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ENGINEERING GEOPHYSICAL CORRELATION OF FOUNDATION SOILS IN A BASEMENT COMPLEX TERRAIN; A CASE STUDY OF O.A.U CAMPUS, SOUTH WESTERN NIGERIA

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ABSTRACT

An extension to the existing Geology Department Building, Obafemi Awolowo University Ile-Ife, Nigeria is under construction. The construction site which covers an area of about 3000 m^2 is located west of the existing Building within the University Campus. A case study is presented here, in order to attempt a correlation between the near surface geology of the site for the extension and the existing Geology Department building. By this correlation, appropriate suggestion on the integrity of the structure being built on the new site can be predicted and recommendations made accordingly. The study was accomplished by the combined use of the vertical electrical resistivity sounding (VES) and the seismic refraction techniques. The subsurface layer delineated are the topsoil, clayey sand/laterite, weathered layer and the weathered/fractured/fresh basement with resistivity and thickness ranging from 103 - 155 Ohm-m and 0 - 1.3 m , 209 - 305 Ohm-m and 1.0 - 3.1 m, 96 - 208 Ohm-m and 3.3 - 14.4 m and 350 - ∞ Ohm-m respectively with depth to rock head between 4.0 - 15.0 m. The resistivity values of the layers, as well as velocities of seismic wave, showed great similarity and one could say that there is little risk attached to the site under construction. The only likely problem is that of water seepage into the foundation floor, as indicated by basement depression from VES and fractured layer from the seismic refraction method, which could be mitigated by designing a channel way for water to flow out or sealing off the fracture and anticipated water flow path with grouted cement. The latter was eventually incorporated into the foundation design of the new building. The near surface geology of the study area is found to be favourable to the structure being put on it and there is practically no risk attached to the integrity of the building.

KEY WORDS: Correlation, Foundation Soils, Basement Complex Terrain

INTRODUCTION

An extension to the existing Geology Department Building, Obafemi Awolowo University Ile-Ife, Nigeria is under construction. The construction site which covers an area of about 3000 m^2 is located west of the existing Building within the University Campus. Geophysical and hydrogeological investigations were undertaken at the site so as to assist in predicting the engineering performance of the site. Generally, the frequent lack of understanding of site geology and hydrogeology is often responsible for the structural failures of civil structures. A combination of geophysical measurements may greatly improve our understanding of the geology and hydrogeology of the site and therefore the quality of building under construction.

A case study is presented here, in order to attempt a correlation between the near surface geology of the site for the extension and the existing Geology Department building. By this correlation, appropriate suggestion on the integrity of the structure being built on the new site can be predicted and recommendations made accordingly. The study will also map the relief of the basement rock and the effect it could have on the structure noting possible structural features e.g. fractures and faults, if any, that may be inimical to engineering structures and also map the groundwater potential of the area.

Ile-Ife is located at $7^{0}30'$ latitude and $4^{0}30'$ longitude. This region lies within the tropical rain forest of Nigeria characterized by two distinct seasons (wet, April-October; and dry, November-March). The annual mean rainfall is about 1600mm. The average daily temperature is 29^{0}C and is seldom lower than 25^{0}C. The study site is on the campus of Obafemi Awolowo University, Ile-Ife, Osun State, Southwestern Nigeria (Figure 1). The geographical coordinates of the study area lie between Latitude N7^{0}31'17.0" and N7^{0}31'12.5" and Longitude E4^{0}31'14.2" and E4^{0}31'18.1". Elevation above sea level in this part of the campus varies between 250m and 300m.

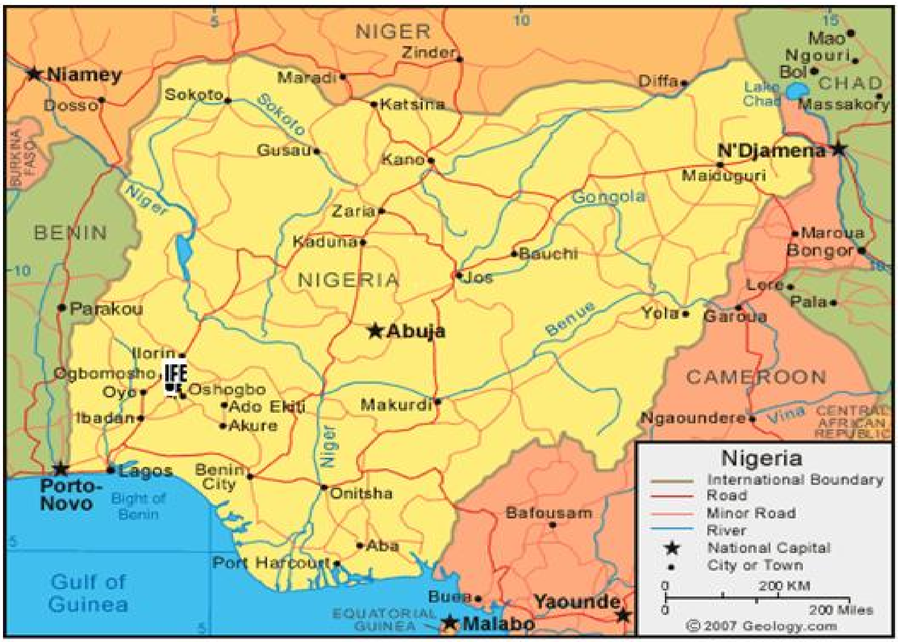


Figure 1: Map of Nigeria showing the town of study (Courtesy: Geology.com, 2007).

Ile-Ife is underlain by crystalline rocks of the Nigeria Basement Complex. Rahaman (1976, 1988) have used both petrographical and petrological properties of these rocks to classify the Precambrian Basement Complex rocks into six lithologic groups. The three main petrological units found in Obafemi Awolowo University campus are; grey gneiss, granite gneiss and mica schist (Figure 2). Veins of quartz and pegmatite occur as intrusive rocks in the three main rock types which have been subjected to

clayey layer which is not good as foundation material because of its high risk of settlement. The main river on the Campus, Opa River and its tributaries, flow within the basins of the bedrock depression. The groundwater flow pattern, which is towards the center of the bedrock depressions, implies that the Opa River and its tributaries are probably recharged by groundwater (Olorunfemi and Okhue, 1992). Water adversely affects engineering structures as it can cause the dissolution of materials with time. Therefore techniques which are capable of mapping subsurface weak zones such as fractures/faults and incompetent soil type that may not be able to sustain heavy structures.

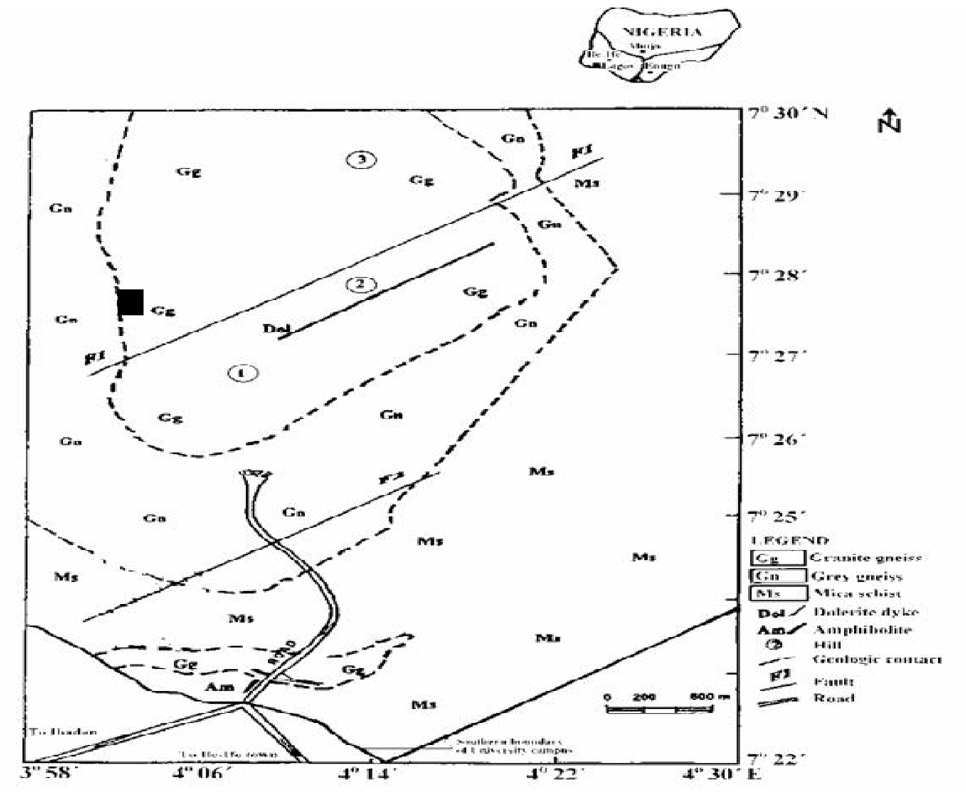


Figure 2: Geological map of Obafemi Awolowo University campus, Ile-Ife (After Adepelumi *et al.*, 2001)

METHODOLOGY

The geophysical methods used in this investigation are the electrical resistivity (VES) and seismic refraction methods. Figure 3 shows the geophysical data acquisition map. Five traverses were established in the E-W direction. These were divided into two, one within the premises of existing geology building where two seismic line (S_{2R}-S_{1R}-S_{2O}-S_{10} and S_{3O}-S_{3R}) and a total of seven VES stations (VES 1, 2, 3, 4, 5, 11 and 12) were occupied ; while at the extension site one seismic line (S_{5R}-S_{4R}-S_{5O}-S_{4O}) and a total of nine VES stations (VES 6, 7, 8, 9, 10,13, 14, 15, 16) were occupied. This was done to allow for correlation of the results obtained from the survey. Garmin Global Positioning System was used to establish the location of all data points and their elevation.

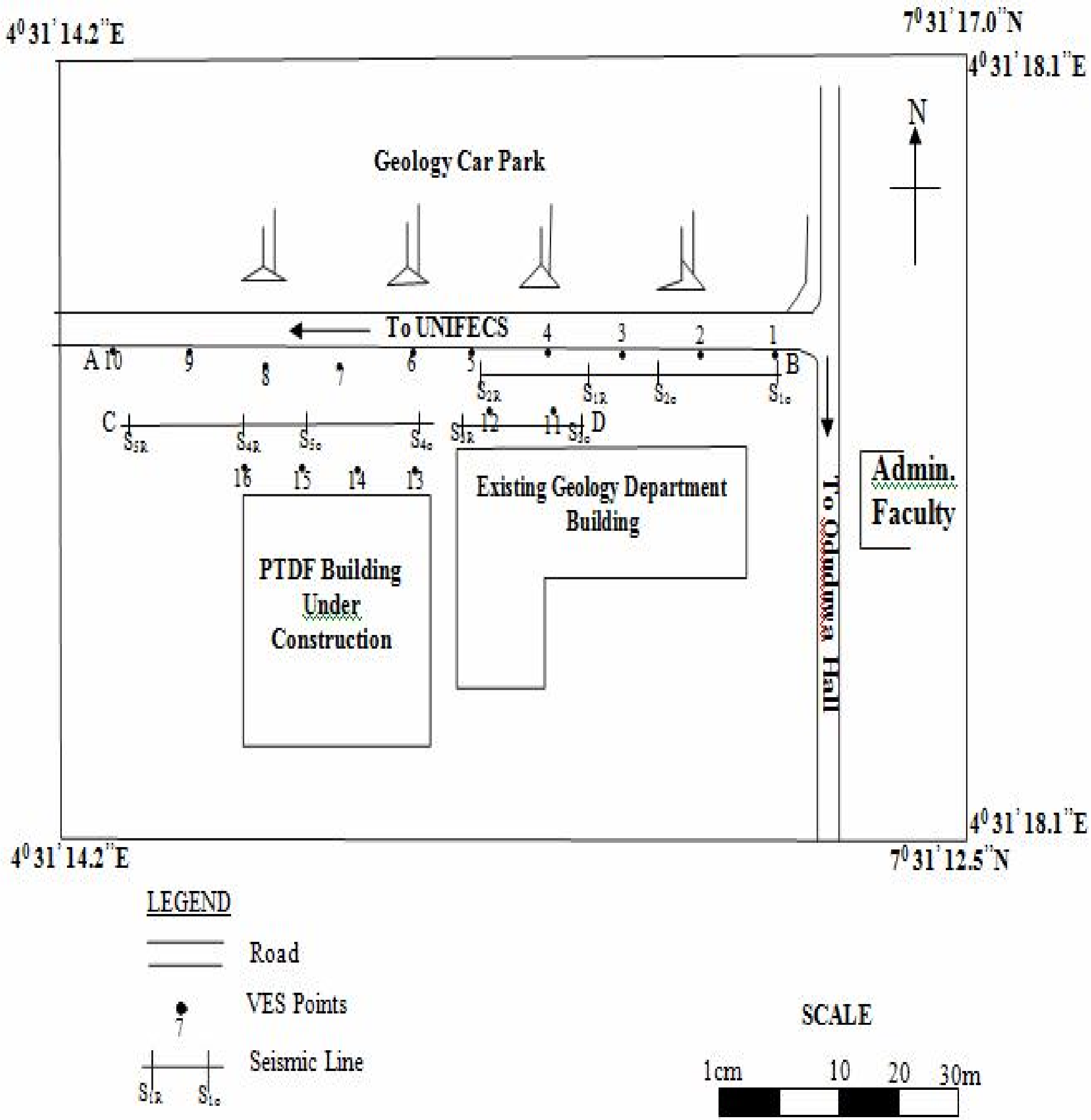


Figure 3: Base map of the study area showing Seismic lines and VES stations

The electrical resistivity survey was carried out with an ABEM SAS 300 Terrameter. The Schlumberger electrode array with half current electrode (AB/2) separation varying between 1m to a maximum of 32m was used.

The data obtained were plotted as VES curves and were quantitatively interpreted using partial curve matching (Zohdy, 1965; Orellana and Mooney, 1966; Keller and Frischkneckt, 1966). Since data with small electrode spacing

Computer iteration was applied on the result from the manual curve matching using WINRESIST and then InterpretVES (Jerry, 2000) software. The software also gave the Dar Zarrouk Parameters for the various VES point. Typical curves from result of WINRESIST and then InterpretVES are presented as Figure 4.

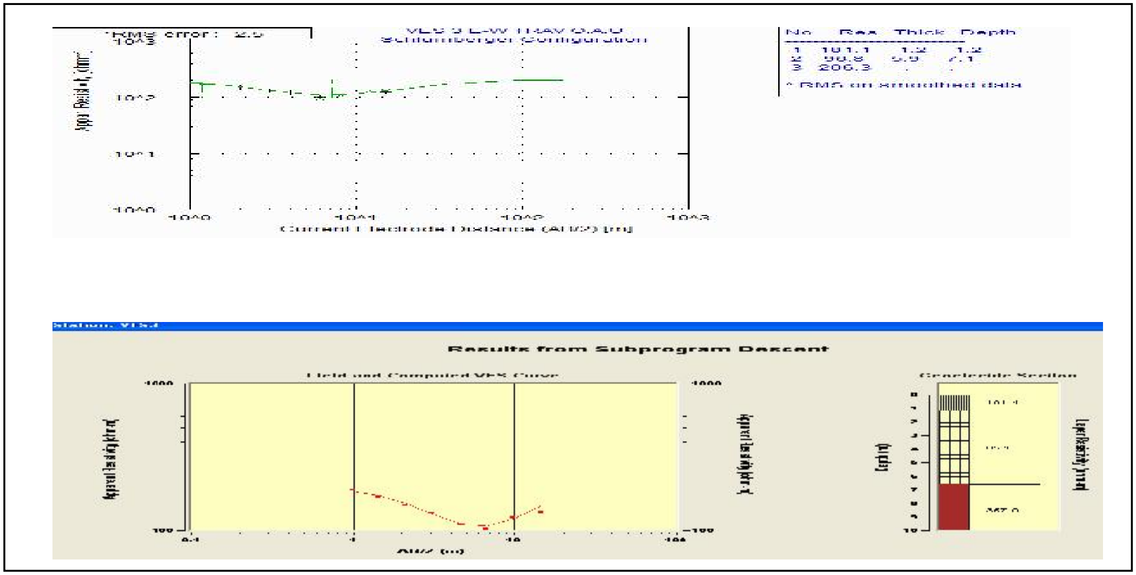
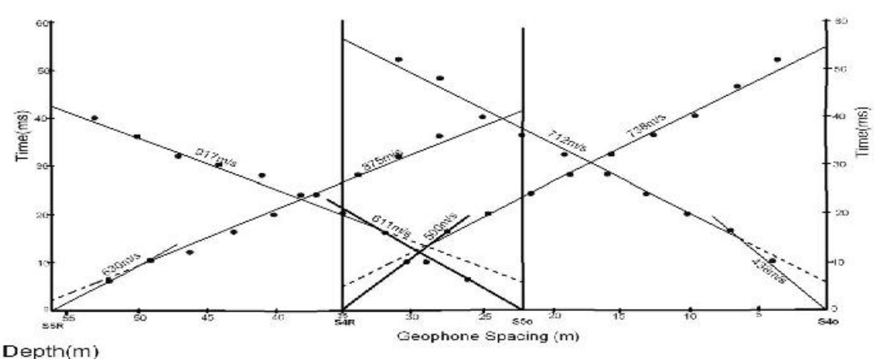


Figure 4: Inversion Result for VES 3

The seismic refraction survey was carried out to complement the VES method. A 12 Channels Digital Instantaneous Floating Point (DIFP) signal stacking seismograph BISON series 7000 was used. However, only 10 geophones were available. Five spreads were established with four of them overlapping (two at the new site and two at the existing building) with one non-overlapping spread at the existing building. An offset distance of 4m was used at both the On- and Reverse shots with a constant geophone spacing of 3m. The spread containing S_{3on} and S_{3rev} utilized a constant offset and geophone-geophone separation of 2m due to non-availability of space.

A Time-Distance (T-X) curve was plotted from the first arrival times and the apparent layer velocities calculated. The true layer velocities, the dip angle of the refractors and the up-dip and down-dip thickness were computed using a FORTRAN 90 computer program. Figure 5 is a typical T-X curve for a spread.



INTERPRETATION AND DISCUSSION OF RESULTS

Electrical Resistivity Method (VES) Survey

The inversion of the VES data resulted in three to four layers model. The type curves are mainly H-type with A-type and KH-types. The result of the geoelectric parameters for both manual and computer iterated results are summarized on Table 1.

Table 1: A summary of the Vertical Electrical Sounding Interpretation

VES Stn	Geographic Co-ordinate		Result				Lithology
			Curve Matching		Computer Iteration		
	Latitude	Longitude	Layer Resistivity (Ω.m)	Depth (m)	Layer Resistivity (Ω.m)	Depth (m)	
1	7^{0}31’14.9’’N	4^{0}31’17.6’’E	155/84/∞	1.4/5.5	155/84/∞	1.4/5.5	Topsoil/Weathered layer/fresh bedrock
2	7^{0}31’15.1’’N	4^{0}31’17.0’’E	260/140/560	1.4/10.5	261/128/556	1.4/10.7	Topsoil/Weathered layer/fractured bedrock
3	7^{0}31’15.2’’N	4^{0}31’16.5’’E	190/102/204/∞	1.2/6.6/15	181/97/206/∞	1.2/7.1/15	Topsoil/Weathered layer/fresh bedrock
4	7^{0}31’15.2’’N	4^{0}31’16.2’’E	235/127/520	0.9/7.2	235/119/381	0.8/6.1	Topsoil/Weathered layer/fractured bedrock
5	7^{0}31’15.2’’N	4^{0}31’15.7’’E	170/205/∞	0.7/6.0	168/213/∞	0.7/6.0	Topsoil/Weathered layer/fresh bedrock
6	7^{0}31’15.5’’N	4^{0}31’14.7’’E	45/23/104/∞	0.8/2.9/10.3	45/23/112/∞	0.8/2.9/6.0	Topsoil/Laterite Weathered layer/fresh bedrock
7	7^{0}31’15.3’’N	4^{0}31’14.4’’E	135/165/450/720	0.8/4.0/10.3	124/173/319/641	0.8/5.9/11.7	Topsoil/Laterite Weathered layer/fractured

9	7031’15.5’’N	4031’13.8’’E	102/168/540	0.8/4.5	93/161/351	1.1/4.0	Topsoil/Weathered layer/fractured bedrock
10	7031’15.4’’N	4031’13.4’’E	120/223/∞	1.9/8.5	120/219/∞	1.9/8.5	Topsoil/Weathered layer/fresh bedrock
11	7031’14.9’’N	4031’16.1’’E	90/177/75/∞	0.8/5.1/8.0	90/180/75/∞	0.8/4.3/8.0	Topsoil/Weathered layer/fresh bedrock
12	7031’14.9’’N	4031’15.9’’E	135/165/∞	0.8/8.0	125/174/∞	0.8/8.0	Topsoil/Weathered layer/fresh bedrock
13	7031’14.6’’N	4031’14.6’’E	250/134/∞	1.7/12.0	222/141/∞	1.7/12.0	Topsoil/Weathered layer/fresh bedrock
14	7031’14.7’’N	4031’14.1’’E	240/288/111/ 555	1.4/3.5/11.5	288/213/103/ 502	1.4/3.5/13.9	Topsoil/Laterite/ Weathered layer/ fractured bedrock
15	7031’14.7’’N	4031’13.7’’E	170/315/213/480	1.0/3.9/11.4	180/308/208/ 478	0.9/3.8/11.3	Topsoil/Laterite/ Weathered layer/ fractured bedrock
16	7031’14.8’’N	4031’13.3’’E	170/340/∞	4.2/15.0	170/340/∞	4.2/15.0	Topsoil/Laterite/ fresh bedrock

The interpreted results of the vertical electrical sounding investigation are presented as geoelectric sections (Figure 6). Figure 6 shows the geoelectric section (A-B) trending W – E in direction. This section covers VES stations 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10. The geoelectric section reveals three subsurface layers. The first layer is the topsoil with resistivity and thickness ranging between 93 to 261 ohm-m and 0.7 to 1.9m respectively. This is underlain by a weathered layer with resistivity and thickness of 97 to 175 Ohm-m and 2.1 to 15 m respectively. The last layer is the fractured/fresh bedrock with depth to rock head of between 4.0 to 15 m.

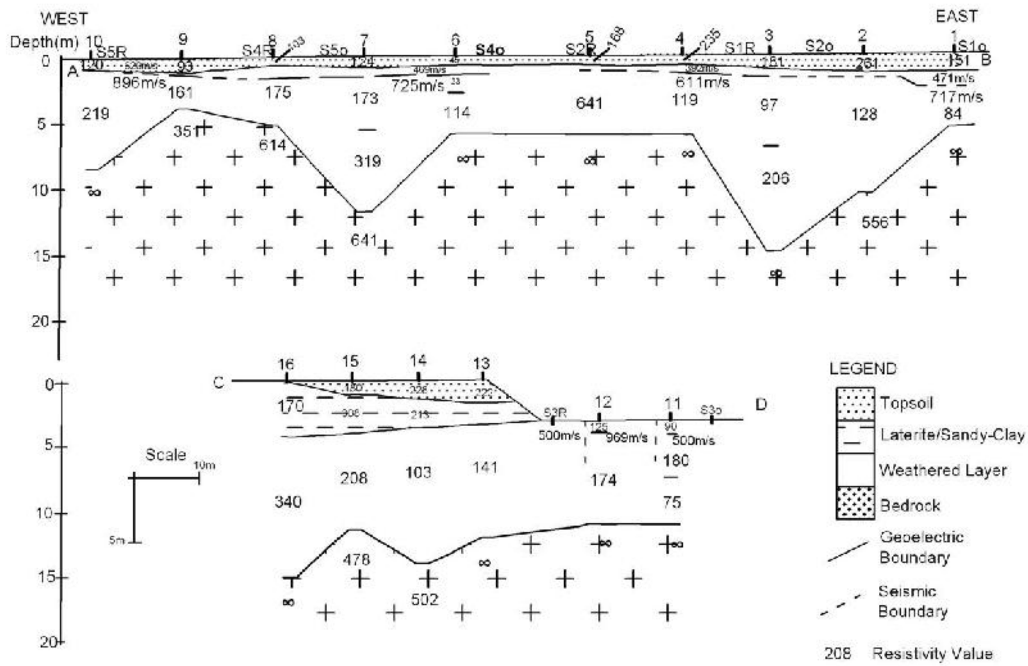


Figure 6: The geoelectric and seismic section of the study area

The geoelectric section (C-D) reveals three to four subsurface layers. The section covers VES stations 11, 12, 13, 14, 15 and 16. The first layer is the topsoil with resistivity and layer thickness ranging between 180 to 222 Ohm-m and 0.8 to 1.4 m respectively. This layer is underlain by the lateritic cover west of the section (C-D) with resistivity and thickness ranging from 170 to 308 Ohm-m and 2.1 to 14.2 m respectively, but this layer is completely missing, east of the section beneath VES 11 and 12 possibly due to erosion. The weathered layer is next with resistivity and thickness ranging between 103 to 208 Ohm-m and 7.5 to 15 m respectively. The last layer is the fractured/fresh

Subsurface hydrogeological and engineering characteristics

Determined depth to basement rock varies from 5.5 to 11.5 m at the existing building and 4.0 to 15m at the site under construction. The foundation of the building under construction, which was cut to an average depth of 3.0 m below the ground, was located within the weathered layer. By the fact that this layer can also accumulate groundwater, there should be a means of sealing off the source of water with grouted cement or channeling the water trapped away from the foundation area in order to prevent water seepage into the building. A similar design was employed at the existing building.

of anisotropy map of the area, Figures 7a & b, show a low value, less than 3000, and the maximum anisotropy (λ) value of 1.18. The work of Olorunfemi et al. (1990) and Olorunfemi and Olorunniwo (1985) showed that the higher the anisotropy coefficient the higher the groundwater yield in a basement complex environment. Since λ is directly related to $\sqrt{T}$, high value (in the order of 7000) of T will indicate high groundwater yield. Ako and Osondu (1986) also found that high transverse resistance value indicates high groundwater yield. The observed value of (T) and (λ) indicate medium groundwater accumulation in the area.

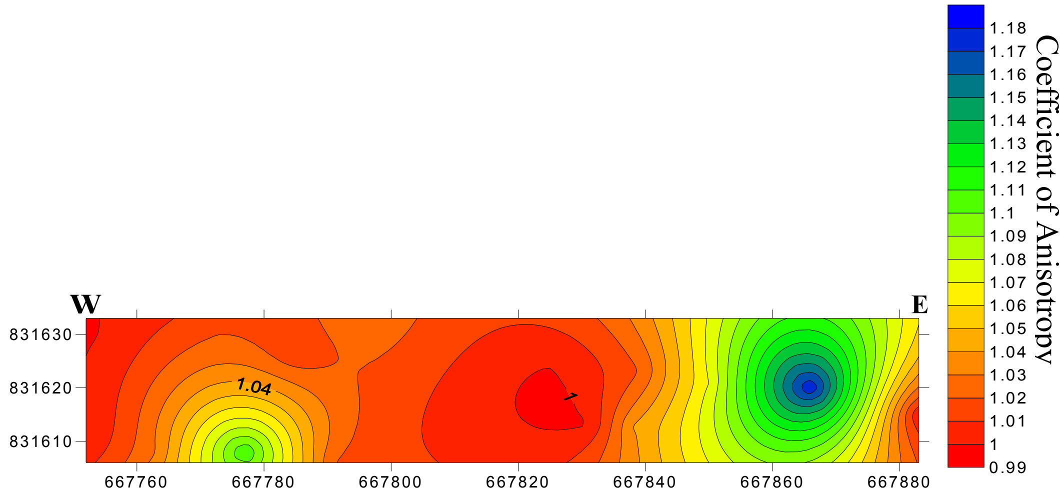


Figure 7a: Map of Coefficient of Anisotropy (λ)

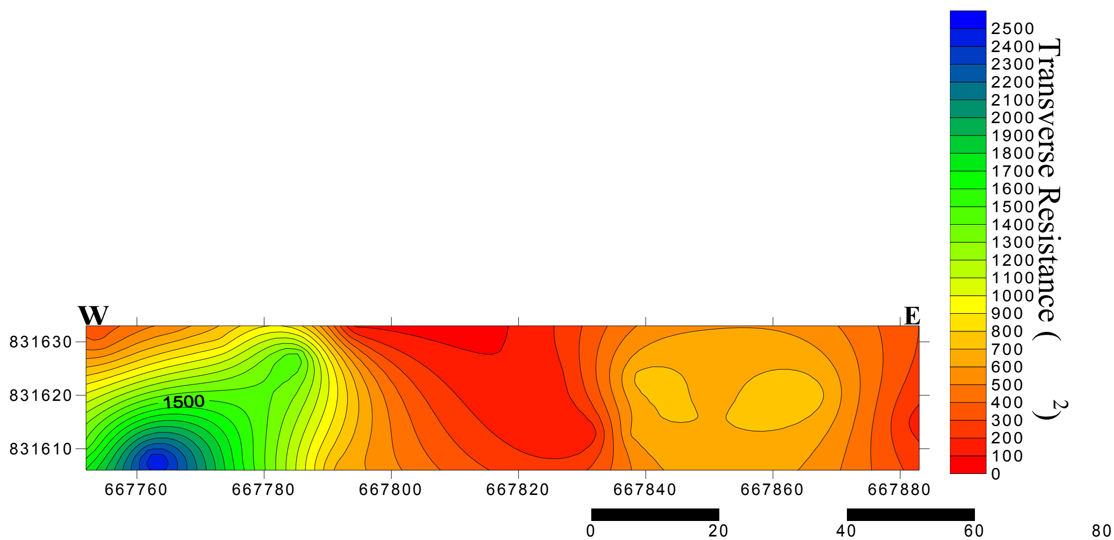


Figure 7b: Map of Transverse Unit Resistance (T)

Bedrock Structure and Soil competence

relatively low values of the bedrock resistivity

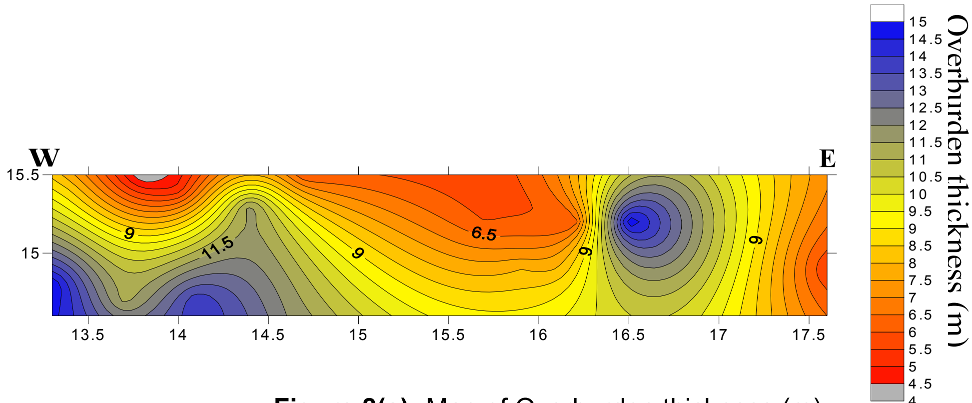


Figure 8(a): Map of Overburden thickness (m)

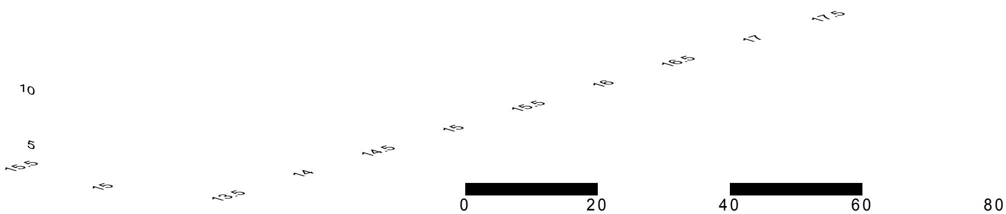


Figure 8(b): Map of Basement relief of the area.

The geologic sequence in the area consists the topsoil, clayey-sand/laterite, weathered layer and fractured/fresh bedrock. The subsoil material on which the foundation of the new building is located, judging from the resistivity values of 84-319 ohm-m, is composed of sandy-clay/clayey-sand, it could be said that the soil is engineering geologically competent (Idornigie et. al., 2006) and under minimal risk of sinking or collapse. Also, since metallic materials e.g. pipes are going to be laid in the subsurface, the corrosivity or aggressivity of the host material has to be known. The structures are usually laid within the first 2m into the subsurface, which in

Seismic Refraction Survey

The output from the surface refraction survey for the various spreads is presented in Table 2. The survey could only detect two subsurface layers due to short spread used (only 36 m long).The result corresponds with that obtained from the VES survey in terms of depth and geology of the subsurface. The depth to the weathered layer as obtained from the result varies between 0.86 to 2.58 m with the seismic velocities of the topsoil and the weathered layer being between 375 m/s to 620 m/s and 617 m/s to 896 m/s respectively. The velocity of 969 m/s obtained for the second layer under S

Table 2: Seismic Refraction Survey results

SEISMIC REFRACTION INTERPRETATION FOR A DIPPING REFRACTOR

SPREAD 1

V1(m/s)	V2(m/s)	DIP ANGLE(deg)	Hu(m)	Hd(m)
471.00	716.50	1.15	1.56	1.88

SEISMIC REFRACTION INTERPRETATION FOR A DIPPING REFRACTOR

SPREAD 2

V1(m/s)	V2(m/s)	DIP ANGLE(deg)	Hu(m)	Hd(m)
375.00	617.50	0.86	1.17	1.64

SEISMIC REFRACTION INTERPRETATION FOR A DIPPING REFRACTOR

SPREAD 3

V1(m/s)	V2(m/s)	DIP ANGLE(deg)	Hu(m)	Hd(m)
500.00	969.00	1.11	2.19	1.31

SEISMIC REFRACTION INTERPRETATION FOR A DIPPING REFRACTOR

SPREAD 4

V1(m/s)	V2(m/s)	DIP ANGLE(deg)	Hu(m)	Hd(m)
469.00	725.00	0.87	1.69	1.54

SEISMIC REFRACTION INTERPRETATION FOR A DIPPING REFRACTOR

SPREAD 5

V1(m/s)	V2(m/s)	DIP ANGLE(deg)	Hu(m)	Hd(m)
620.50	896.00	1.29	2.58	0.86

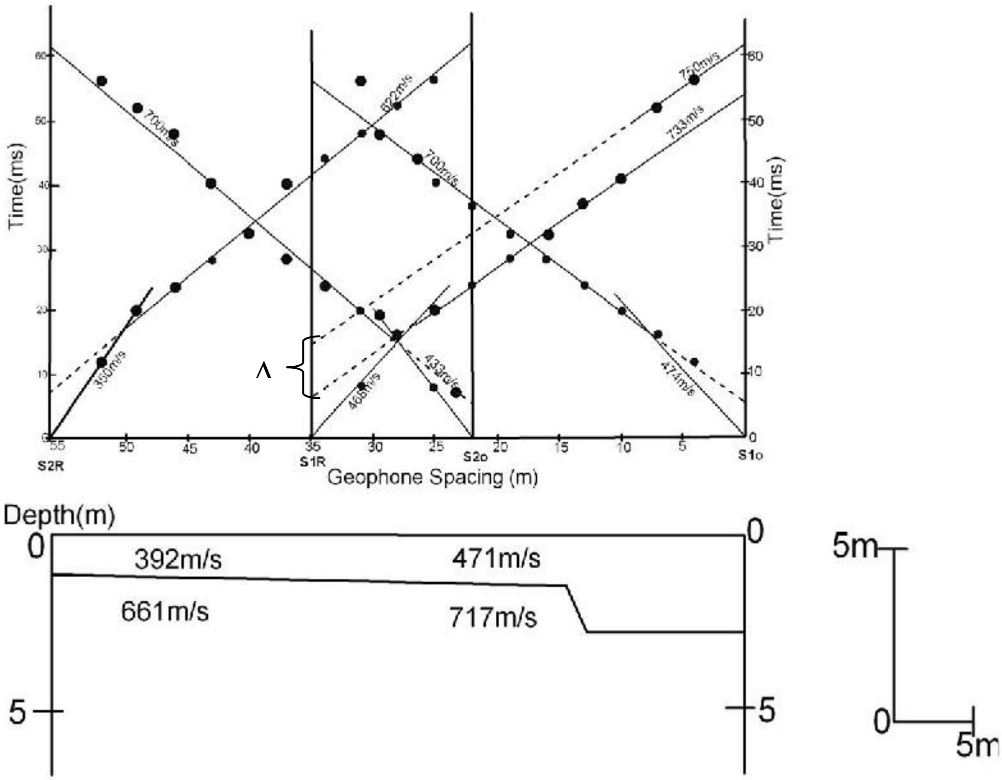


Figure 9: T-X curve of spread 1 and 2

The results of both the seismic refraction survey and the electrical resistivity survey were used to produce a geoelectric section and seismic refraction section of the subsurface (Figure 7). There is good correlation between the depth to the top of the weathered layer obtained from the electrical and seismic refraction survey. The section gives a visual impression and the summary of the way in which the geology of the study area with respect to the resistivity and elasticity of different media that constitute the subsurface are related. Elastic Modulus for the subsurface layers delineated from the seismic refraction survey was estimated based on the approximate empirical relation between P-wave velocity and Young's modulus by Brown and

velocity as velocities less than 1560 m/s to 1875 m/s, may usually be easily ripped by bulldozer (Hawkin, 1961). This indicates that the two layers mapped would rip easily with a bulldozer.

CONCLUSIONS AND RECOMMENDATIONS

The results of the two geophysical techniques employed at the premises of the existing geology building and the PTDF sponsored building showed sufficient correlation between the subsurface properties. The overburden electrical characteristics are similar in terms of resistivity values and thickness. The subsurface layer delineated are the topsoil, clayey sand/laterite, weathered layer and the and 350 to ∞ Ohm-m respectively with depth to rock head between 4.0 to 15.0 m.

The resistivity values of the layers, as well as velocities of seismic wave, showed great similarity and one could say that there is little risk attached to the site under construction. The only likely problem is that of water seepage into the foundation floor, as indicated by basement depression from VES and fractured layer from the seismic refraction method, which could be mitigated by designing a channel way for water to flow out or sealing off the fracture and anticipated water flow path with grouted cement. The latter was eventually incorporated into the foundation design of the new building.

Strength estimates were made with the result of the seismic refraction survey using the values of the P-wave velocity. The elastic modulus and rippability were obtained by empirical relations between the seismic velocity and these strength parameters.

It can be concluded that the near surface of the geology of the study area is favourable to the structure being put on it and there is practically no risk attached to the integrity of the building.

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