

Original Research Article

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

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 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.

33 **Keywords:** Seismic refraction, Early warning, Elastic parameters, Foundation material,
34 Engineering strength.

35 INTRODUCTION

36 The determination of rock/soil condition for civil engineering construction has gained
37 increasing importance in recent years as this is attributed to the recognition of the importance
38 of geological structure in virtually all aspects of engineering concerned with excavation of
39 material or selection of sites for dams, houses, roads and other civil engineering works
40 (Oyeyemi and Akintunde, 2000). Seismic refraction method is the geophysical technique
41 frequently used to assess the strength of a formation or interface as a foundation material in
42 engineering works such as construction of dams, high rise buildings and highways (Griffiths
43 and Kings, 1981; Agha et al., 2006). Different layers of the pavement are the target of
44 investigation in highway construction works. For a flexible pavement, the layers from the
45 bottom include the subgrade, subbase, base, base course and wearing course (Ilori et al.,
46 2014). Usually, the materials for the subgrade and subbase are the native soil and borrow pit
47 soil, respectively (Ilori et al., 2013). In the building/construction industry, elastic behaviour
48 of rocks and their characteristics have been extensively used to test the bearing strength of
49 foundation material prior to construction work (Okwueze, 1991).

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

63 Useful relation usually used for describing and characterizing the elastic nature of the
64 earth is the stress-strain relation (Dobrin and Savit, 1988; Domenico, 1997; Agha et al.,
65 2006). A stress applied to the surface of a body tends to change the size and shape of the
66 body. The external stress gives rise to opposing forces within the body. The ability to resist

67 deformation and the tendency of the body to restore itself to the original size and shape
68 defines the elasticity of a particular material (Turker, 2004; Emujakporue and Ekine, 2009).
69 A perfectly elastic body is one that recovers completely after being deformed.

70 In seismic refraction prospecting, artificially induced seismic waves propagate
71 through the earth with different velocities depending on the elastic parameters of the rocks
72 through which they travel. At layer boundaries, the waves incident at critical angles are
73 refracted and travel along the boundaries in accordance with Huygen's principle. These
74 headwaves travel to the surface at the same critical angles as their initial incidence at the
75 layer boundary for a horizontal, homogenous and isotropic situation. The total travel time of
76 these waves between the source and the various receivers gives information on the seismic
77 velocities and depths of sub-surface formations along which they propagate. However, the
78 refraction method is feasible only when formation velocities increase with depth otherwise no
79 headwave can be generated. The higher the velocity-contrast between adjacent layers, the
80 more distinct the delineation of their boundary will be (Okwueze, 1988; Tezcan et al., 2006).

81 When the mode of propagation of both the compressional and Shear waves and their
82 analysis are used along the same profile, a better evaluation of the elastic parameters of rocks
83 through which they travel is obtained (Richards et al., 1993; Kumar and Rao, 2002; Rosyidi,
84 2007; Atat et al., 2012). The determination of elastic parameters such as Poisson's ratio (σ),
85 Shear modulus (μ), Young's modulus (E) Bulk modulus (K), Lamé's constant (λ) and density
86 (ρ) is important for the study of how susceptible a particular region is to stress.

87 The general trend in developed and even developing countries is to use various
88 methods depending on what is available and considered useful by the investigator(s) to assess
89 the causes of road failures and collapse of civil engineering structures. In highway
90 construction works, the different layers of the pavement are compacted to reduce void ratio
91 and achieve optimum density, thereby making the material more stable (Ilori et al., 2013).
92 These efforts are routinely carried out during the repairs and rehabilitation of urban and inter-
93 city roads, however, in Akpabuyo there are still vast areas land that are yet to have modern
94 intra-city roads, intercity highways and huge civil engineering structures for commerce and
95 industry.

96 In Nigeria where this investigation took place, the economy is growing pretty fast and
97 there is the need for Local, State and Federal Governments in partnership with the private
98 sector to open up more villages through the construction of huge residential and commercial
99 buildings, industries, highways, bridges, etc. The Federal Road Management Agency
100 (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. During rehabilitation, repair, or construction of some of these highways, geophysical methods have been used to assess failed sections of the highway (Ilori et al., 2014). Electrical methods were used by some researchers to study the subgrade in response to pavement failure. Some researchers were able to qualitatively map clay/sandy clay soil, exhibiting low resistivity (highly porous) in the failed sections of the highways (Momo et al., 2008; and Oladapo et al., 2008; Aigbedion, 2007). 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 (Wolfe et al., 2003). Seismic refraction and surface waves methods (refraction microtremor (ReMi), Louie (2001)) were used to characterize and investigate a major road failure in some sections of highway NM 128 near Carlsbad, New Mexico, USA (Rucker, 2006). Also, Miller et al. (2008) 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. 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.

LOCATION AND GEOLOGY OF THE STUDY AREA

Akpabuyo Local Government Area which is part of Cross River State is located between latitude 4° 05' N and 5° 40' N and longitude 8° 25' E and 8° 32' 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. The study area comprises of sediments whose age is from tertiary to recent (Edet and Okereke, 2002). 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 (Nton and Esua, 2010).

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 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.

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 Refractor 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, 2001). The common elastic parameters which include Poisson's ratio (σ), Shear modulus (μ), Bulk modulus (K), Young's modulus (E) and Lamé's constant (λ) are related to the seismic wave velocities V_p and V_s by the following equations:

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

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

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

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:

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

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

LOCATION	LAYER ONE		LAYER TWO					
	Compresional	Shear Wave	Compresional			Shear Wave		
	Wave	Velocity (ms ⁻¹)	Wave			Velocity (ms ⁻¹)		
	Velocity (ms ⁻¹)	Velocity (ms ⁻¹)	Velocity (ms ⁻¹)			Velocity (ms ⁻¹)		
	V ₁	V ₁	V _d	V _u	V ₂	V _d	V _u	V ₂
Ikot Offiong	447	266	608	610	609	354	412	383
Ikot Edem	402	223	500	633	567	306	314	310
Odo								
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

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

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

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

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

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207 where ρ = density.

These calculations were done using average value of density of sedimentary rock that is, 2,670kg/m³ (Gibbs, 1997). The summary of elastic parameters for the various locations

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

Location	Elastic constants of each layer											
	Poisson's ratio		Shear modulus,		Young's modulus, E		Bulk modulus, K		Lamé lambda constant, λ		V_p/V_s	
	(σ)		μ (x 10 ⁸ Nm ⁻²)		(x 10 ⁸ Nm ⁻²)		(x 10 ⁸ Nm ⁻²)		(x 10 ⁸ Nm ⁻²)			
	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
Ekpri 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

215	Ikot Nakanda	5.2	6.0
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229 Table 3 were generated automatically by the IX Refrex software. The average depth to the
 230 refractor in almost all the locations surveyed indicates that the overburden thickness is
 231 significant, hence in terms of cost of operation treatment of the rock/soil may be preferred to
 232 complete excavation and replacement with better foundation materials. However, total
 233 avoidance of vulnerable areas is considered to be the best option for communities where
 234 developments in terms of gigantic civil engineering works are almost non-existent.

235

236 **RESULTS AND DISCUSSION**

237 The results show that Poisson's ratio ranged from 0.16 to 0.28 for the first layer and
 238 0.10 to 0.31 for the second layer. These low values of Poisson's ratio in principle indicate
 239 that the materials here are very good as foundation materials. The Poisson ratio distributions
 240 in the first two layers of the study area are captured in Figs 2 (a) and (b). The area between
 241 latitudes 4.93° and 5.02° and longitudes 8.40° and 8.52° have considerably low Poisson's
 242 ratio for both the first and second layers indicating fairly high level of consolidation, hence
 243 the foundation condition is good, except at Ekpiri Ikang and Ikot Effiom where the first
 244 layers gave lower Poisson ratios than that of the second layers. This suggests that the second
 245 layers though of higher densities, are less consolidated.

246 Shear modulus for the first layer ranges from $1.29 \times 10^8 \text{ N/m}^2$ to $3.06 \times 10^8 \text{ N/m}^2$. The
 247 second layer has Shear modulus which varies form $2.57 \times 10^8 \text{ N/m}^2$ to $13.30 \times 10^8 \text{ N/m}^2$.
 248 Figure 3 shows the contour distribution map 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 $3.04 \times 10^8 \text{ N/m}^2$ to a maximum value of $5.43 \times 10^8 \text{ N/m}^2$. The second layer has minimum value of Young's modulus of $3.28 \times 10^8 \text{ N/m}^2$ and a maximum value of $29.30 \times 10^8 \text{ N/m}^2$. 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 $1.22 \times 10^8 \text{ N/m}^2$ to $3.62 \times 10^8 \text{ N/m}^2$ for the first layer and $2.94 \times 10^8 \text{ N/m}^2$ to $22.50 \times 10^8 \text{ N/m}^2$ 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 (Ikelle & Amundsen, 2005).

The values of the Lamé lambda constant ranges from $0.62 \times 10^8 \text{ N/m}^2$ to $2.17 \times 10^8 \text{ N/m}^2$ for the first layer . The second layer has Lamé lambda constant values which ranges from $1.22 \times 10^8 \text{ N/m}^2$ to $18.58 \times 10^8 \text{ N/m}^2$. The Lamé lambda constant has no simply physical meaning (Ikelle & Amundsen, 2005), but it is sometimes referred to as fluid incompressibility (Sheriff, 2002). 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 Lamé's constant for the two layers. Again, there is evidence of lateral and vertical in-homogeneity in the distribution of Lamé'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, $E > K > \mu$. Since the deviation from this usual hierarchy of magnitude of elastic constants, occurred at only one location, i.e. at Ekpri Ikang, reasons other than quality of data collected at the study area were considered responsible for the anomaly. It is considered that the Ekpri 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 Ekpri 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 (Telford et al., 1990). In order to make a

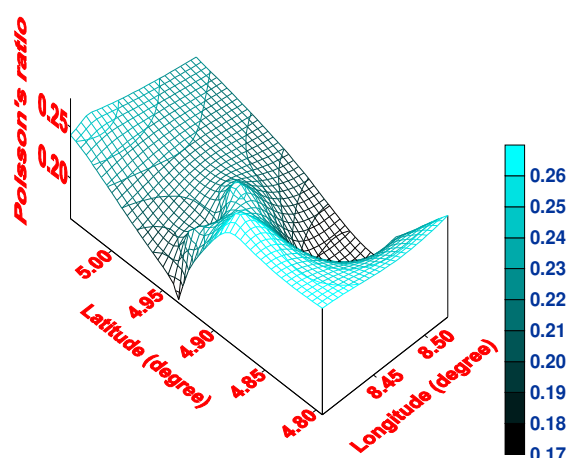


FIG. 2 (a): Contour map distribution of Poisson's ratio for layer one of the study area

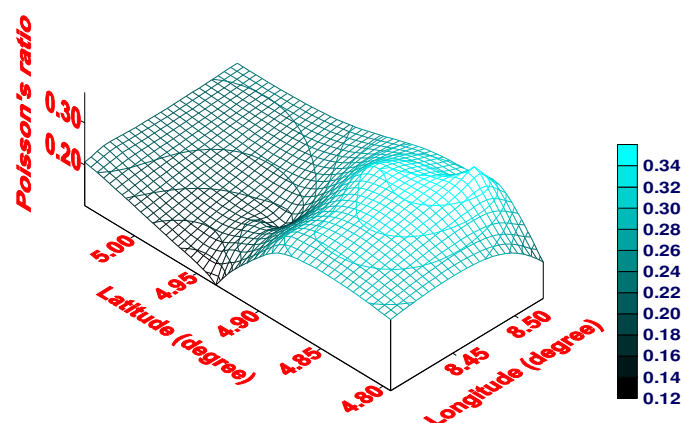


FIG. 2 (b): Contour map distribution of Poisson's ratio for layer two of the study area

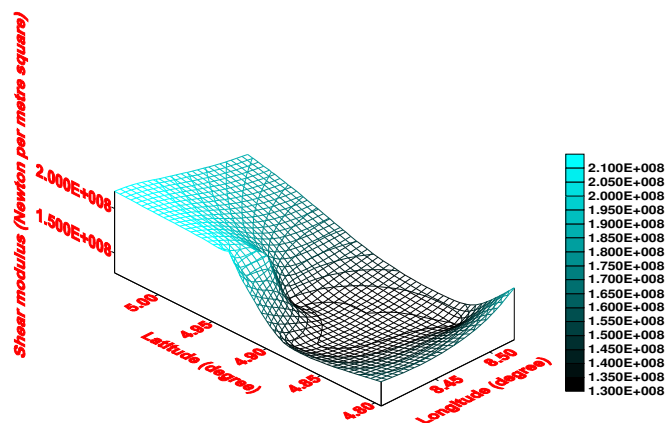


FIG. 3 (a): Contour map distribution of Shear Modulus for layer one of the study area

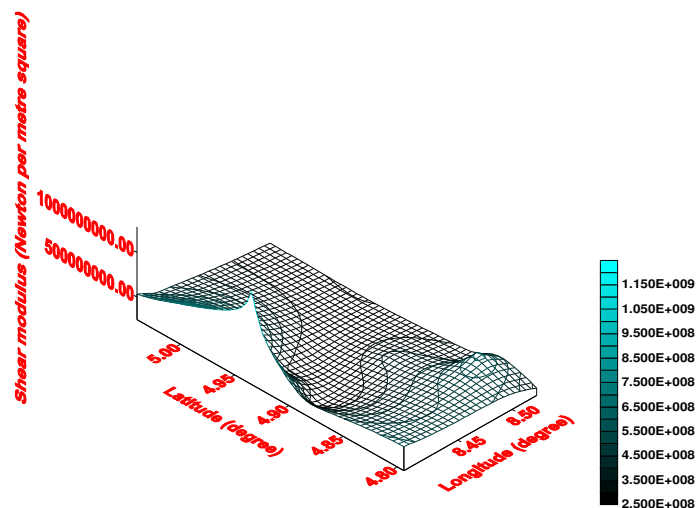


FIG. 3 (b): Contour map distribution of Shear Modulus for layer two of the study area

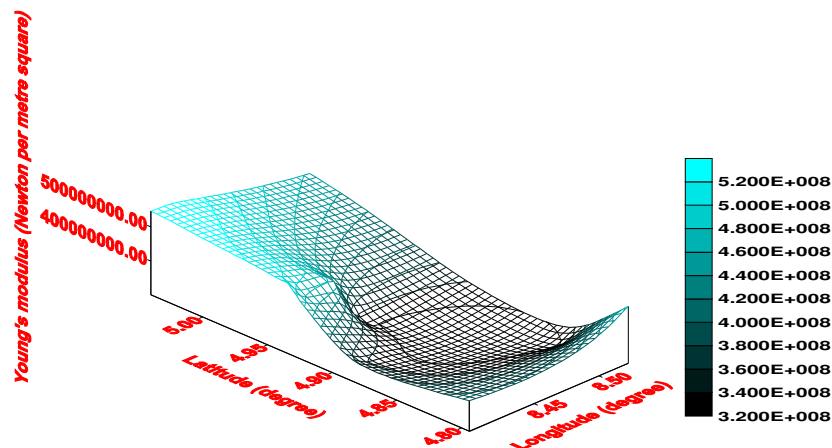


FIG. 4 (a): Contour map distribution of Young's modulus for layer one of the study area

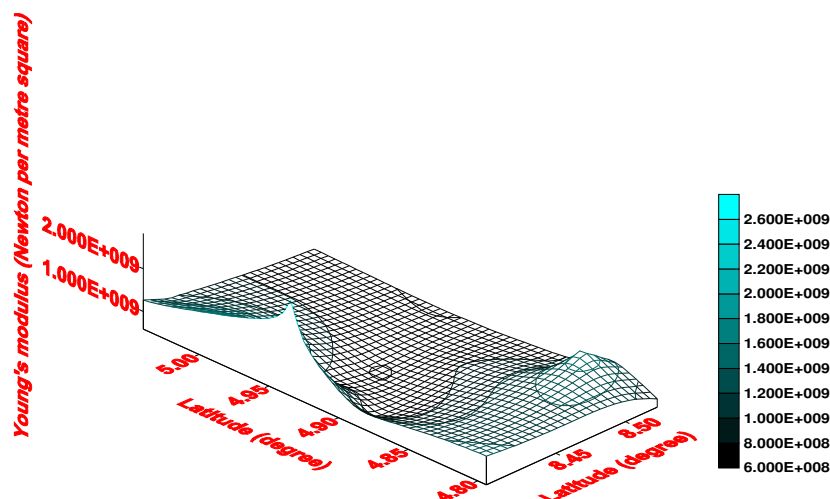


FIG. 4 (b): Contour map distribution of Young's modulus for layer two of the study area

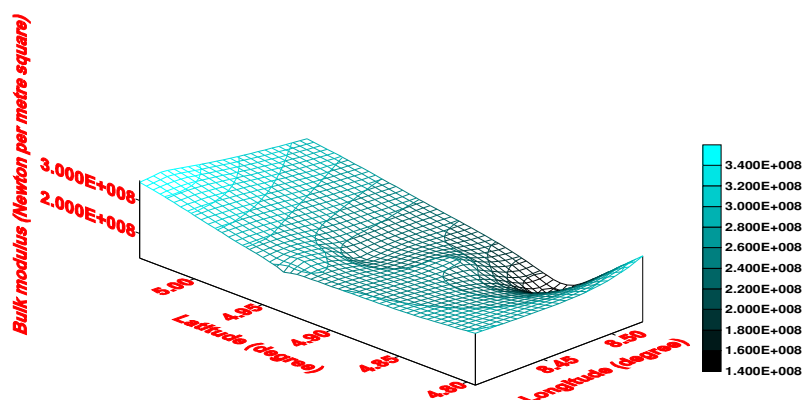


FIG. 5 (a): Contour map distribution of Bulk modulus for layer one of the study area

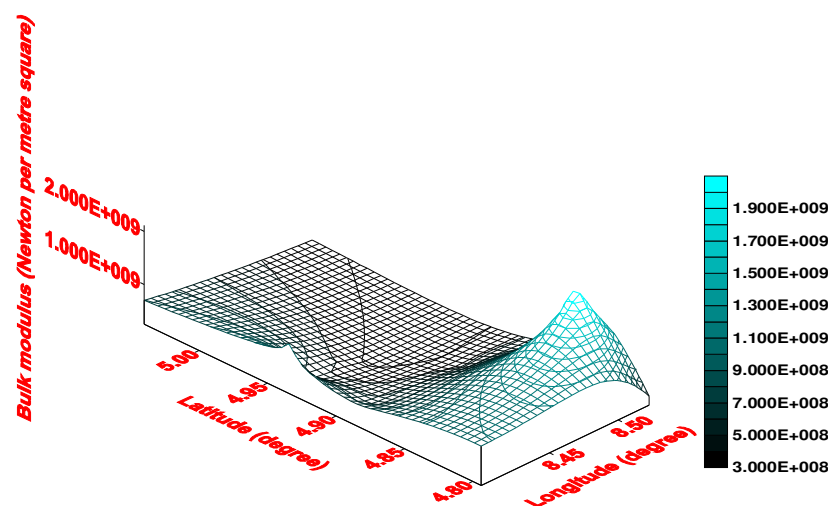


FIG. 5 (b): Contour map distribution of Bulk modulus for layer two of the study area

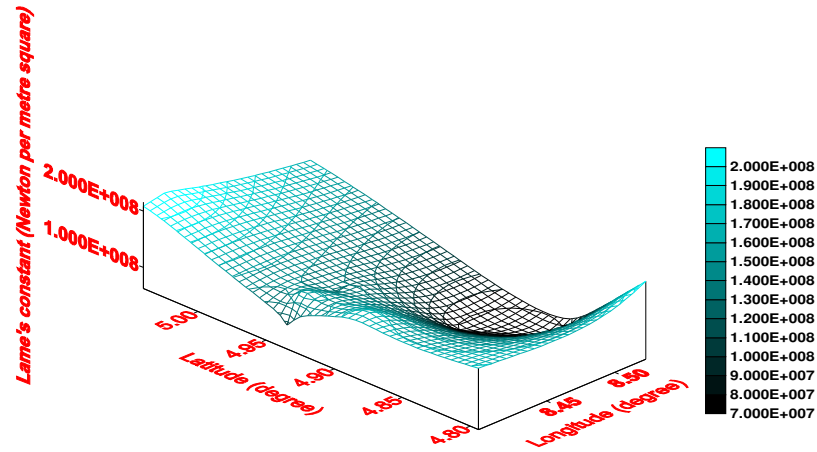


FIG. 6 (a): Contour map distribution of Lamé lambda constant for layer one of the study area

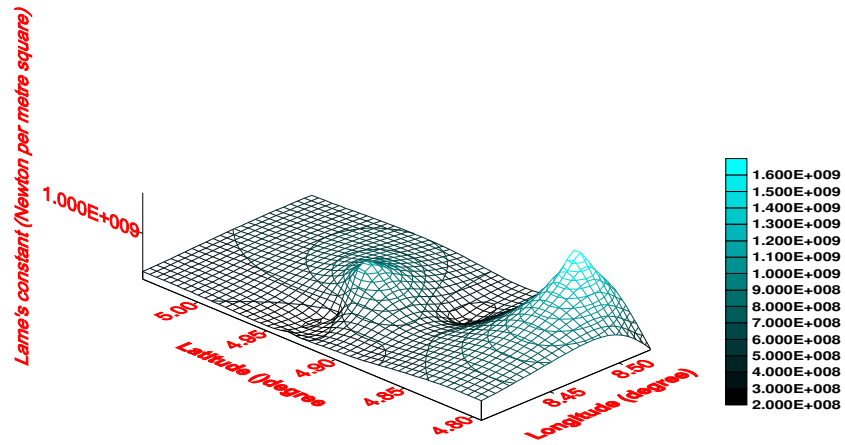


FIG. 6 (b): Contour map distribution of Lamé constant for layer two of the study area

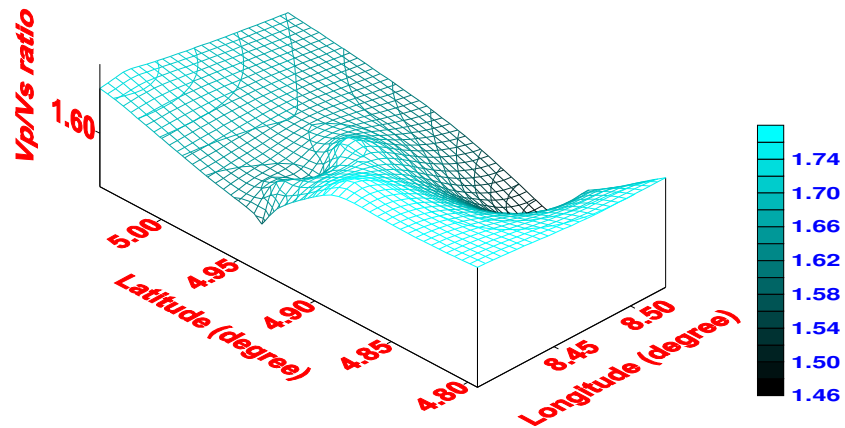


FIG. 7 (a): Contour map distribution of V_p/V_s ratio for layer one of the study area

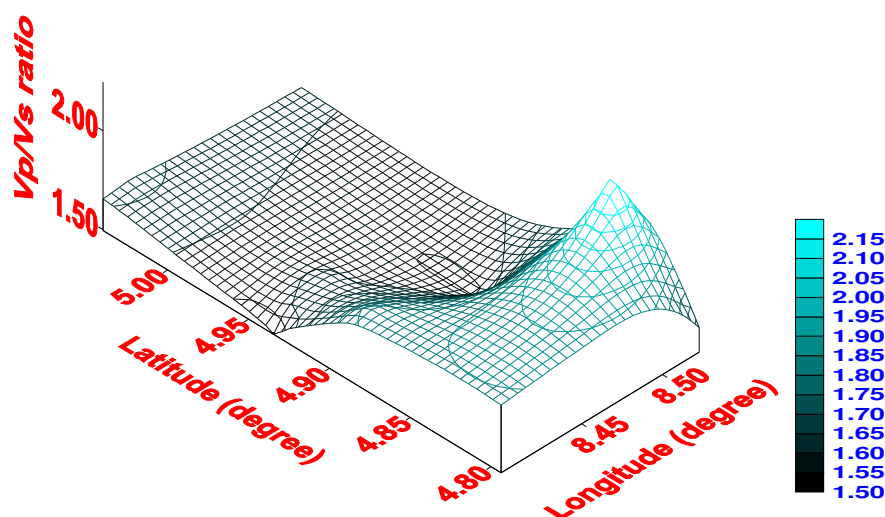


FIG. 7 (b): Contour map distribution of V_p/V_s ratio for layer two of the study area

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. In general therefore, the study area has fairly 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.

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 4.93° and 5.02° and longitudes 8.40° and 8.52° 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 Ekpri 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, especially 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° 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 fairly 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

475 maintenance of roads and such structures that would have been mistakenly built on areas
476 with low integrity of foundation materials.

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

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REFERENCES

- 487
488
489 Agha, S. O; Akpan, A. E. and Okuweze, E. E. (2006). Assessment of the strength of
490 foundation materials in some parts of Afikpo, Nigeria using seismic refraction method.
491 Nigerian Journal of Physics, **18**(1): 33-37.
- 492 Aigbedion, I. (2007). Geophysical investigation of road failure using electromagnetic profiles
493 along Opoji, Uwanlenbo, and Illah in Ekpoma, Nigeria, Middle East Journal of Scientific
494 research, **2**(3-4): 111- 113.
- 495 Atat, J. G; Akpabio, G. T; George, N. J. and Umoren, E. B. (2012). Geophysical Assessment
496 of Elastic constants of Top soil using seismic refraction compressional and shear wave
497 velocities in Eastern Niger Delta, Nigeria, **1**(1): 7-19.
- 498 Dobrin, M. B. and Savit, C. H. (1988). Introduction to Geophysical prospecting. 4th ed.
499 McGraw Hill Book Company, New York.
- 500 Domenico, S. N. (1997). Elastic properties of unconsolidated porous sand reservoirs
501 geophysics, **42**:1339- 1368.
- 502 Edet, A. E. and Okereke, C. S. (2002). Delineation of shallow groundwater aquifers in the
503 coastal plain sands of Calabar area southern Nigeria using surface resisting and
504 hydrogeological data. Journal of African Earth Sciences, **35**: 433-434.
- 505 Emujaporue, G. O. and Ekine, A. S. (2009). Determination of Rocks
506 elastic constants from compressional and Shear waves velocities for Western Niger
507 Delta Nigeria. J. of App. Sci. & Environ. Management, **13**(3) 53-55.
- 508 Gibbs, K. (1997). Fundamentals of Geophysics. Cambridge University Press, London: 58-60.
- 509 Griffiths, D. H. and Kings, R. F. (1981). Applied Geophysics for Geologist and Engineers.
510 Pergamon Press. New York. 110-112.
- 511 Ikelle, L. T. and Amundsen, L. (2005). Introduction to petroleum seismology (Investigations
512 in geophysics no. 12). Society of Exploration Geophysicists, Tulsa.
- 513 Ilori, A. O., Okwueze, E. E. and Obianwu, V. I. (2013). Evaluating compaction quality using
514 elastic p wave. Journal of materials in Civil Engineering, **25** (6), 693-700.
- 515 Ilori, A. O., Obianwu, V. I., and Okwueze, E. E. (2013). Seismic investigation of highway
516 pavement failures in parts of southeastern Nigeria, **19** (2), 113-134.
- 517 Kumar, J. and Rao, V. B. (2002). Seismic bearing capacity factors for spread foundations.
518 Geotechnique,
519 **52**(2):71-88.

- 520 Louie, J. N. (2001). Faster, Better: Shear-wave velocity to 100 meters depth from refraction
521 microtremor arrays: *Bulletin of the Seismological Society of America*, **91**, 347-364.
- 522 Miller, J., Schurtz, G., Calkins, D., and Bemda, C. (2008). Assessing non-destructive
523 geophysical methods for investigating highway structural health: in *Proceedings of the*
524 *Symposium on the application of Geophysics to Engineering and Environmental*
525 *problems*, 841-851.
- 526 Momoh, I. O., Akintorinwa, O. and Olorunfemi, M. O. (2008). Geophysical investigation of
527 highway failure: A case study from the basement complex terrain of southwestern
528 Nigeria. *Journal of Applied Science Research*, **4**(6): 637-648.
- 529 Nton, M. E. and Esua, T. B. (2010). Sequence stratigraphy of EMI field, offshore eastern
530 Niger Delta. *SPDC of Nigeria. European J. Sc. Res*, (44):115-132.
- 531 Okwueze, E. E. (1988). Velocity contrast in determining the minimum spread length in
532 seismic refraction prospecting. *Journal of mining and geology*, **24**(1):81-83.
- 533 Okwueze, E. E. (1991). Shear wave observation in seismic refraction surveys: Hydro-
534 geological and Engineering applications. *Journal of mining and Geology*, **27**(1): 61-
535 65.
- 536 Oladapo, M. I., Obafemi, M. O. and Ojo, S. J. (2008). Geophysical investigation of road
537 failures in the basement complex of southwestern Nigeria. *Research Journal of Applied*
538 *Sciences*, **3**(2): 103-112.
- 539 Oyeyeme, E. O. and Akintunde, O. M. (2000). Applications of surface geophysical methods
540 to civil engineering (A Review) proceedings of the 23rd Annual Conference of the
541 Nigerian Institute of Physics. Ahmadu Bello University, Zaria, 148-151.
- 542 Palmer, D. (2001). "Digital processing of shallow seismic refraction data with the refraction
543 convolution section". Ph.D thesis, School of Geology, University of New South Wales,
544 Sydney, Australia.
- 545 Richard, R; Elms, D. G. and Budhi, M. (1993). Seismic bearing capacity and settlement of
546 foundations. *J. Geotechnical Eng.*, **119** (4):662-674.
- 547 Rosyidi, S. A (2007). Seismic refraction method for road survey. *Laboratory of transportation*
548 *Engineering and Infrastructures*.
- 549 Rucker, M. I. (2006). Integrating seismic refraction and surface waves data collection and
550 interpretation for geotechnical site characterization. *Geophysics 2006 Conference*,
551 *Federal Highway Authority (FHA), Missouri*.
- 552 Telford, W. M., Geldart, L. P., Sherif, R. E. and Keys, D. A. (1990). *Applied geophysics*, 2nd
553 *Ed.*, Cambridge University Press, London.

554 Tezcan, S. S; Keceli A and Ozdemir, Z. (2006). Allowable bearing: Capacity of shallow
555 foundation based on Shear wave velocity. J. Geotechnical Geological Eng., **24**: 203-218.

556 Turker, E. E. (2004). Computation of ground bearing capacity from Shear wave velocity
557 proceedings of Tenth international symposium on continuous models and discrete
558 systems, Netherlands. 175-180.

559 Sheriff, R. E. (2002). Encyclopedic dictionary of Applied Geophysics (13 Geophysical
560 References Series). 4th Ed. Society of Exploration Geophysicists, Tulsa.

561 Wolfe, P. J. Hauer, E. C. and Richard, B. H. (2003). Identifying potential collapse features
562 under highways: Report prepared with the Ohio Department of Transportation and the
563 U.S. Department of Transportation, Federal Highways Administration.

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