	Ultimate bearing Capacity (kN/m^2)	Safe Bearing Capacity (kN/m^2)
1	**0.00-0.50**	....	....
2	**0.50-1.00**	414	277
3	**1.00-1.50**	638	222
4	**1.50-2.00**	827	275
5	**2.00-2.50**	1029	343
6	**2.50-3.00**	1246	458

5.2.5 Permeability Test Result

Results of falling head permeability obtained from sample F is shown in Table 4. These are indicative that the clay material is impermeable and suites recommendations of (Rowe *et al*., 2005; Daniel, 1993) as good material for dam core.

Table 4: Permeability test data for Sample F

Sample	Length of sample(cm)	Elapsed Time(mins)	H_1 (cm)	H_2(cm)	H (H_1-H_2)	Permeability k(mm/sec)
Sample B	13	2.34	145	120	25	$1.578x10^{-6}$
Sample B	13	2.35	140	120	25	$1.571x10^{-6}$
Sample B	13	2.35	150	120	25	$1.571x10^{-6}$

Average Permeability =$1.578x\ 10^{-6}$ (mm/sec)

5.2.6 Triaxial Result

The Shear strength of sample F was determined by means of Quick Undrained Triaxial Compression Tests and the result obtained for clay layers is 55 KN/m² as shown in Fig. 10, clay with cohesive value between 45–95 KN/m² suggest firm clay material (Bjerrum and Simons, 1960). (Terzaghi, 1967) equation; $Q_u=1.3\ CN_c\ +\ \Upsilon D_f N_q\ +\ 0.4\Upsilon BN_\Upsilon$ Was use to determine bearing capacity as shown in Table.

Table 5: Allowable bearing capacity for dam core foundation from Trial test for sample F

	Differential Depth (m)	**Ultimate bearing Capacity (KN/m^2)**	**Safe Bearing Capacity (KN/m^2)**
1	**0.00-0.50**	**................**	**................**
2	**0.50-1.00**	517	172
3	**1.00-1.50**	525	175
4	**1.50-2.00**	536	179
5	**2.00-2.50**	544	182
6	**2.50-3.00**	554	185

5.2.7 Consolidation Test

Deformation characteristics on the same sample from Ekiti) were determined in an oedometer apparatus. The tests were conducted in accordance to BS 1377: Part 5:1990, Clause 3 (British Standard Institution, 1990) which gives the standard procedure for the test. Compressibility Mv: 0.260, 0.305, 0.256, 0.213, 0.166, 0.153 and consolidation Cv: 5.600, 5.000, 4.000, 3.200, 2.400 and 1.700 at various overburden pressures Fig. 11, this suggest firm clay.

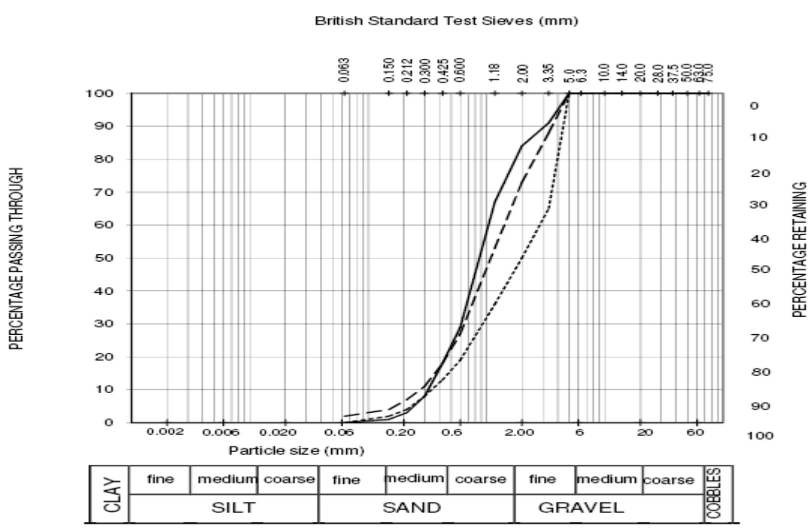


Fig. 6: Particle Size Distribution Curve for Sample A, B and C

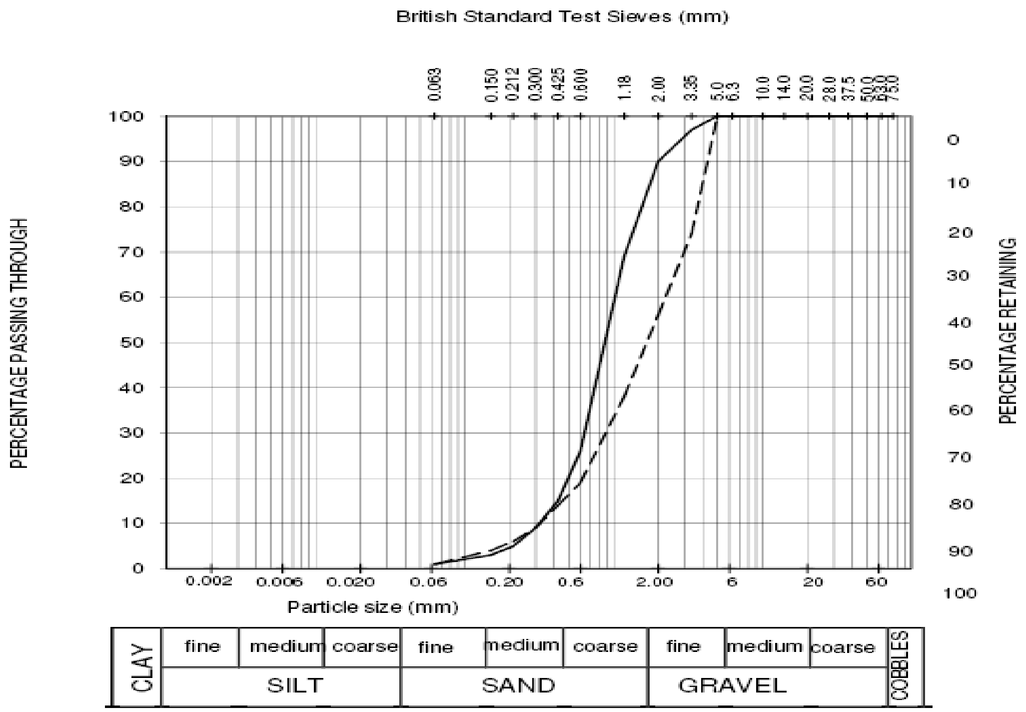


Fig. 7: Particle Size Distribution Curve for Sample D and E

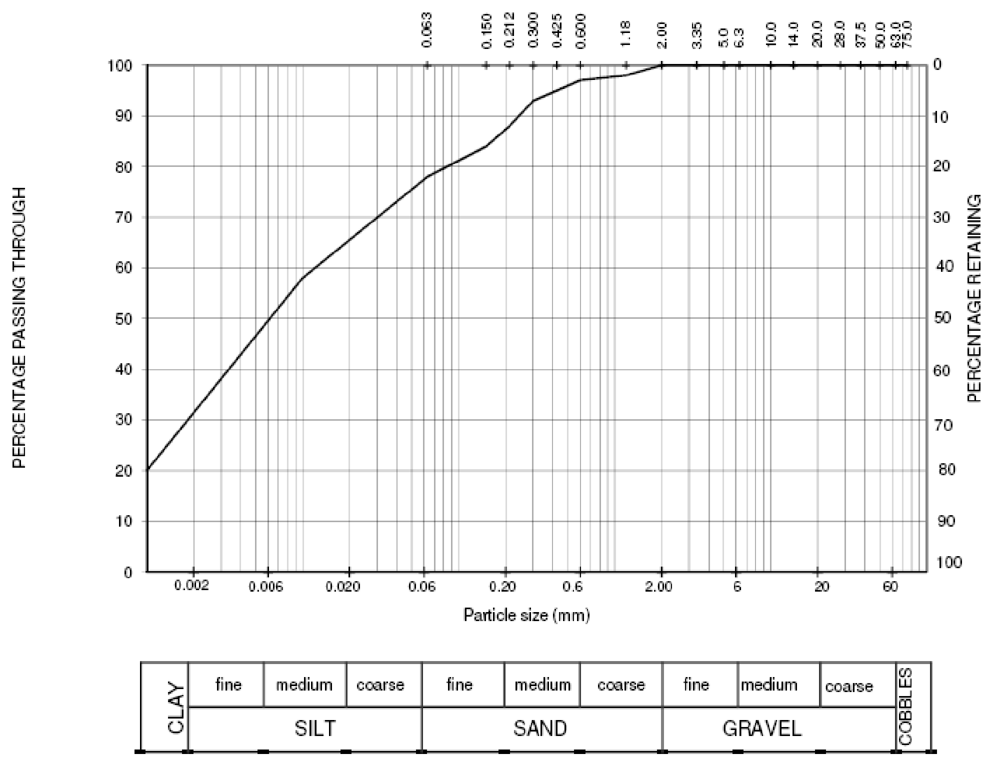
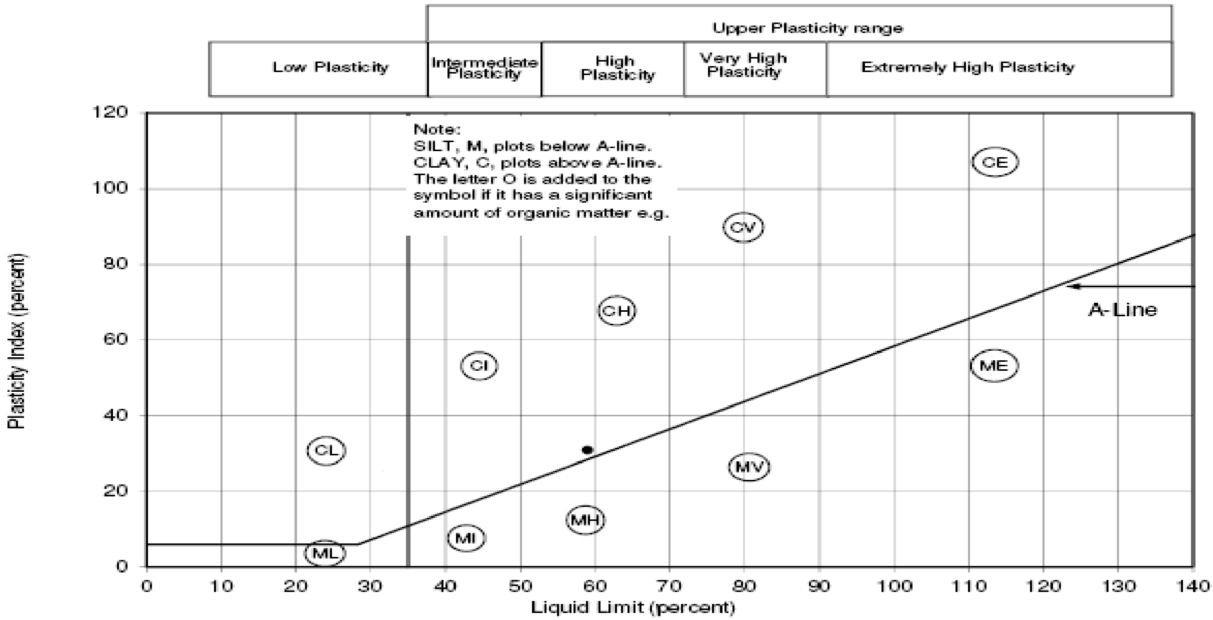


Fig. 8: Particle Size Distribution Curve for Sample F



Symbol	Sample		Natural Moisture Content	Liquid Limit [%]	Plastic Limit [%]	Plasticity Index [%]
●	F		99	59	28	31
■						
▲						

Fig. 9: Atterberg Limit Curve for Sample F (Ekiti clay sample for dam embankment core)

Undrained Cohesion	55 KN/m2
Angle of Friction (Ø)	4 deg

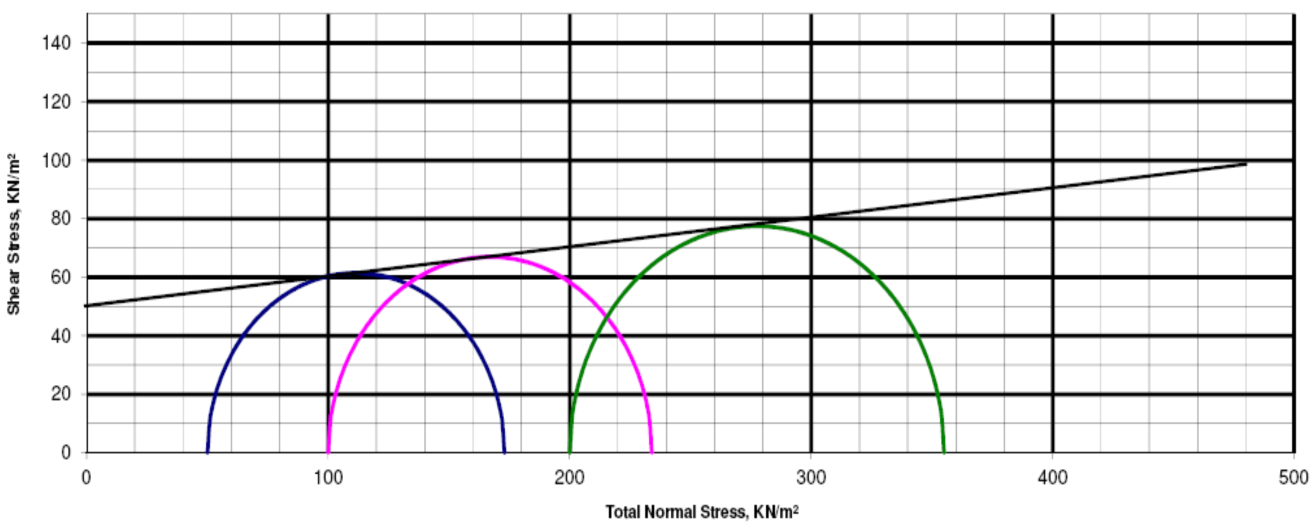
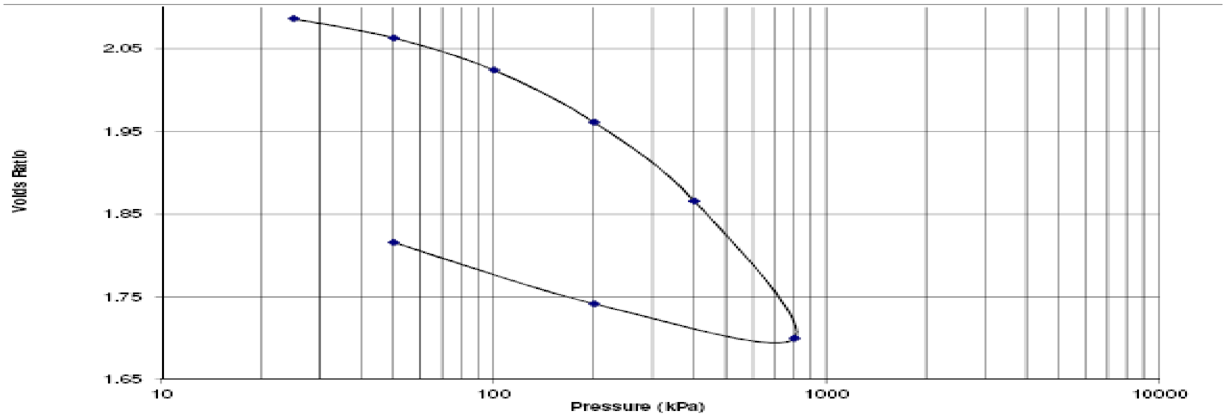


Fig. 10: Triaxial Plot for Sample F (Ekiti clay sample for dam embankment core)



SPECIFIC GRAVITY	G_s 2.39	INITIAL VOID RATIO	:	2.106
SPECIMEN SIZE	(mm): 69.10mm*18.60mm			99.00

Pressure (kPa)	m_v (m^2/MN)	c_v (m^2/year)
0	0.260	5.600
25	0.305	5.000
50	0.256	4.000
100	0.213	3.200
200	0.166	2.400
400	0.153	1.700
800		
200		

Fig. 11: Consolidation Plot of Sample F

6. CONCLUSIONS

The geophysical investigation conducted along and across River Ero site at Ajuba shows that the stream is underlain by fairly thin superficial soil (overburden) materials of less than 6m. The bedrock is close to the surface along the river area. The overburden materials consist of sandy material with generally drier top soil as shown in the relatively high resistivity values. The general characteristics of the materials within the study area as reveal from resistivity of shallow bedrocks indicate that they are competent. However, some form of remediation in the design process is required for reducing the threat that may be posed by the existence of thin fractures which may possible cause subsurface seepage channels.

Based on engineering geological investigation together with classification, strength and specialized test carried out, the area is feasible for an earth and rock fill reservoir but based on allowable bearing capacity calculated, deep foundation is recommended for a massive earth or rock filled dam. Construction materials can be found within a reasonable distance from the site, such as sand, gravel and clay.

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