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SEISMIC REFRACTION SURVEY FOR FOUNDATION INVESTIGATION AT AHMADU BELLO UNIVERSITY ZARIA PHASE II, KADUNA STATE, NIGERIA.

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ABSTRACT

Ahmadu Bello University Zaria Phase II was investigated for foundation purpose. Four shallow seismic refraction profiles were carried out using the ABEM Terraloc Pro seismograph. Compressional (P) and shear (S) waves were acquired and the time-term technique, which is a combination of linear least squares and delay time analysis to invert the first arrivals for a velocity section and then to tomography section was adopted. These sections were correlated with a borehole report and a good matching was observed. The result shows that the area consists of three subsurface layers; an overburden with average thickness of about 10.5 m and P- and S-wave velocities (velocities) of about 550 m/s and 345 m/s respectively, the weathered basement with an average thickness of 12.5 m and velocities of 950 m/s and 550 m/s respectively, while the fresh basement was found at a depth of about 24 m with velocities of 1250 m/s and 680 m/s respectively. The Concentration Index, Material Index, Poisson's Ratio, and Stress Ratio were calculated to be in the range of 4.869 – 6.128, -0.032 – 0.312, 0.172 – 0.258, and 0.267 – 0.346 respectively in the study area. The seismic velocity values, engineering consolidation, and strength parameters showed that the subsurface soil/rock at the eastern parts of the study area is characterized by less competent soil/rock quality while the western parts are characterized by more competent soil/rock quality. Hence, the western and northwestern parts are more preferable for the foundation of structures to be erected.

Keywords: Seismic refraction, P-and S-waves, geotechnical, near-surface.

INTRODUCTION

The statistics of failure of structures such as buildings, roads, bridges, dams and even boreholes throughout the nation has increased geometrically (Akintorinwa and Adeusi, 2009). The need for the pre-foundation study has, therefore, become very imperative so as to prevent loss of lives and properties that always accompany such failure (Akintorinwa and Adeusi, 2009). Much attention has not been given to the nature of the subsoil at construction sites in the country where buildings have collapsed unexpectedly taking the lives of citizens without knowing the cause or tying it to bad building materials. The increase in student population year in year out on the campuses of Ahmadu Bello University (A.B.U.) Zaria has led to more expansion work. One of such expansion is the A.B.U. Zaria Phase II. Though, a Standard Penetration Test (SPT) was carried out prior to laying the foundation of some buildings, nevertheless, that is not sufficient enough in proper site characterization, hence the need to use a geophysical method (seismic refraction survey because of its cost-effectiveness, high resolution of images for detail subsurface structures, and its capability to effectively reconstruct subsurface image for complex velocity structures (Bullen and Bruce, 1993; Charles and William, 2005) at this building sites to double-check the competence of the soil required to hold such high rising buildings and structures.

MATERIALS AND METHOD

Location and geology of the study area

The study area is situated in A.B.U. Zaria main campus Samaru, Kaduna state, Nigeria which is bounded by latitude 11º 08′ 32″ N to 11º 07′ 53″ N and longitude 7º 37′ 56″ E to 7º 39′ 00″ E. It is occupying 9% area of Kubanni River Basin and positioned on the North-Western part of the basin as shown in figure 1. The study area is part of the Nigeria Basement Complex which according to McCurry (1970), is composed of two distinct rock types;

Fig. 1: Google map showing the location of the study area (courtesy of Google earth).

The Basement gneiss which outcrops mostly along stream channels/valleys in deeply weathered forms. Examples are found along Kubanni valley. It is medium to coarse-grained and moderately to weakly foliated (Wright and McCurry, 1970).
The Older granite which has two textural varieties, the porphyritic variety and the evenly grained medium to coarse-grained type. It is weakly foliated and mostly occurs as inselbergs and low whalebacks. Its exposure is mostly cross-cutted by pegmatites and aplites.
Granitic intrusions form a suite of batholiths (the Zaria Batholiths) which outcrops as the *Kufena Hill*. The gneisses are found as small belts within the granite intrusions and are also found east and west of the batholiths. The biotite gneiss extends westwards to form a gradational boundary with the schist belt. The gneiss continues eastwards to some extent and is occasionally broken up by the Older Granite (McCurry, 1970). The Older Granite intrusion is supposed to have been formed at the bottom of a fold mountain belt (Wright and McCurry, 1970).

Data acquisition and processing

To achieve a 2D seismic tomography of the study area, the ABEM Terraloc Pro seismograph was used to conduct four seismic profiles; two profiles each for P- and S-waves respectively. Each profile extends for a total length of 115 m. The inter-geophone spacing was 5 m and an offset of 5 m at both ends of the profile with a total of 24 (10Hz) vertical and horizontal geophones per profile respectively. The total record length (time) for both the P- and S-waves was 327.7 ms with a sampling interval of 20 µs and the number of samples per trace was of 16384.
For both P- and S-waves data acquisition, vertical and horizontal geophone is set as the receiver type respectively in the "layout geometry" settings in the seismograph. A total of seven shots (figure 2) was taken including the two offsets; shot 1 (offset1) at -5 m, shot 2 at 0 m, shot 3 at 30 m, shot 4 at 60 m, shot 5 at 90 m, shot 6 at 115 m and shot 7 (offset2) at 120m) for both P- and S-waves profiles.

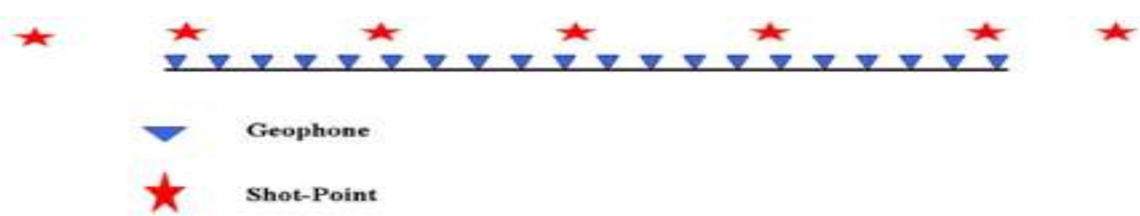

Fig. 2: Profile layout of both P- and S-wave.

A sledgehammer weighing 16 lb was used to generate both waves. For the P-waves, vertical geophones, a trigger geophone was arranged according to the layout geometry. A sophisticated round rubber-like plate (about 38 cm diameter and 6 cm thick) was used to receive the sledgehammer strikes (plate1a). A total of 2 stacks were made per each P-wave shot location. The position and elevation of all the geophones and shot locations are noted and the data saved in the memory of the ABEM Terraloc Pro.

To generate the S-waves, the Kobayashi method was adopted along with horizontal geophones. In this method, a wooden plate (2 m x 0.5 m x 0.2 m) was held in firm contact with the earth surface by the weight of two heavy persons standing on it was used to receive the sledgehammer strike. The piece of wood was located such that its long side (2 m) was perpendicular and centered relative to the line of geophones (profile line). Two separate files were recorded (a) a right-side shot, where the sledgehammer was striking on the wood in a horizontal direction at its right side, and (b) a left-side shot, where the sledgehammer was striking on the wood in a horizontal direction at its left side. This was done in other to facilitate the identification of shear waves arrivals and suppressing the compressional (P) waves. S-waves records are usually displayed in the same manner as P-waves. Similarly, the position and elevation of all the geophones and shot locations are noted and the data saved in the memory of the ABEM Terraloc Pro.

The data collected was processed using SeisImager 2D software developed by Geometrics Inc. The time-term technique which is a combination of linear least squares and delay time analysis to invert the first arrivals for a velocity section and then to tomography section. The two sets of data (right-side shot and left-side shot) gotten for the S-waves shots are subtracted from each other to get a good shear wave velocity before picking the first arrivals.

Boreholes are often used to correlate results obtained from geophysical surveys as these surveys are indirect. This is often done by correlating the tomography sections obtained in the area with the lithological information in the area. Boreholes which provide lithologic information, are a necessary and reliable source of primary data and Seismic Refraction Tomography (SRT) interpretations provide secondary information. The 2D tomography results of the survey were correlated with Borehole log (table 1) taken about 3 km from the study area but of the same geological setting. The seismic velocities are used to calculate elastic moduli and engineering parameters using the relationships in table 2 and 3 respectively then compared with standard tables which are shown in table 4 and 5.

Table 1: Lithology and Geologic section of borehole 1 – Akenzua Hostel (Hydro-Skill Ltd., 2006)

DEPTHS (m)		THICKNESS(m)	LAYER DEPTH (m)	INTERPRETED LITHOLOGY
FROM	TO			
0.0	5.0	5.0	Overburden 0.0 – 9.0	Reddish-brown topsoil
5.0	9.0	4.0		Reddish-brown sandy soil
9.0	12.0	3.0	Weathered Basement 9.0 – 22.0	Grayish brown sandy soil
12.0	17.0	5.0		Mottled clay
17.0	22.0	5.0		Coarse to medium-grained sand
22.0	27.0	5.0	Fresh Basement 22.0- 27.0	Fractured basement

Table 2: Equations of elastic moduli used. V_p and V_s are P-and S-waves velocities respectively.

Elastic Modulus	Used Equation	Reference
Poisson's Ratio	$\sigma = \frac{1}{2}\left(1 - \left\{\frac{1}{\left(\left(\frac{V_p}{V_s}\right)^2 - 1\right)}\right\}\right)$	Adams (1951), Salem (1990)
Young's Modulus	$E = \rho\left[\frac{(3V_p^2 - 4V_s^2)}{\left(\left(\frac{V_p}{V_s}\right)^2 - 1\right)}\right]$	Adams (1951)
Lame's constants	$\lambda = \frac{\sigma E}{((1+\sigma)(1-2\sigma))}$	King (1966), Toksoz, *et al.*, (1976)
Density	$\rho = \left[0.3\ V_p^{0.25}\right]$	Gardner *et al.*, (1974)

Shear Modulus	$\mu = \frac{E}{(2\,(1+\sigma))}$	King (1966), Toksoz, *et al.*, (1976)

Table 3: Engineering parameters equations used.

Engineering parameter	Used equation	Reference
Concentration index	$C_i = \frac{\left[3-4\left(\frac{V_s^2}{V_p^2}\right)\right]}{\left[1-2\left(\frac{V_s^2}{V_p^2}\right)\right]}$	Abd El-Rahman (1991)
Material index	$\nu = \frac{(\mu - \lambda)}{(\mu + \lambda)} = (1 - 4\,\sigma)$	Abd El-Rahman (1989)
Stress Ratio	$S_i = \left[1 - 2\left(\frac{V_s^2}{V_p^2}\right)\right] = (C_i - 2)^{-1}$	Abd El-Rahman (1991)

Table 4: Soil description with respect to Poisson's ratio and Material Index, after Birch (1966), Gassman (1973), Tatham (1982), Sheriff and Geldart (1986).

Soil Description Parameter	Incompetent to slightly competent	Fairly to moderately competent	Competent materials	Very high competent materials
Poisson's Ratio (σ)	0.41 – 0.49	0.35 – 0.27	0.25 – 0.16	0.12 – 0.03
Material Index (ν)	(-0.5) – (-1)	(-0.5) – (0.0)	0.0 – 0.5	> 0.5

Table 5: Ranges of Concentration Index and Stress Ratio correspondent to soil competent degree, after Abd El-Rahman (1989).

	Weak (Incompetent)		Fair (Fairly Competent)		Good (Competent)
	Very soft	Soft	Fairly compacted	Moderate compacted	Compacted
Concentration Index (*Ci*)	3.5 – 4.0	4.0 – 4.5	4.5 – 5.0	5.0 – 5.5	5.5 – 6.0
Stress Ratio (*Si*)	0.70 - 061	0.61 – 0.52	0.52 – 0.43	0.43 – 0.34	0.34 – 0.25

RESULTS AND DISCUSSION

The results of both the P- and S-waves profiles are presented in figures 3 and 4. They are all characterized by similar features of slight undulating subsurface and consist of five lithological sections which are indicated as colors (pink, red, yellow, green and blue) with respect to velocity contrast.

Profile 1 of the P-waves (figure 3) runs along the east-west direction in the study area. The first section (pink color) is having an average thickness of about 14 m with a velocity range of 450 to 550 m/s. The second section (red color) is having an average thickness of about 2.5 m with a velocity range of 550 to 700 m/s. The third section (yellow color) is having an average thickness of about 3 m with a velocity range of 700 to 900 m/s.

The fourth section is greenish in color with an average thickness of 6 m with a velocity range of 900 to 1250 m/s and finally, the fifth section which is blue in color with a velocity range of 1250 to 1375 m/s at an average depth of about 22.5 m. Profile 2 of the P-waves runs along the north-south direction on the study area. This tomography section also reveals a slight undulating subsurface with also five lithological sections. The first section (pink color) is having a velocity range of 500 to 600 m/s with an average thickness of 17.5 m. The second is red in color with a velocity range of 600 to 700 m/s with an average thickness of 3 m. The third section is yellowish in color having a velocity range of 700 to 850 m/s with an average thickness of 3 m too. The fourth section (green color) is having a velocity range of 850 to 1250 m/s with an average thickness of 8 m. The final section (blue color) is having a velocity range of 1250 to 1350 m/s with an average depth of about 29.5 m.

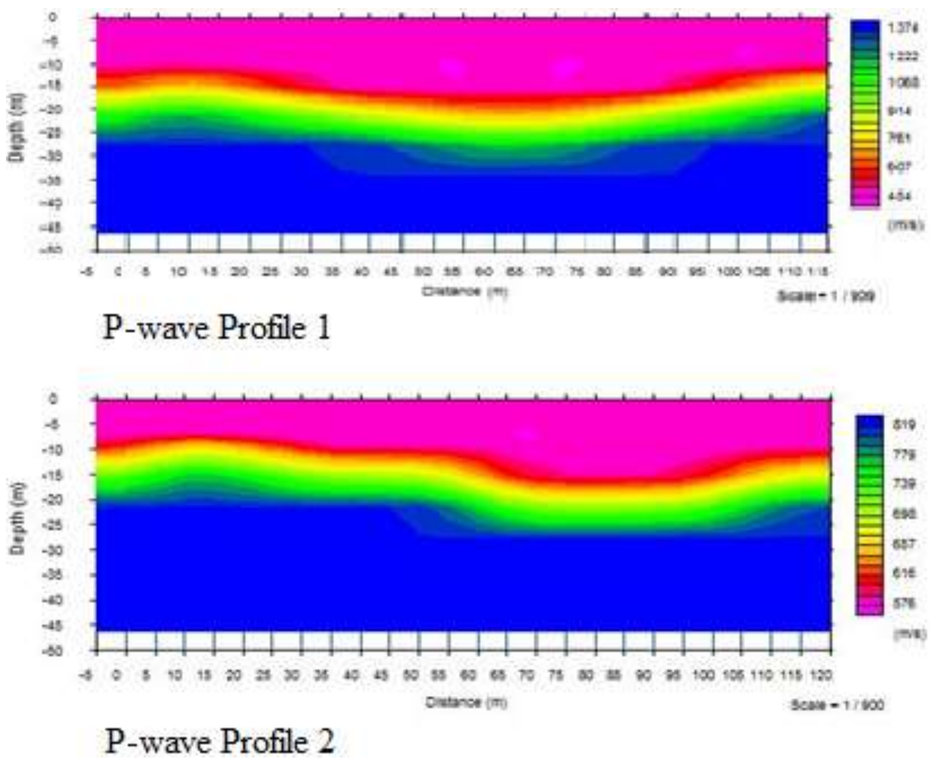

Fig. 3: Tomography section of profile 1 and 2 of the P-waves.

The S-waves profiles (1 and 2) (figure 4) are aligned along the same direction with that of the P-waves profiles, this is done in other to get uniformity of P- and S-waves velocities for calculations of engineering parameters. The first S-waves profile is also characterized by five lithological sections. The first section which is pink in color is having a velocity range of 300 to 350 m/s with an average thickness of 7 m. The second is red in color with a velocity range of 350 to 400 m/s with an average thickness of 2 m. The third section is yellowish in color having a velocity range of 400 to 480 m/s with an average thickness of 2.5 m. The fourth section (green color) is having a velocity range of 480 to 620 m/s with an average thickness of 6 m. The final section (blue color) is having a velocity range of 620 to 700 m/s with an average depth of about 16 m. The second is characterized also of five lithological section and undulating too. The first section which is pink in color is having a velocity range of 300 to 380 m/s with an average thickness of 8 to 15 m at the edges of the profile. The second is red in color with a velocity range of 380 to 420 m/s with an average thickness of 2.5 m. The third section is yellowish in color having a velocity range of 420 to 450 m/s with an average thickness of 3 m. The fourth section (green color) is having a velocity range of 450 to 600 m/s with an average thickness of 6 m. The final section (blue color) is having a velocity range of 600 to 650 m/s with an average depth of about 20 to 26 m at the edges.

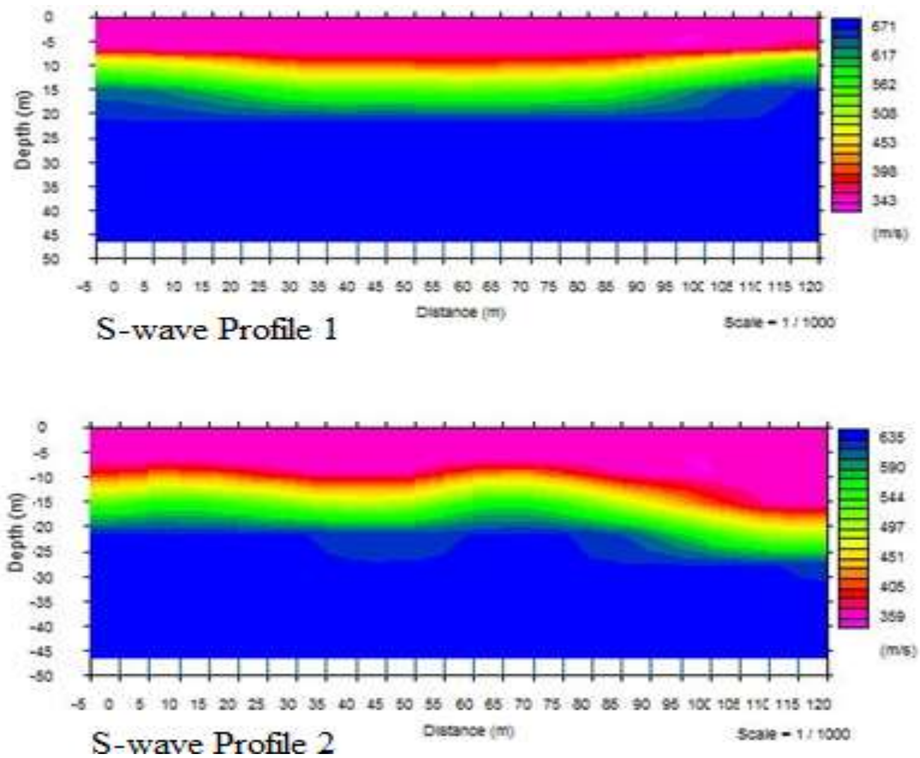

Fig. 4: Tomography section of profile 1 and 2 of the S-waves.

The average P- and S-waves velocities of the first layer in all profiles are considered for the calculations of elastic moduli because no foundation depth exceeds 2 m which the first layer depth is beyond in all cases of the tomography sections. Table 2 shows the list of equations used to calculate the elastic moduli. Table 3 shows the list of equations used to compute the engineering parameters. Table 6 shows the results of calculated elastic moduli and velocities (V_p and V_s) and table 7 shows results of the estimated geotechnical parameters.

Table 6: Results of calculated elastic moduli and velocities (Vp and Vs).

Profile	Vp (m/s)	Vs (m/s)	ρ (gm/cc)	σ	E (MPa)	λ (MPa)	μ (MPa)
P1	545	343	1.4495	0.172	0.39975	0.0894	0.1705
P2	629	359	1.5024	0.258	0.48734	0.2065	0.1937

Table 7: Results of the estimated geotechnical parameters.

Profile	Concentration Index (Ci)	Material Index (ν)	Stress Ratio (Si)
P1	6.128	0.312	0.278
P2	4.869	-0.032	0.346

These calculated results when compared with table 4 and 5 show some variation which is of importance to the civil engineers. Generally, properties of the location of profile 1 show competent earth materials than profile 2 which the concentration index, material index, stress ration, and Poisson's ration shows lesser competency (fairly competent).

CONCLUSION

Seismic refraction survey was successfully carried out at A.B.U. Zaria, Phase II, Northwestern Nigeria with the aim of checking the suitability of the study area for the foundation of buildings. For that purpose, both compressional (P) and shear (S) wave velocities were determined and interpreted using the tomography technique to give us a 2-D velocity model. These models show that the area consists of three layers; an overburden with average thickness of about 10.5 m and P- and S-wave velocities of about 550 m/s and 345 m/s respectively, the weathered basement with an average thickness of 12.5 m and velocities of 950 m/s for P wave and 550 m/s for S-wave respectively, while the fresh basement was found at a depth of about 24 m with velocities of 1250 m/s for P- wave and 680 m/s for S-wave respectively. A number of shallow soil engineering parameters such as Concentration Index, Material Index, and Stress Ratio were calculated to be in the range of 4.869 – 6.128, -0.032 – 0.312, and 0.267 – 0.346 respectively to assess the subsurface from geophysical and engineering perspective. Integration between different engineering elastic, consolidation, and strength parameters indicates a high competent soil in the western and northwestern parts while the eastern parts indicate lesser competency. This could be attributed to the proximity of the Kubanni river basin to the area, erosion, and level of excavation and embankment noticed during the survey. Hence, the western and northwestern parts are more preferable for the foundation of structures to be erected.

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REFERENCES

Abd El-Rahman, M., (1991). The potential of absorption coefficient and seismic quality factor in delineating less sound foundation materials in Jabal Shib Az Sahara area, Northwest of Sanaa, Yemen Arab Republic. *Egypt, M. E. R. C. Earth Sci.*, Vol. 5. Ain Shams University, pp. 181–187.

Abd El-Rahman, M., (1989). Evaluation of the kinetic elastic moduli of the surface materials and application to engineering geologic maps at Maba-Risabah area (Dhamar Province), Northern Yemen. *Egypt. Journal. Geol*. 33 (1–2), 229–250.

Adams, L.H., (1951). Elastic properties of materials of the Earth's Crust. Internal Construction of the Earth (edited by Gutenberg). Dover publications, Inc., New York.

Akintorinwa, O. J., and Adeusi, F. A., (2009). Integration of geophysical investigations for a proposed lecture room complex at the federal university of technology, Akure, SW, Nigeria. *Journal of Applied Sciences* 2(3).

Birch, F., (1966). Handbook of physical constants. Geol. Soc. Amer. Men. 97, 613. 85

Bullen, K. E., and Bruce, A. B., (1993). An Introduction to the theory of seismology, fourth edition.

Charles, F. N., and Williams P. O., (2005). Seismic refraction analysis of landslides. *Geophysics and Geology branch California Department of Transportations, Sacramento.*

Gassman, F., (1973). Seismische Prospektion. Birkhaeuser Verlag, Stuttgart, p. 417. 86.

Gardner, G.H.F., Gardner, L.W., Gregory, A.R., (1974). Formation velocity and density – The diagnostic basics for stratigraphic traps. Geophysics 39, 770 -780.

Hydro Skill Ltd., (2006). Hydrological log of boreholes at students' hostels, Ahmadu Bello University, Zaria.

King, T.V.V., (1966). Mapping organic contamination by detection of clay-organic processes. Proceeding AGWSE/NWWA/API.

McCurry, P. (1970). The Geology of the Zaria sheet 102 S.W. and its Region. Mortimore, M.J. (Ed.). Department of Geography Occasional Paper No. 4, Ahmadu Bello University, Zaria. pg 7.

Salem, H.S. (1990). The theoretical and practical study of petrophysical, electric and elastic parameters of sediments. Germany, Kiel Insitut for geophysik. Ph.D. thesis.

Sheriff, R.E., and Geldart, L.P., (1986). Exploration Seismology. Cambridge Univ. Press, Cambridge, p. 316.

Tatham, R.H., (1982). Vp/Vs and lithology. Geophysics 47 (3), 336–344. https://doi.org/10.1190/1.1441339.

Toksoz, M.N., Cheng, C.H., and Timur, A., (1976). Velocities of seismic waves-porous rocks. Geophysics 41, 621 – 645.