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Determination of elastic properties of the overburden materials in parts of Akamkpa, southeastern Nigeria using seismic refraction studies

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Abstract

Seismic refraction study was used to determine the depth, thickness and elastic properties of parts of Oban massif basement complex in Akamkpa which lies between latitude 5^0 00'-5^0 50'N and longitude $8^0$00'-$8^0$50'E in Cross River State, Southern Nigeria. This was done using a twelve – channel signal enhancement seismograph, geophones, sledge hammer and metal plate. The P-wave and S-wave velocities were obtained from the arrival travel time read from velocity data. With the aid of standard velocity values for various rocks and the mathematical relationship of the measured and unknown parameters, the lithology, depth, thickness and elastic properties of the basement rocks were deciphered using V_P/V_S ratios and the associated calculated Poisson's ratios.

Keywords: elastic properties, basement, seismic refraction, V_P/V_S ratio and Akamkpa.

INTRODUCTION

It is quite not inconclusive to say that the variation of the ratio of compressional and shear wave velocities (V_P/V_S) is very much significant in the determination of the site for quarrying activities and engineering foundations since velocity varies withe densities and elastic moduli The elastic properties and the depth to different layers as well as the thickness of the layers can be determined from the knowledge of compressional and shear wave velocities [1]. The presence of gas in sedimentary rocks reduces the elastic moduli, Poisson's ratio and the V_P/V_S ratio [2].V_P/V_S ratio greater than 2.0 are diagnostic of unconsolidated sand, while values less than 2.0 may indicate either consolidated sandstone or a gas- filled unconsolidated sand. The potential value of

V_s in detecting gas-filled sediments accounts for the current interest in shear wave seismic surveying [3]. It is worthwhile to say that compressional wave velocity increases with confining pressure. Sandstone and shale velocities show systematic increase with depth of burial and with age, due to the combined effects of progressive compaction and cementation [4, 5]

The knowledge of velocity enables the depth of the basement rock type and theelastic properties to be deciphered. These information obtained from the velocity data are very useful in geotechnical and engineering constructions such as road construction, building and scaffolding. The Poisson's ratio is a property of rock material, which defines the ratio of the fractional change in width to the fractional change in length of rock sample. The value for the Poisson's ratio at different locations speaks volumes for the elastic properties of rocks and in this work; the Poisson's ratios for the basement rocks in *Akamkpa* were determined using the compressional and shear wave velocity ratios. The layers of the two locations were assessed through seismic refraction wave, produced from a mechanical source. The study attempts to determine the shallow depth of the basement rock as well as the type of basement rock and their set of elastic properties.

The susceptibility of rocks to stress and the consequent strain implies that wildcat geotechnical and engineering constructions may be both impracticable and unreliable as even the hard rocks under load may slide or weather at the point where they have cracks. In civil engineering, with particular reference to site investigation for the design of building foundation, roads, railways, dam site, hydroelectric power station and hydrogeology, it is important to know the subsurface rock elastic properties in order to design a befitting engineering structure [6-8] .

Location and geology of the study Area.

The study area is located in part of the Oban massif basement complex, which lies between latitude $5^o00`$-$5^o50`$N and longitude $8^o00`$-$8^o50`$E in the southern part of Nigeria, extending into the Cameroon (Fig.1). This region is generally represented as undifferentiated basement complex in the geology map of the region in which this study is carried out [9].The Precambrian crystalline basement complex is approximately 10,000km^2 in area with mappable rock units such as phyllites, schist, gneisses and amphibolites. In general these rocks are intruded by pegmatites, granites,grandiorites, diorites, tonalities, monzonites and dolorites [9].

The study area lies between latitude $5^o15'$-$5^o18'$N and longitude $8^o20'$-$8^o23'$E. It is about 50km^2 in area. The area covers Akamkpa and old Dunlop Town (now Cross River Estate Limited) all in Akamkpa Local Government Area, Cross River State, Nigeria (Fig. 2). Particularly, the three major groups of rocks recognized in the region are magmatic and sheared gneissic rocks, older granite intrusive series and unmetamorphosed dolerite intrusive (Fig. 2).

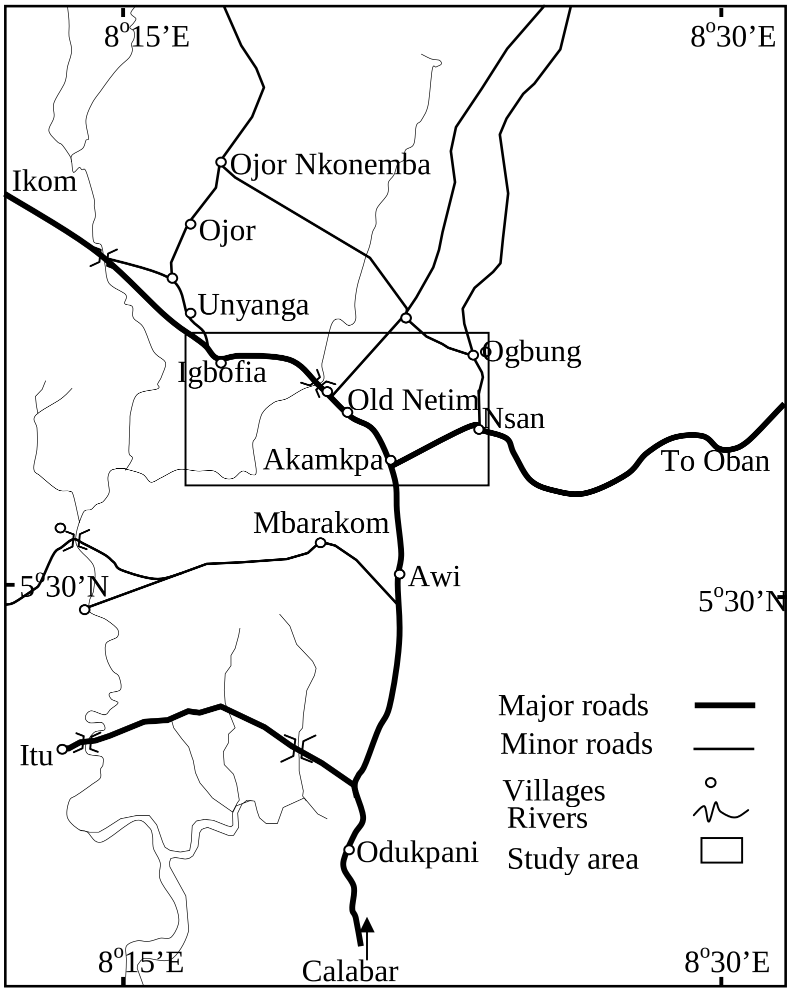

Fig. 1: Location map of Akamkpa area

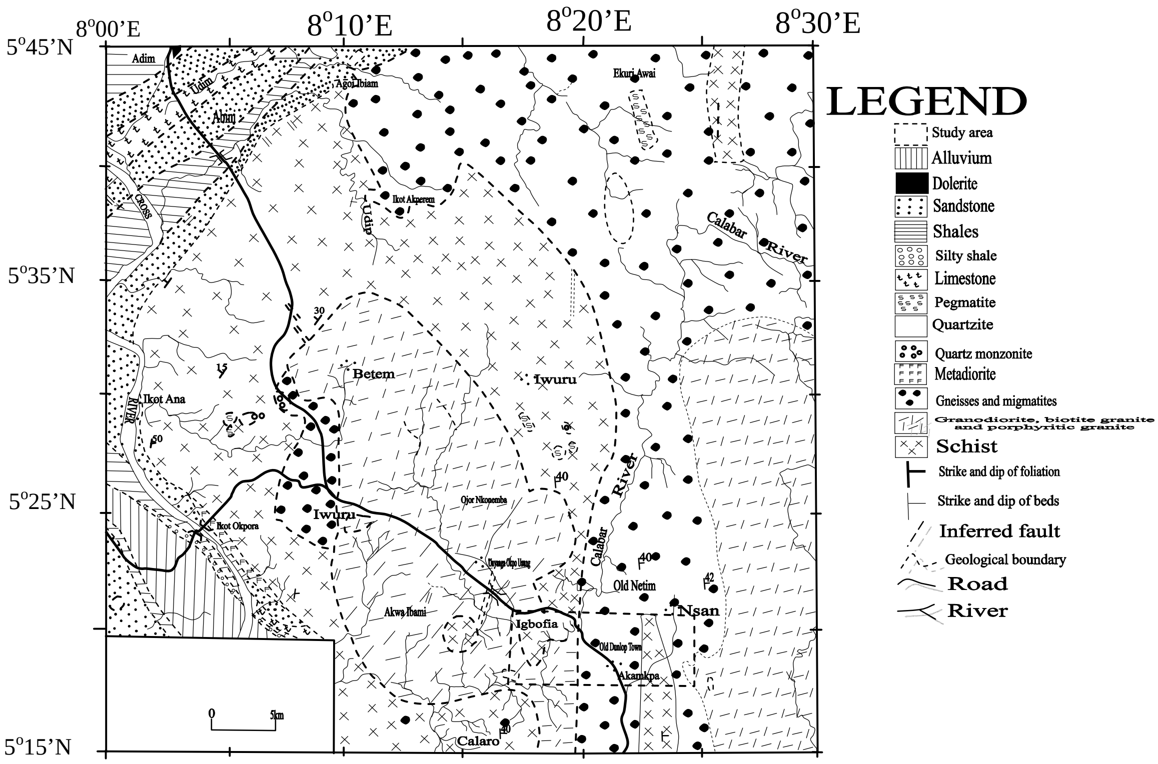

Fig. 2: Geological map of Akamkpa area of the Precambrian Oban Massif

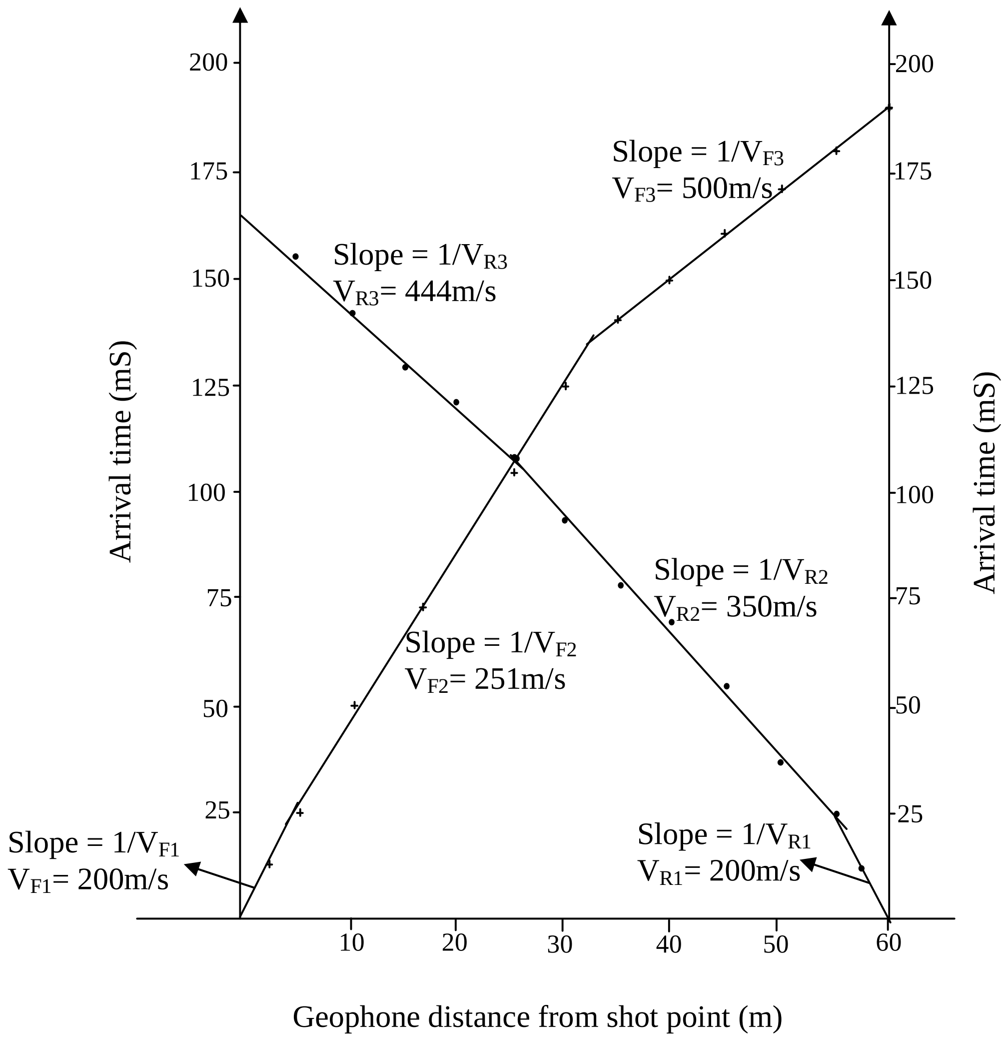

Fig. 3: S-wave Time-Offset plot for Cross River State Estate Limited

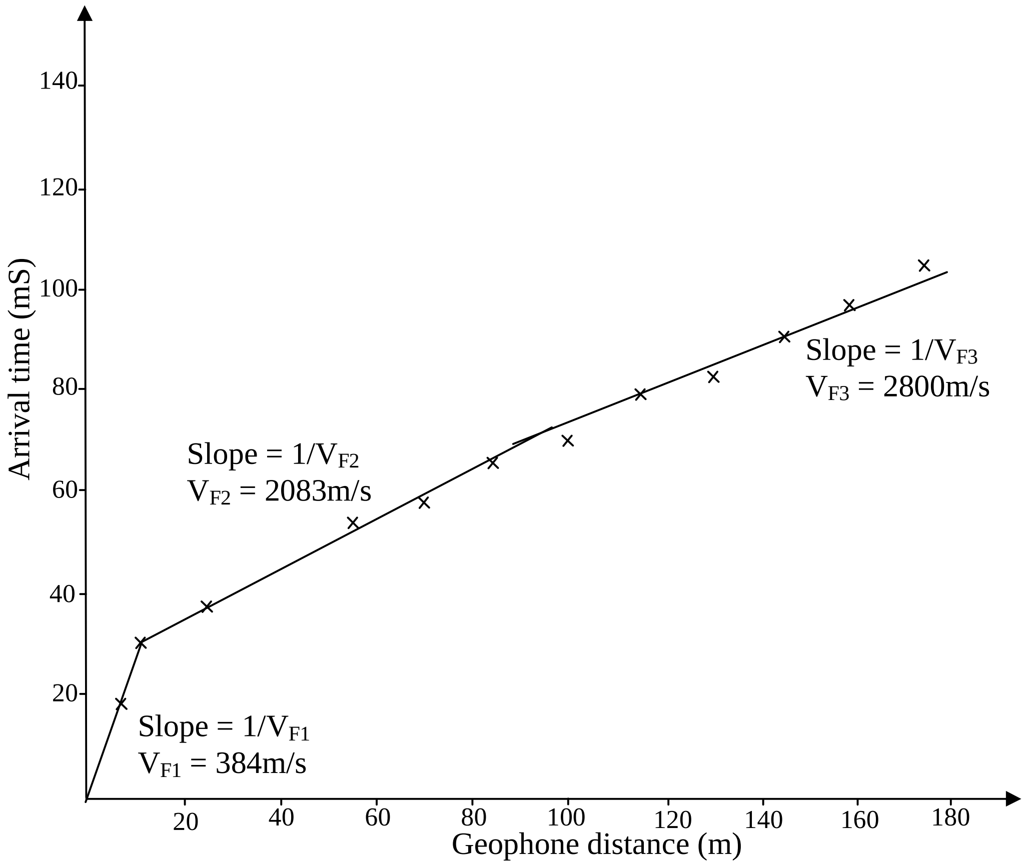

Fig. 4: P-wave time-Offset graph for Cross River Estate Limited

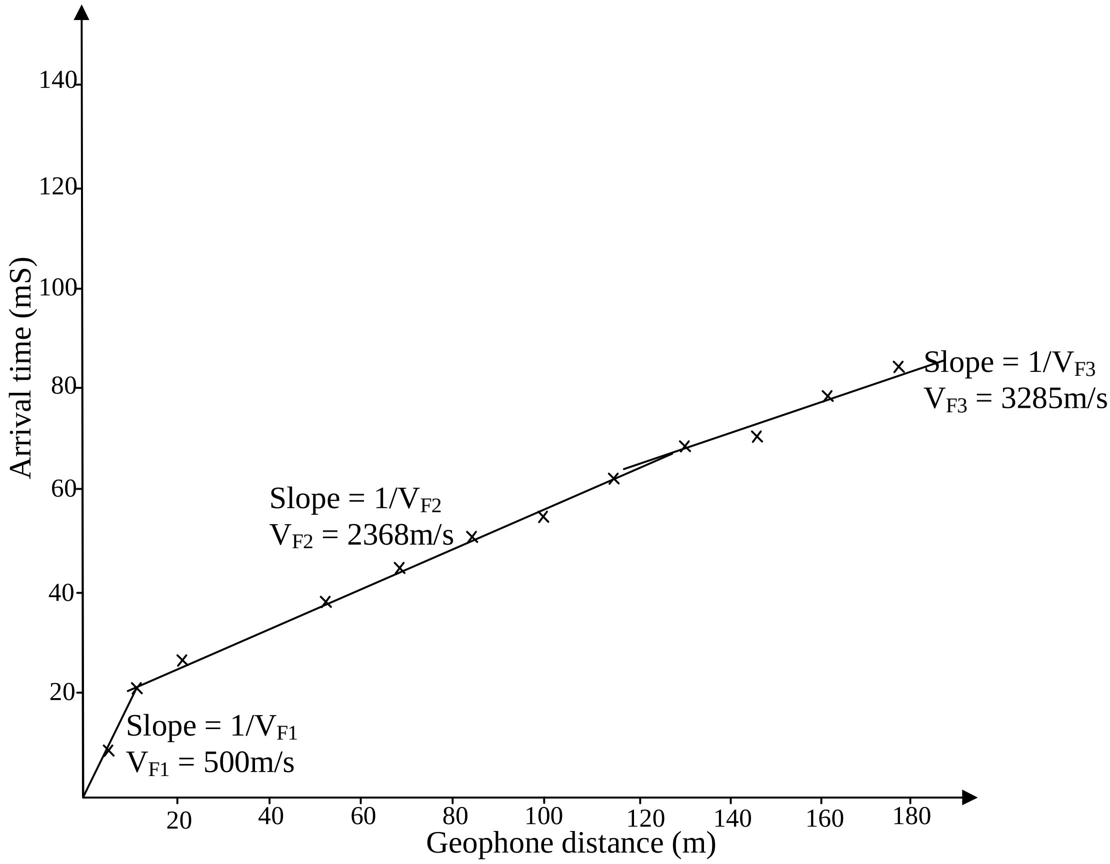

Fig. 5: S-wave Time-Offset graph for Cross River Estate Limited

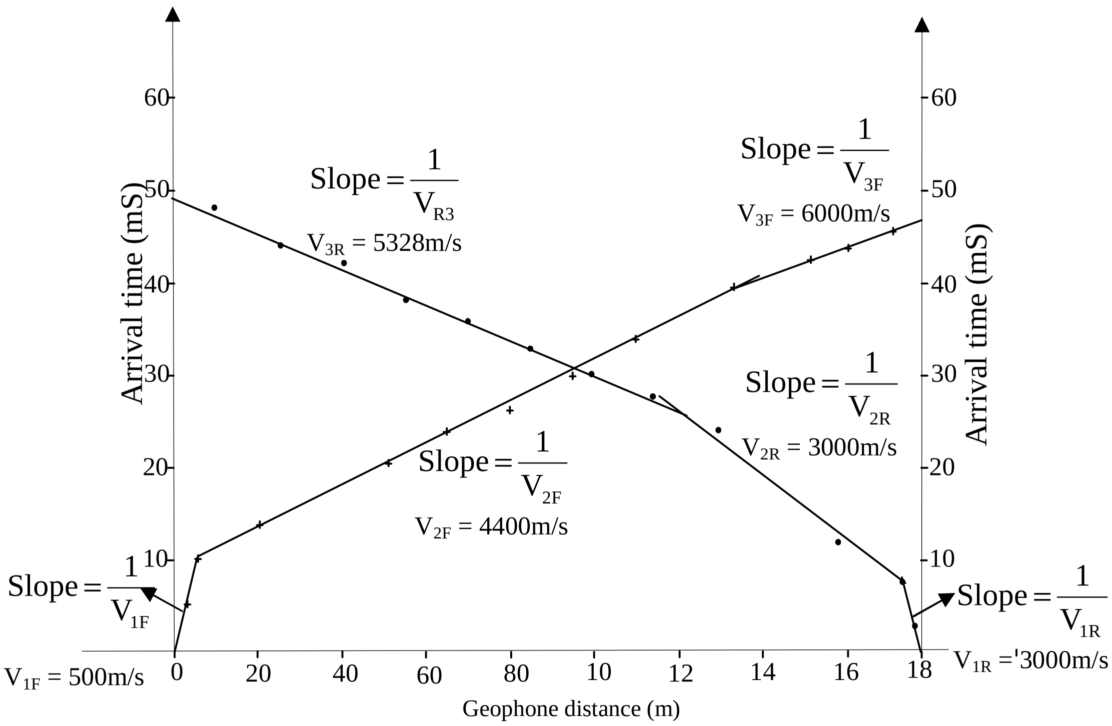

Fig. 6: P –wave Time-Offset (T-X) plot for Akamkpa Headquarters

MATERIALS AND METHODS

In this study, 12 –channel signal enhancement seismograph, geophones, sledge hammer and metal plate for generating seismic waves were used. Other accessories were measuring tape, extension cables, battery, switch and cardinal compass. The electromagnetic geophones, which were in direct contact with the earth, transformed the seismic energy generated by the source to electrical voltage, which is a function of velocity. The mechanically generated seismic disturbances sensed by the geophones were received and recorded by the seismograph cascaded with the geophones. The double seismic source in which one of them was for shear wave source and the other, the compressional wave source, has two sets of geophones for the S-wave and P-wave respectively. The geophones for P-wave and S-wave were arranged in line from the source. A sledge hammer and metal plate were used to generate seismic waves in this refraction study. A P-wave was generated when the hammer was struck vertically on the metal plate while shear wave was generated when the hammer was struck horizontally on the metal plate. A simple inertia switch attached to the handle of the hammer registered the moment of impact by closing the circuit formed between the hammer, seismograph, geophone and the ground. The generated energy penetrated into the subsurface and refracted off at various interfaces corresponding to geological boundaries and consequently returned to the surface at later time to be picked up by the geophone. The seismic wave received by the geophones was converted into electrical pulse and were amplified by the preamplifier. The part of the signal that was deemed undesirable (noise) was attenuated by frequency or intensity characteristic filter. The output, after filtration was then recorded in the form of a photographic trace of moving light spot. The recoded signal obtained is known as seismogram and it is analog Plot of the time of wave arrival against source - receiver separation. This plot was printed out from the seismograph from which arrival times were read. The refraction time-distance measurements at the surface of the ground led to the determination of V_P/V_S ratio and other physical properties of the near surface rocks. A total of two spreads at two different locations were taken. Since the rock layers beneath the ground may not be parallel as in the theoretical case, reverse profiles were taken to help determine the dip of the interface.

Seismic data analysis and Interpretation.

The field data for the two locations were analysed and interpreted to obtain for each location, the velocities for different layers, depth and the elastic properties using time- distance plots and appropriate equations which connect elastic parameters, velocities and depth/thickness as useful parameters. When time (T) read from seismograms were plotted against source – detector distance (X) for the first layer, the relationship between (T) and (X) is given as

$$T = \frac{X}{V_O} \qquad (1)$$

Equation (1) is a straight-line graph through the origin. The slope $1/v_{0,}$ shown in Figs 3-6 was evaluated to obtain the velocity of the first layer as $V_{o.}$ For the second layer velocity the equation,

$$T = \frac{X}{V_1} + 2Z_0\sqrt{\frac{V_1^2 - V_O^2}{V_1^2 V_O^2}} \qquad (2)$$

was used to determine the slope $\frac{1}{V_1}$ and the depth Z_0 of first layer. The value of V_1 was then evaluated from the slope of Figs 3, 4, 5 and 6 of the two locations for respective shear wave and P- wave velocities. For the third layer, the equation

$$T = \frac{X}{V_2} + 2Z_0\sqrt{\frac{V_2^{\ 2} - V_O^{\ 2}}{V_2^{\ 2}V_0^{\ 2}}} + 2Z_1\sqrt{\frac{V_2^{\ 2} - V_1^{\ 2}}{V_2^{\ 2}V_1^{\ 2}}} \qquad (3)$$

was used to obtain $1/v_2$ as slope and the value of v_2 which is the velocity of the third layer was worked out in the respective diagrams for shear wave and P-wave of Figs 3 – 6 in the two locations surveyed. In the spreads where forward and reverse shootings were done, the mean velocities of various layers were calculated using the equation

$$V_M = \frac{1}{2}(V_F + V_R) \qquad (4)$$

The symbols $V_{0,}$ V_1 and V_2 respectively represent velocity of the first, second and third layers and Z_O and Z_1 represent the depth of first layer and second layer respectively while V_F and V_R represent velocity of reverse and forward shootings respectively.
The summary of inferred velocities and V_P/V_S ratios for the two locations are shown in Tables 1 and 2.

Table 1: Inferred shear and p – wave velocities at the Cross River Estate Limited and their V_P/V_s ratios

Layer velocity symbol	Mean shear wave velocity (m/s)	P-wave velocity (m/s)	V_P/V_S ratio
V_O	200	384	1.9
V_1	300	2083	6.9
V_2	472	5619	5.9

Table 2: Inferred shear and P- wave velocities at the Akamkpa Headquarters and their V_P/V_S ratios

Layer velocity symbol	**Shear wave velocity in (m/s)**	**Mean P- wave velocity (m/s)**	**V_P/V_S ratio**
V_O	500	562	1.1
V_1	2368	3700	1.6
V_2	3285	5619	1.7

Table 3: values of elastic constants for the sandstone layer

Elastic constant	Magnitude and Units
ρ	2320 kg/m^3
λ	1.715X10^{10} N/m^2
μ	5.168X10^8 N/m^2
K	1.749X10^{10} N/m^2
E	7.6 40X10^8 N/m^2
σ	0.485

Table 4: Values of elastic constants obtained for the granite – gneiss layer

Elastic constant	Calculated values
ρ	2610kg/m^3
λ	2.607x10^{10}N/m^2
μ	2.817X10^{10}N/m^2
K	4.168X10^{10}N/m^2
E	1.681X10^{10}N/m^2
σ	0.240

Depth determination

Since V_o, V_1 and V_2 were known for the two locations, it was possible to determine the depth to two layers out of the three geological boundaries assessed using Figs 3-6 and their corresponding intercept time equations $2Z_O\sqrt{\frac{V_1^{\,2}-V_0^{\,2}}{V_1^{\,2}V_0^{\,2}}}$ and $2Z_O\sqrt{\frac{V_2^{\,2}-V_0^{\,2}}{V_2^{\,2}V_0^{\,2}}}+2Z_1\sqrt{\frac{V_2^{\,2}-V_2^{\,1}}{V_2^{\,2}V_1^{\,2}}}$ obtained from equations (2) and (3) above for thicknesses of first and second layers respectively. Again, for forward and reverse shooting the mean intercept time

$$T_1=\frac{1}{2}\left(T_{1F}+T_{1R}\right) \tag{5}$$

was calculated. It was possible to determine the depth Z_0 and Z_1 for the first and second layers and their corresponding thicknesses. In the first location (Cross River Estate Limited), the thickness of the first two layers was 2.0m and 6.8m respectively. Similarly for the second locations (Akampka Headquarters), the thickness of the first and the second layers were 2.0m and 21. 7m respectively. The calculated elastic properties shown in Tables 3 and 4 were done using equations 6 to 11.

$$V_S=\left(\frac{\mu}{\rho}\right)^{\frac{1}{2}}=\left(\frac{2E}{5\rho}\right)^{\frac{1}{2}} \tag{6}$$

$$\frac{V_p}{V_S}=\left(\frac{2-2\sigma}{1-2\sigma}\right)^{\frac{1}{2}}=\left(\frac{K}{\mu}+\frac{4}{3}\right)^{\frac{1}{2}} \tag{7}$$

$$V_P = \left(\frac{\lambda + 2\mu}{\rho}\right)^{\frac{1}{2}} = \left(\frac{K + \frac{4}{3}\mu}{\rho}\right)^{\frac{1}{2}} \quad (8)$$

$$\mu = \frac{E}{2(1+\sigma)} \quad (9)$$

$$K = \frac{5}{3}\mu \quad (10)$$

$$\lambda = \frac{E\sigma}{(1+\sigma)(1-2\sigma)} \quad (11)$$

where λ = Lame's constant, μ = rigidity modulus (Lame's constant), ρ = average density of rock, k= bulk modulus, E = Young's modulus, σ = Poisson's ratio, V_p = p – wave velocity and V_s = shear wave velocity. With the mean density of probable geologic layer identified using velocity information for each of the locations, it was possible to determine the elastic properties such as rigidity modulus (μ), Young's modulus (E), Poisson's ratio (σ), Bulk modulus (K) and one of the Lame's coefficient (λ) for locations 1 and 2. The results are summarized in Tables 3 and 4.

The interpretation done so far was principally aided by the comparison of evaluated compressional and shear wave velocities shown in tables 1 and 2 with the theoretical compressional and shear wave velocities shown in Table 5.

Table 5: Compressional and shear velocities in rocks (After [2] and [4])

Geologic material	V_p (m/s)	V_s(m/s)
Granite	5520-5640	2870-3230
Sandstone	1400-4300	-
Limestone	1700-4200	-
Clay	1100-2500	-
Loose sand	1800	500
Sandy clay	360-430	-
Sand with gravel (dry)	430-690	-
Sand with gravel (wet)	690-1150	-
Coarse gravel (wet)	1150-1670	-

DISCUSSION

By comparing the inferred velocity results in tables 1 and 2 with theoretical velocity in Table 5, it is possible to deduce that Cross River Estate Limited (CREL) is characterized with weathered surface material with P- wave velocity of 384m/s and thickness of 2.0m. The second layer is probably reminiscent of sand- clay sequence with velocity of 2083m/s and thickness of 6.8m. It has been observed that clay or sand with P-wave velocity of 1100m/s - 2500m/s has a V_P/V_S

ratio of the range between 2.08 and 8.5 [10]. The field determined V_P/V_S value for this layer is 6.9, which suggests more presence of clay than sand. For most rocks of the earth's surface, the poison's ratio is of the order of 0.25 [4]. For a perfect fluid, the Poisson's ratio is 0.5[11]. The Poisson's ratio for the third layer is 0.485 with a velocity of 2800m/s. This probably suggests that the third layer is saturated sandstone since the P-wave velocity is within the range of sandstone and the Poisson's ratio is almost that of a perfect fluid. The determination of the thickness for the third layer was not possible because the velocity of fourth layer was not known within the seismic energy available for use. The investigation of the Akamkpa Headquarters shows that the first layer with velocity 562m/s and thickness of 2ms is probably weathered surface material. The second layer is probably sandstone with velocity of 3700m/s and thickness of 21.7m.The third layer was probably granite with velocity of 5619m/s. The thickness was not possible because the seismic source could not generate large enough energy that could make the evaluation of the fourth layer velocity possible.

The results of the measurements in the two locations seem to agree with the nature of the subsurface material. As it is evident in the interpretation of seismic refraction, one is confronted with the inverse problem of calculating and inferring velocities and depths from measured travel time obtained from the seismograms. Since seismic investigations are carried out with the aim of finding the position of the interfaces between media of different velocities, the values of these velocities in different media should be known. These velocities are needed in the interpretation process because they also furnish information about the nature of rocks. It is difficult from measurement of velocity alone to determine the type of lithologic compositions underneath, since two different materials may have overlapping values of velocities. However, with the knowledge of the elastic properties of different rock samples coupled with their velocities, it is possible to deduce the type of geological formation underneath with a small percentage error.

Table 5 shows the theoretical values of the compressional and shear wave velocities in different types of rocks. It is important to note that the values of velocities given in table 5 may vary because of the differences in facies of the individual strata and structural history. Moreover, the velocity of seismic wave increases with depth and this is symptomatic of the combined effect of changes in terms of progressive compaction and cementation. The V_P/V_S ratio for a particular area derived from travel time measurements on vertical and radial component velocity data is reasonably robust and relatively sensitive to lithology of interstitial fluid [12, 13]. Beyond the determination of the lithologic compositions of the study areas using the measured P-wave and S-wave velocities, the elastic properties of the rocks in the shallow depths investigated were also determined and these properties are summarized in tables 3 and 4 for the basement rocks deciphered. The characterization of the area shallow geologic basement – the surface beneath which no sedimentary rocks are found, in terms of the elastic properties and V_P/V_S ratio is not only instrumental to research advances in the area, but also significant for the economic potential of the underneath geology which promotes quarrying activities for the continued sophisticated construction works within the geographical area and outside its environs.

CONCLUSION

The evaluation of V_P/V_S ratio derived from the travel time measurement of vertical and radial components velocity data is a robust procedure for the determination of the elastic parameters of the rock samples deciphered in the two locations of the study area. This rare study in the area has enabled the values of the elastic constants of the rocks to be evaluated. The depths and thicknesses of the basement rocks within the capacity of the seismic source energy used in the work have equally been evaluated. It is therefore quite not inconclusive to say that the area has a broadened economic potential as the basement rocks can be commercially quarried and used as raw materials by construction companies. These highly folded sandstone and granite identified in the study area can be used for consolidation of the surface roads under load and the reinforcement of the building foundations. The basement rocks identified support piling works, the construction of bridges and flyovers that can withstand the load of the modern and sophisticated vehicles used in our roads need hardened foundations reinforced with such rocks. The broader view of the qualitative and quantitative properties of rocks beneath the area will be very useful to the civil engineers who might want to exploit the natural resources of the area.

REFERENCES

[1] Sheriff, E. R. Encyclopedia Dictionary of Exploration Geophysics society of exploration Geophysics, 3rd ed **1991**.

[2] Dorbrin, M. B., Introduction to Geophysical Prospecting, International ed. Mc Graw Books Company, **1981**.

[3] Kearey P, and Brooks, M. Introduction to Geophysical Exploration. London Black Well Scientific Publication, **1991**.

[4] Griffiths, D. H. and King R. E., Applied Geophysics for Engineers and Geologist. Oxford, Pergamon Press, **1981**.

[5] Owoyemi, E. B; Okokie, E. C; Atakpo, E. A, Engineering Geophysical Investigation of Road failure in parts of Western Niger Delta, *Nigerian Journal of Physics*, **2002**.

[6] George N. J, Akpabio, G. T. and Evans, U.F. *International Journal of Environmental Studies*, **2008**, 3(1) 17-26

[7] George, N. J, Akpan, A. E; Obot, I. B and Akpanetuk, N. J, *Indian Journal of Disaster Advances*, **2008** 1 (4) 46-51.

[8] Shemang, E. M, Ajayi; C. O and Ozazunwa, I. B, *Journal of Mining and Geology*, **1992**, 28, 119-124

[9] Ekweme, B. N and Onyeagocha C. A., Nigerian *Journal of African Earth's Science*, **1985** 3 (1), 17-26.

[10] Lecky J., Seismic retraction and electrical resistivity surveys of the University of Calabar, unpublished disertation, University of Calabar, Calabar Southern-eastern Nigeria, **1981**

[11] Runcorn, S. K.; International Dictionary of Geophysics, pergamon press, London, **1967**, Vol. 2.

[12] Kanli, A. I, Journal of Applied Geophysics, **2009**, 67, 52 – 62

[13] Zhang, D. A and Lines L. R, *Journal of Society of exploration Geophysics*, **2006**, 25 (6) 674-792