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Seismic Early Warning Foundation Conditions Evaluation Survey for Civil Engineering Constructions in Akpabuyo Local Government Area of Cross River State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Seismic refraction method was used to study the rock/soil conditions for civil engineering construction in Akpabuyo Local Government Area in Cross River State, Nigeria. Akpabuyo was chosen for this research because it is a rural countryside with high potentials of future rapid increase in developmental activities due to its closeness to the State capital. The aim is to provide information on foundation materials, which would serve as an early warning data base for avoiding sites that are vulnerable to structural failures. This approach is in contradistinction to the conventional approach which seeks to find solutions to structural failures when the damage has already been done. The results of the survey show that soil/rock in most parts of the study area have good engineering strength and are suitable for the construction of civil engineering works. A few of the locations are suspected to be vulnerable to structural failure under high stress conditions, due to the anomalous

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values of their elastic constants, hence should be avoided if possible, otherwise detailed investigations should be carried out before any significant civil engineering work is sited there.

Keywords: Seismic refraction; early warning; elastic parameters; foundation material; engineering strength.

1. INTRODUCTION

The determination of rock/soil condition for civil engineering construction has gained increasing importance in recent years as this is attributed to the recognition of the importance of geological structure in virtually all aspects of engineering concerned with excavation of material or selection of sites for dams, houses, roads and other civil engineering works [1]. Seismic refraction method is the geophysical technique frequently used to assess the strength of a formation or interface as a foundation material in engineering works such as construction of dams, high rise buildings and highways [2,3]. In the building/construction industry, elastic behaviour of rocks and their characteristics have been extensively used to test the bearing strength of foundation material prior to construction work [4]. The frequency of building collapse in Nigeria in recent past has become a major issue and the magnitude of the losses being recorded in terms of lives and properties are becoming worrisome and alarming [5].

Hence, a fair knowledge of the lateral changes in the strength of foundation materials at Akpabuyo, will without doubt help town planners in avoiding the location of civil engineering structures in sites where they would be vulnerable to structural failure. Akpabuyo is an underdeveloped countryside which is expected to open up very rapidly because of its nearness to the capital city, Calabar, which is now experiencing congestion. Thus, mitigating civil engineering construction failures and the attendant cost of repairs and rehabilitations, which would have resulted if expected upcoming structures are erected on avoidable places with poor foundation conditions, is the goal of this research. Consequently, this work is based on the determination of elastic properties of rock/soil in Akpabuyo L.G.A using seismic refraction method, so as to assess the rock strength and also provide useful early warning information on the relative strength of foundation materials, for the purpose of avoiding vulnerable sites in the process of planning and location of relevant civil engineering structures.

Useful relation usually used for describing and characterizing the elastic nature of the earth is the stress-strain relation [6,7,3]. A stress applied to the surface of a body tends to change the size and shape of the body. The external stress gives rise to opposing forces within the body. The ability to resist deformation and the tendency of the body to restore itself to the original size and shape defines the elasticity of a particular material [8,9]. A perfectly elastic body is one that recovers completely after being deformed [9,10].

In seismic refraction prospecting, artificially induced seismic waves propagate through the earth with different velocities depending on the elastic parameters of the rocks through which they travel [11]. At layer boundaries, the waves incident at critical angles are refracted and travel along the boundaries in accordance with Huygen’s principle. These headwaves travel to the surface at the same critical angles as their initial incidence at the layer boundary for a horizontal, homogenous and isotropic situation [12]. The total travel time of these waves between the source and the various receivers gives information on the seismic velocities and depths of sub-surface formations along which they propagate. However, the refraction method is feasible only when formation velocities increase with depth otherwise no headwave can be generated [12]. The higher the velocity-contrast between adjacent layers, the more distinct the delineation of their boundary will be [13,14].

When the mode of propagation of both the compressional and Shear waves and their analysis are used along the same profile, a better evaluation of the elastic parameters of rocks through which they travel is obtained [15-17,10]. The determination of elastic parameters such as Poisson’s ratio (σ), Shear modulus (μ), Young’s modulus (E) Bulk modulus (K), Lame’s constant (λ) and density (ρ) is important for the study of how susceptible a particular region is to stress.

The general trend in developed and even developing countries is to use various methods depending on what is available and considered useful by the investigator(s) to assess the causes of road failures and collapse of civil engineering structures. In highway construction works, the different layers of the pavement are compacted to reduce void ratio and achieve optimum density, thereby making the material more stable. These efforts are routinely carried out during the repairs and rehabilitation of urban and inter-city roads, however, in Akpabuyo there are still vast areas of land that are yet to have modern intra-city roads, intercity highways and huge civil engineering structures for commerce and industry.

In Nigeria where this investigation took place, the economy is growing pretty fast and there is the need for Local, State and Federal Governments in partnership with the private sector to open up more villages through the construction of huge residential and commercial buildings, industries, highways, bridges, etc. The Federal Road Management Agency (FERMA) is engaged in an ongoing program for the rehabilitation of old or failed pavements, while new highways are being constructed to meet the ever growing demand for motor-able roads. Electrical methods were used by some researchers to study the subgrade in response to pavement failure. These researchers were able to qualitatively map clay/sandy clay soil, exhibiting low resistivity (highly porous) in the failed sections of the highways [18,19,20]. Seismic refraction, P-wave reflection, resistivity, gravity, and ground penetrating radar (GPR) were used in identifying potential collapse features under highways in Jackson County, Vinton County, and Perry County, all in Ohio, USA [21]. Seismic refraction and surface waves methods (refraction microtremor (ReMi) [22]) were used to characterize and investigate a major road failure in some sections of highway NM 128 near Carlsbad, New Mexico, USA [23]. Also, Miller et al. [24] used GPR, induced polarization, and falling weight deflectometer (FWD) to investigate road subsidence along highways I-89, Hartford, New Hampshire and US-7 Bypass, Manchester, Vermont, USA.

A high rise building with pile-raft foundation suddenly experienced extraordinary settlements and seriously tilted after 6 years of use in Wenzhou, a city in southern China and the result of investigations conducted to determine the cause of the distress indicated that the inadequate bearing capacity of the pile foundation was the reason for the extraordinary settlement [25]. The majority of damage attributable to collapsible soils likely involves much less visible low rise buildings and homes for which damage costs are rarely summarized [26]. The cost of remedial measures required to repair structures at a cement plant in central Utah located on collapsible soil was more than $20,000,000 [27].

Most of the efforts and the attendant costs, exemplified by the surveys above and many others not mentioned for want of space, would have been saved if there were early warning foundation condition survey results available to town, state and national planners and decision makers during the formative stages of the planning of the aforementioned highways and buildings.

1.1 Location and Geology of the Study Area

Akpabuyo Local Government Area which is part of Cross River State is located between latitude 4º 05ꞌ N and 5º 40ꞌ N and longitude 8º 25ꞌ E and 8º 32ꞌ E (Fig. 1). It lies within the vegetation belt of southern Nigeria and shares the Atlantic coastline with Bakassi and the Republic of Cameroun to the West. The study area measures approximately 28.5 square kilometers.

The geology of the study area is coastal plain sands otherwise referred to as Benin formation, which comprises sediments whose age is from tertiary to recent [28]. The Benin formation consists of predominantly coastal sediments which are essentially sand, sandstone, siltstone, minor clay lenses and the lignite formation which consists essentially of shale, mudstone, clay and lignite series. They are strongly weathered and are characterized by coarse to fine sand texture in the surface to subsurface soils [29].

2. MATERIALS AND METHODS

The seismic refraction data were collected by using ABEM Terraloc MK6 multi-channel digital enhancement seismograph with internal storage capacity of 2.0 GB, 10 Hz P-wave and S-wave geophones, 9 Kg sledge hammer and 2.54 by 15 by 15 cm steal base plate. Other components were measuring tape, extension cables, 12 V car battery, switch and GERMIN Montana 650t Global Positioning System (GPS). The sledge hammer in addition to the metal striking plate makes up the seismic source. Seismic waves were transformed into electrical voltage by the electromagnetic geophones, which are the units in direct contact with the earth. This signal was received and recorded by the seismograph. The

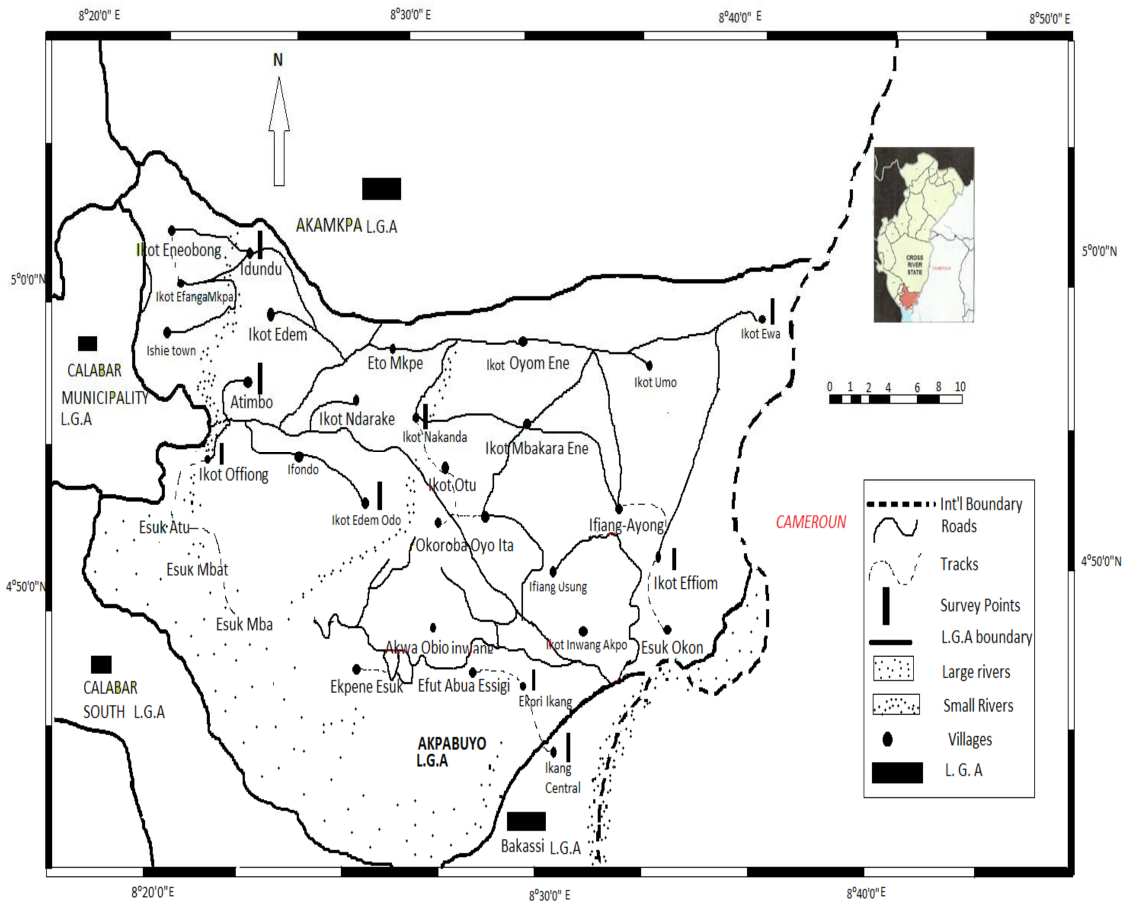

Fig. 1. Location of Akpabuyo local government area, cross river state

in-line profiling arrangement was used throughout. The geophones for p-wave and s-wave were both arranged in an in-line pattern from the source. For p-wave to be generated, the hammer was struck vertically on the metal plate. Also, the hammer was struck horizontally on the metal plate to generate s-wave, the direction of strike being perpendicular to the line of profile. Reverse profiles were taken to enable the determination of a more reliable refractor velocity.

A total of ten seismic refraction profiles were completed in ten communities. The length of each profile line was 60 meters with geophones inter-spaced by 5 meters. To reduce noise and improve the data quality in each shot, the traverses were sited at locations that are free from road traffic noise and other seismic noise.

2.1 Data Analysis

The field data was analyzed by picking the first arrival time from the seismogram with the help of Pickwin Computer Software Version 4.2.0.0. The time (T) was plotted against source detector distance (X) for the different locations using IX Refrax Computer Software Version 1.14. These graphs also known as T-X plots were plotted for P-waves and S-waves. From the graphs, the inverse of the slope were obtained as velocity shown in Table 1 and the depths were calculated for each of the layers, based on the intercept time method (Palmer [30]). The common elastic parameters which include Poisson's ratio (σ), Shear modulus (μ), Bulk modulus (K), Young's modulus (E) and Lame's constant (λ) are related to the seismic wave velocities Vp and Vs by the following equations [31]:

$$V_p = \left[\frac{\lambda+2\mu}{\rho}\right]^{1/2} = \left[\frac{K+\frac{4\mu}{3}}{\rho}\right]^{1/2} \quad (1)$$

$$V_s = \left[\frac{\mu}{\rho}\right]^{1/2} = \left[\frac{3kE}{(9k-E)\rho}\right]^{1/2} \quad (2)$$

$$\frac{V_p}{V_s} = \left[\frac{2-2\sigma}{1-2\sigma}\right]^{½} = \left[\frac{K}{\mu} + \frac{4}{3}\right]^{½} \quad (3)$$

The values of Poisson's ratio, σ, Shear modulus, μ, Bulk modulus, K, Young's modulus, E, and Lamé lambda constant, λ, for rock/soil constituting various subsurface formations within the study area were calculated using the following relations [31]:

$$\sigma = \left[\frac{V_\rho^2 - 2V_s^2}{2(V_p^2 - V_s^2)}\right] \quad (4)$$

$$\mu = [\rho V_s^2] \quad (5)$$

$$E = 2\mu[1+\sigma] \quad (6)$$

$$K = \left[\frac{E}{(1-2\sigma)}\right] \quad (7)$$

$$\lambda = \left[\frac{E\sigma}{(1+\sigma)(1-2\sigma)}\right] \quad (8)$$

where ρ = density.

These calculations were done using average value of density of sedimentary rock that is, 2,670kg/m^3 [32]. The summary of elastic parameters at the various locations where the survey took place are presented in Table 2. The data reported in Table 3 were derived by the 1xRefrax software.

The average depth to the refractor in almost all the locations surveyed indicates that the overburden thickness is significant, hence the few areas that are deemed to be vulnerable should be avoided in the construction of structures of significant foundation condition implications. This is due to the attendant high extra cost of chemical treatment, compaction or excavation and replacement involved in the preparation of vulnerable soils of significant thickness for construction purposes. Indeed, there is a limit to the thickness of a soil layer that can be compacted throughout, usually about 9 inches of loose soil per layer unless very heavy equipment with long wedge penetration is used [33].

It is also noted that development in terms of gigantic civil engineering works are almost non-existent in the communities within the survey area, due mostly to scarcity of resources, hence common sense dictates that new structures to be provided in these communities should be located where their structural safety could be guaranteed. Building on vulnerable soils/rocks which involves initial activities like soil treatment, compaction, etc and control activities involving frequent repairs and maintenance, are considered beyond the very scarce resources of government, thus it should be avoided except where it is inevitable.

Table 1. Seismic wave velocities at various locations within the study area

Location	Layer one		Layer two					
	Compresional wave velocity (ms^{-1})	Shear wave velocity (ms^{-1})	Compresional wave velocity (ms^{-1})			Shear wave velocity (ms^{-1})		
	V_1	V_1	V_d	Vu	V_2	V_d	V_u	V_2
Ikot Offiong	447	266	608	610	609	354	412	383
Ikot Edem Odo	402	223	500	633	567	306	314	310
Ikot Ewa	386	222	459	516	488	267	355	310
Ekpene	435	269	547	569	558	297	391	344
Ekpiri Ikang	367	220	677	1469	1073	453	484	469
Ikot Effiom	349	242	613	708	661	346	351	349
Ikang Central	465	264	538	600	569	307	394	351
Idundu	496	285	658	671	665	307	491	399
Atimbo	449	221	903	1209	1056	431	983	707
Ikot Nakanda	353	221	533	615	574	373	373	373

Table 2. Summary of elastic parameters at various locations within the study area

Location	Elastic constants of each layer											
	Poisson's ratio (σ)		Shear modulus, μ (x 10^8 Nm^{-2})		Young's modulus, E (x 10^8 Nm^{-2})		Bulk modulus, K (x $10^8 Nm^{-2}$)		Lamé lambda constant, λ (x 10^8 Nm^{-2})		V_p/V_s	
	Layer 1	Layer 2	Layer 1	Layer 2	Layer 1	Layer 2	Layer 1	Layer 2	Layer 1	Layer 2	Layer 1	Layer 2
Ikot Offiong	0.23	0.17	1.89	3.92	4.64	9.17	2.75	4.63	1.61	2.02	1.68	1.59
Ikot Edem Odo	0.28	0.29	1.33	2.57	3.41	3.28	2.58	5.26	1.17	3.55	1.80	1.83
Ikot Ewa	0.25	0.16	1.31	2.58	3.28	5.99	2.19	2.94	1.31	1.22	1.74	1.57
Ekpene	0.20	0.19	1.93	3.16	4.63	7.52	2.57	4.04	1.29	1.94	1.62	1.62
Ekpri Ikang	0.22	0.38	1.29	5.87	3.15	16.20	1.88	22.50	1.01	18.58	1.67	2.29
Ikot Effiom	0.16	0.31	3.06	3.25	3.06	8.52	1.22	7.47	0.62	5.31	1.44	1.89
Ikang Central	0.26	0.19	1.86	3.29	4.68	7.83	3.25	4.21	2.01	2.02	1.76	1.62
Idundu	0.25	0.22	2.17	4.25	5.43	10.40	3.62	6.19	2.17	3.35	1.74	1.67
Atimbo	0.16	0.10	2.16	13.30	5.01	29.30	2.46	12.22	1.02	3.33	1.58	1.49
Ikot Nakanda	0.17	0.14	1.30	3.71	3.04	8.46	1.54	3.92	0.66	1.44	1.60	1.54

Table 3. Depth to refractor generated from the P-wave data

Location	Depth to refractor	
	Down dip depth Z_d (m)	Up dip depth Z_u (m)
Ikot Offiong	4.1	5.3
Ikot Edem Odo	4.1	10.7
Ikot Ewa	4.0	4.2
Ekpene	2.9	8.3
Ekpiri Ikang	4.0	6.3
Ikot Effiom	9.4	11.0
Ikang Central	6.9	12.3
Idundu	2.2	5.1
Atimbo	7.3	12.1
Ikot Nakanda	5.2	6.0

3. RESULTS AND DISCUSSION

The results show that Poisson's ratio ranged from 0.16 to 0.28 for the first layer and 0.10 to 0.31 for the second layer. These low values of Poisson's ratio in principle indicate that the materials here are very good as foundation materials. The Poisson ratio distributions in the first two layers of the study area are shown in Figs. 2(a) and (b). The area between latitudes 4.93º and 5.02º and longitudes 8.40º and 8.52º have considerably low Poisson's ratio for both the first and second layers indicating fairly high level of consolidation, hence the foundation condition is good, except at Ekpiri Ikang and Ikot Effiom where the first layers gave lower Poisson ratios than that of the second layers. This suggests that the second layers though of higher densities, are less consolidated.

Shear modulus for the first layer ranges from 1.29 x 10^8 N/m^2 to 3.06 x 10^8 N/m^2. The second layer has Shear modulus which varies from 2.57 x 10^8 N/m^2 to 13.30 x 10^8 N/m^2. Figs. 3(a) and (b) show the contour map distributions of Shear modulus in layers one and two. The resistance to Shear at the South Western and Eastern axes of the study area is relatively high for the two layers. These areas would express higher resistance to Shearing Stress, while the central region would express less resistance to Shear. There is however, elements of both lateral and vertical in-homogeneity in Shear modulus of the rocks within the study area. This attribute which signifies non-homogeneity may endanger pavement integrity, though the general foundation condition is good.

Young's modulus for the first layer ranges from a minimum of 3.04 x 10^8 N/m^2 to a maximum value of 5.43 x 10^8 N/m^2. The second layer has minimum value of Young's modulus of 3.28 x 10^8 N/m^2 and a maximum value of 29.30 x 10^8 N/m^2. The contour distribution of Young's modulus in the study area for layer one and layer two is shown in Figs. 4(a) and (b), respectively. The map of the distribution of Young's modulus in the study area is quite similar to that of Shear modulus which is expected. The high values of Young's modulus across the study area qualify the rock/soil to be likely good foundation materials.

Bulk modulus ranges from 1.22 x 10^8 N/m^2 to 3.62 x 10^8 N/m^2 for the first layer and 2.94 x 10^8 N/m^2 to 22.50 x 10^8 N/m^2 for the second layer. The contour map distributions of Bulk modulus in Figs. 5(a) and (b) show peak at the North Eastern boundary of the study area for the two layers, but the central region indicates vertical variations, with the first layer having higher values. This tendency of the first layer showing better foundation attributes than the second layer in some sites is considered not a good foundation layers configuration, especially for big high rise buildings and highways that are intended to service heavy duty trailers. This assertion is base on the premise that Bulk modulus is the material resistance to a change in volume when subjected to a load [34].

The values of the Lamé lambda constant ranges from 0.62 x 10^8 N/m^2 to 2.17 x 10^8 N/m^2 for the first layer . The second layer has Lamé lambda constant values which ranges from 1.22 x 10^8 N/m^2 to 18.58 x 10^8 N/m^2. The Lamé lambda constant has no simply physical meaning [34], but it is sometimes referred to as fluid incompressibility (Sheriff [31]). The contour map of Lamé lambda constant is shown in Figs. 6(a) and (b) for layers 1 and 2, respectively. Areas of higher peaks reflect high levels of fluid incompressibility. The area around latitude 4.88° and longitude 8.47° have relatively low values of Lame's constant for the two layers. Again, there is evidence of lateral and vertical in-homogeneity in the distribution of Lame's constant in both layers.

The V_p/V_s ratio for the first layer ranges from 1.44 to 1.80. The values for the second layer varies from 1.49 to 2.29. In Figs. 7(a) and (b), the V_p/V_s ratios are found to vary more laterally than vertically. However, the lateral variation is less rapid. The high values of V_p/V_s ratio is an indication that the rock/soil in most parts of the study area have high percentage of water saturation.

At all the sites investigated except for Ekpri Ikang area, E>K>μ. Since the deviation from this usual hierarchy of magnitude of elastic constants, occurred at only one location, i.e. at Ekpiri Ikang, reasons other than quality of data collected at the study area were considered responsible for the anomaly. It is considered that the Ekpiri Ikang case resulted from a combination of geologic factors like lateral inhomogeneity and intercalation of clay lenses and boulders, which are noticeable in an excavation site within the area. Hence Ekpiri Ikang may require a more detailed investigation of the integrity of the foundation rocks based on the delay-time method of interpretation, because the various schemes based on the use of delay times are less susceptible to the difficulties encountered when we use the intercept time method with refractors that are curved or irregular [12]. In order to make a good appraisal of the study area the distribution pattern of elastic parameters of the first two layers of soil formation were analyzed. The surfer software was used to show the contour distribution of the relevant elastic constants.

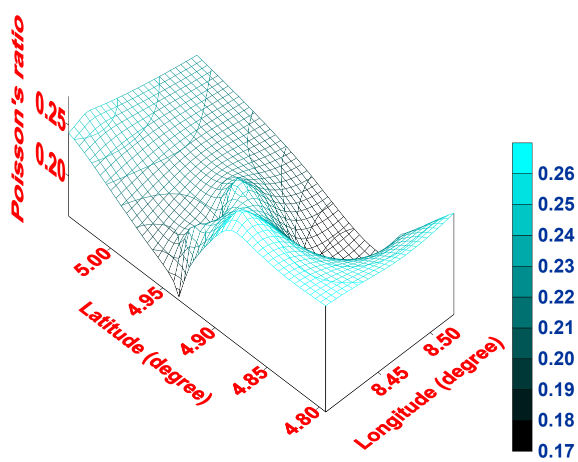

Fig. 2a. Contour map distribution of poisson's ratio for layer one of the study area

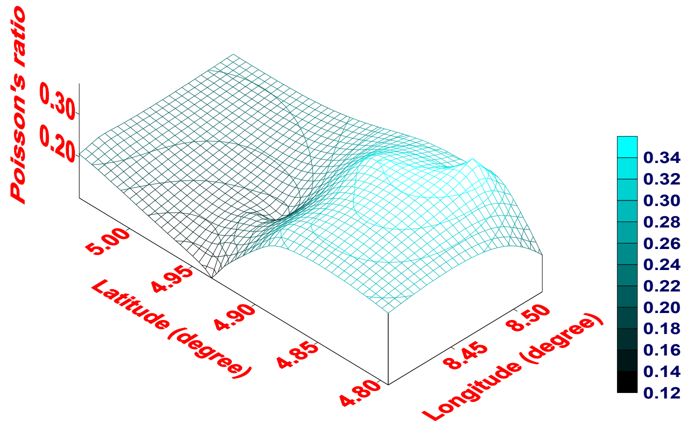

Fig. 2b. Contour map distribution of poisson's ratio for layer two of the study area

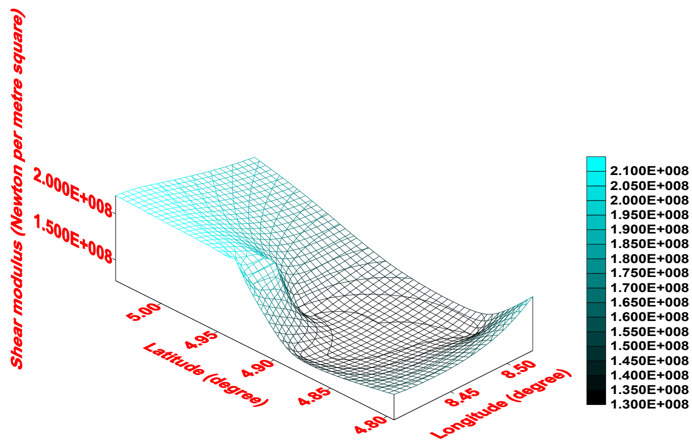

Fig. 3a. Contour map distribution of shear modulus for layer one of the study area

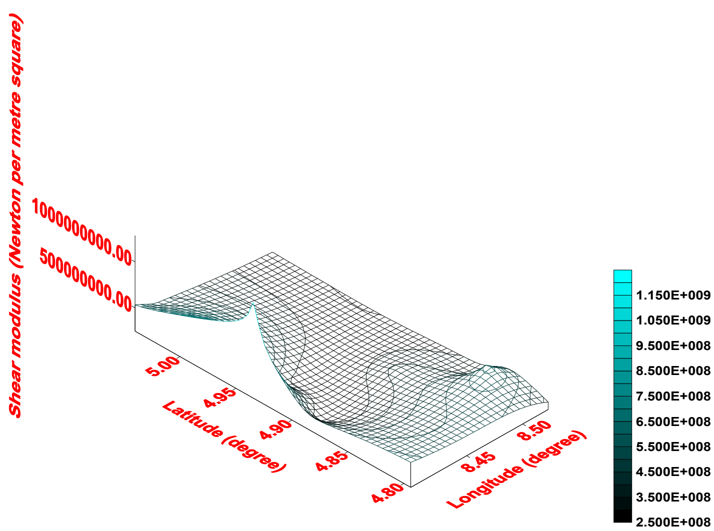

Fig. 3b. Contour map distribution of shear modulus for layer two of the study area

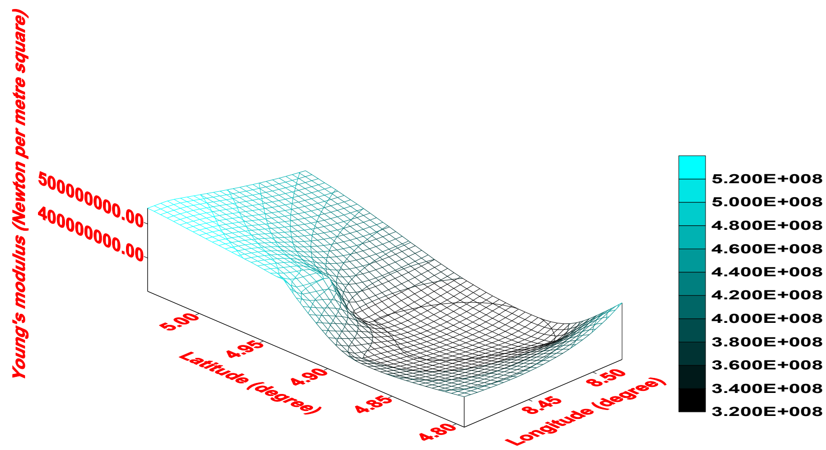

Fig. 4a. Contour map distribution of young's modulus for layer one of the study area

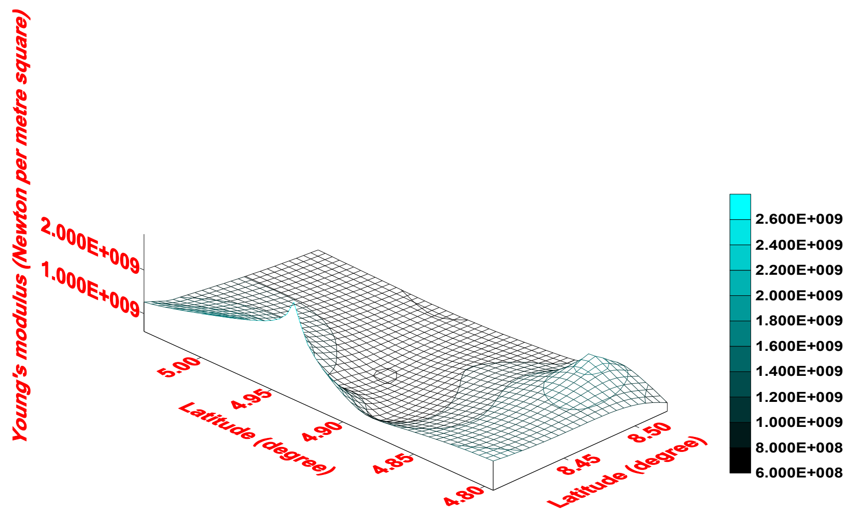

Fig. 4b. Contour map distribution of young's modulus for layer two of the study area

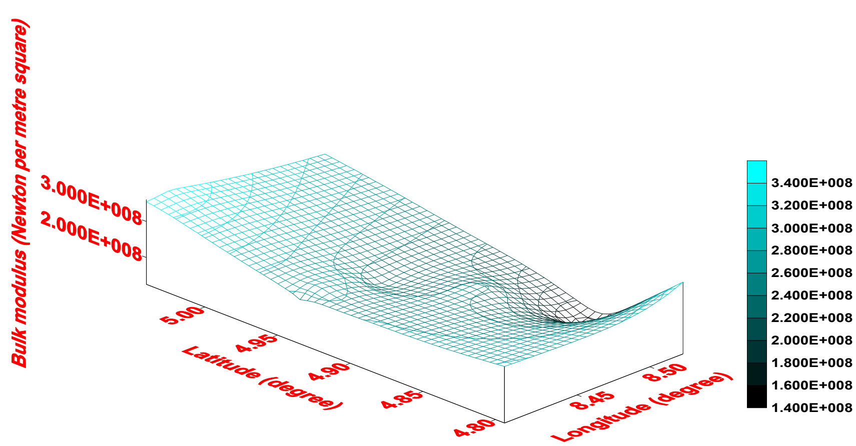

Fig. 5a. Contour map distribution of Bulk modulus for layer one of the study area

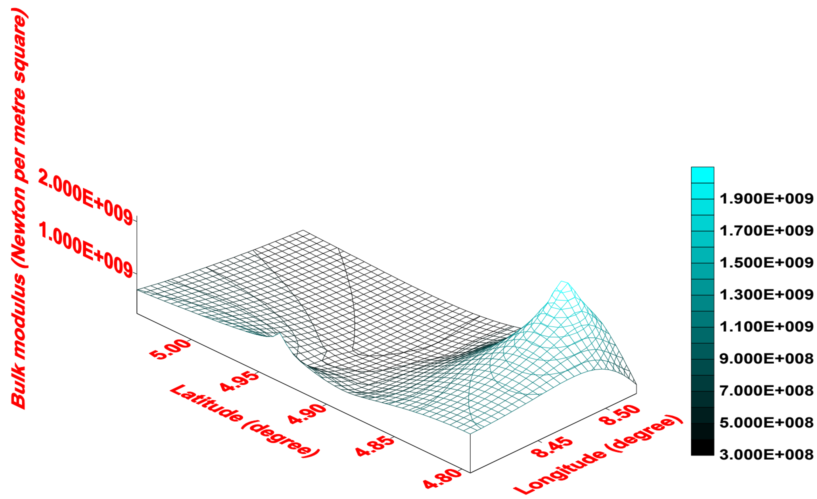

Fig. 5b. Contour map distribution of bulk modulus for layer two of the study area

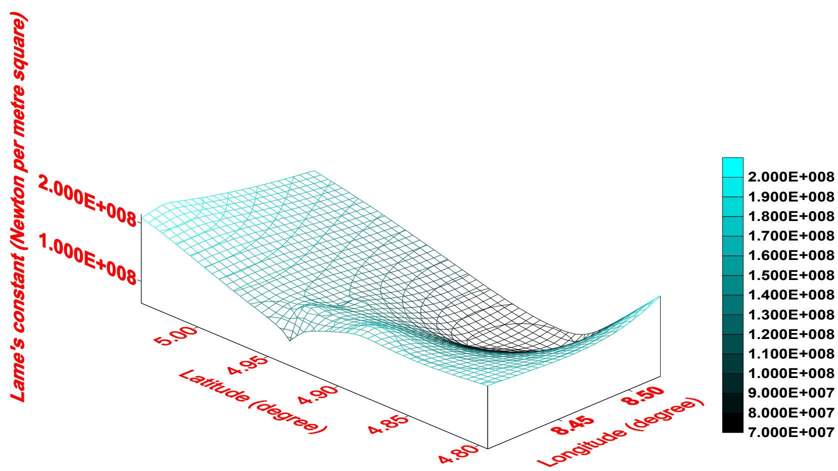

Fig. 6a. Contour map distribution of lamé lambda constant for layer one of the study area

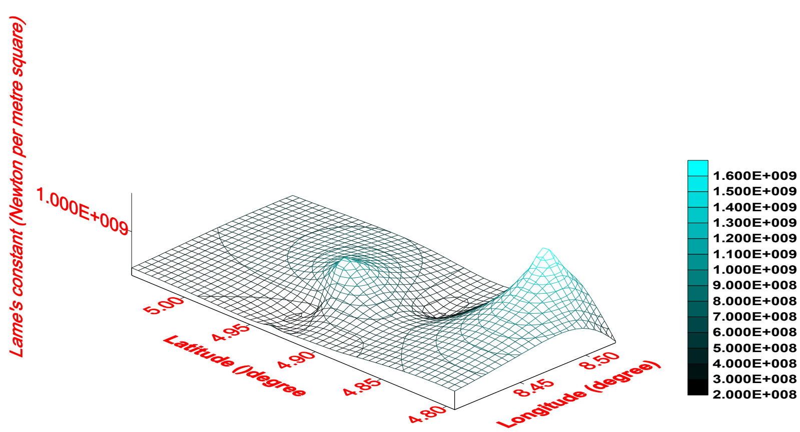

Fig. 6b. Contour map distribution of lamé constant for layer two of the study area

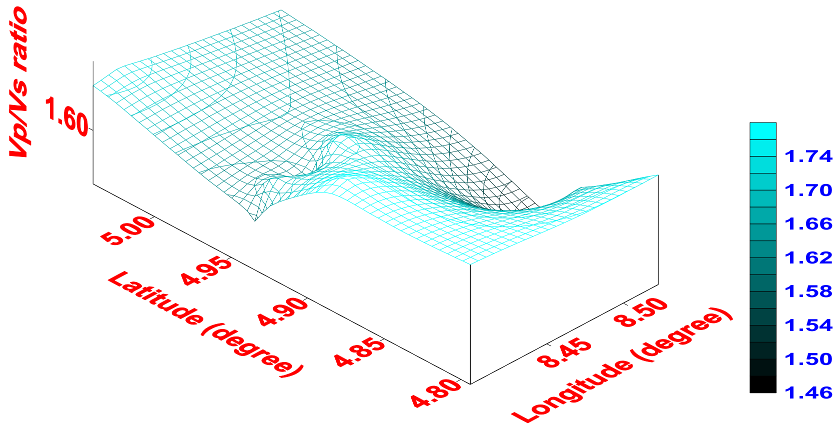

Fig. 7a. Contour map distribution of V_p/V_s ratio for layer one of the study area

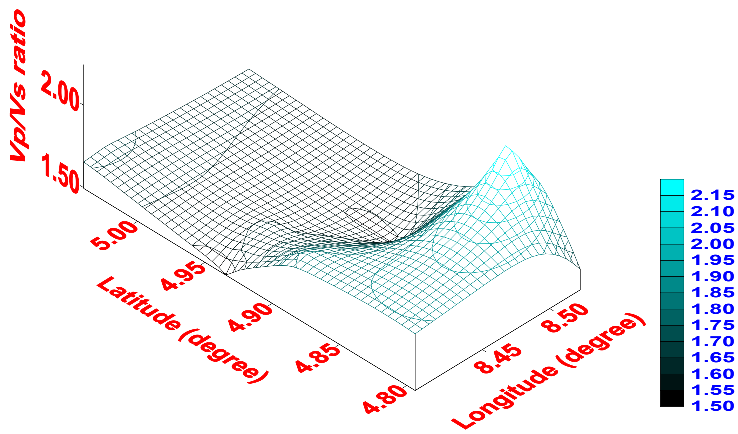

Fig. 7b. Contour map distribution of V_p/V_s ratio for layer two of the study area

4. CONCLUSION

The seismic refraction study carried out in Akpabuyo Local Government Area produced a set of reliable data which were used to determine the elastic parameters of soil/rock in the area. The results obtained qualify the soil/rock in most parts of the study area to be likely good foundation materials for civil engineering works such as construction of dams, highways and large buildings. This information is relevant to engineers and developers in locating the optimum sites for laying of foundations of infrastructure in the area. Most importantly the information will enable planners to avoid areas where the integrity of the foundation materials is a suspect.

The area between latitudes 4.93º and 5.02º and longitudes 8.40º and 8.52º have considerably low Poisson's ratio for both the first and second layers indicating fairly high level of consolidation, hence the foundation condition is good, except at Ekpiri Ikang and Ikot Effiom where the first layers gave lower Poisson ratios than that of the second layers. This suggests that the second layers though of higher densities, are less consolidated, which indicates that the integrity of the foundation materials is a suspect.

Though the high values of Young's modulus across the study area qualify the rock/soil to be likely good foundation materials, the contour map distribution of Bulk modulus shows that the central region of the study area indicates vertical variations, with the first layer having higher values. This tendency of the first layer showing better foundation attributes than the second layer in some sites is considered not a good foundation layers configuration, expecially for big high rise buildings and highways that are intended to service heavy duty trailers.

There is also, elements of both lateral and vertical in-homogeneity in Shear modulus of the rocks within the study area. This attribute which signifies non-homogeneity may endanger pavement integrity, though the values of the elastic constants are suggesting a fairly good foundation condition. The area around latitude 4.88^{o} and longitude 8.47° have relatively low values of Lamé lambda constant for the two layers. Again, there is evidence of lateral and vertical in-homogeneity in the distribution of Lamé lambda constant in both layers. However it is noted that the observed lateral variations in elastic constants are less rapid at the scale of houses.

In general therefore, the study area has faily good foundation conditions. Individual houses are likely to be stable because much cases of in-homogeneity are not expressed at the scale of houses or plots of land. However, roads that traverse from one community to another in Ekpri Ikang may experience permanent failures at places with marked lateral and vertical variations especially in Shear and Young's moduli.

One of the aims of this research is to create awareness on the need to use seismic method to do reconnaissance surveys on the integrity of foundation materials in developing countries. This has become necessary, because most developing countries are so poor that they cannot afford repairs and maintenance, if they make the avoidable mistake of relying on uninformed town and regional planning schemes as regards the building of civil engineering structures. Since the required civil engineering infrastructures are yet to be put in place in most towns and villages in these counties, the town and regional planners can take advantage of this kind of survey to avoid suspected areas with poor foundation materials in sitting civil engineering works that require foundation materials with high bearing capacity. Avoiding areas suspected of having low bearing capacity in the planning and location of heavy duty roads and structures will save developing countries of the cost of repairs and frequent maintenance of roads and such structures that would have been mistakenly built on areas with low integrity of foundation materials.

The survey plan for this research was designed to be simple and cost effective. It was considered that designing such early warning reconnaissance surveys based on delay time method of interpretation and increasing the data points for more detailed information may be counterproductive in terms of viability of this kind of research, due to cost implications and lack of awareness. The governments or construction companies can be prompted by this kind of research to now focus on areas suspected of having unfavourable foundation conditions, for more detailed surveys. Better still such areas may be avoided entirely if possible, since the infrastructures are yet to be put in place.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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