ASSESSMENT OF MECHANICAL AND ELASTIC PROPERTIES OF SOILS IN THE SOUTH EASTERN PART OF NIGER DELTA, NIGERIA

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ABSTRACT

Seismic refraction method was carried out in six locations in Eket Local Government Area within latitudes $4^0 33^1$N and $4^0 45^1$N and longitudes $7^0 52^1$E and $5^0 02^1$E of Akwa Ibom State, Nigeria to assess the fundamental period of soils. The result shows that the fundamental periods of soils range from 0.07299s to 0.26470s. Therefore, soils in locations considered are classified as bedrock site except the one at 4.6206 ^{o}N and 7.9325 ^{o}E (fundamental period of 0.26475s) which is stiff soil site. Results are useful for foundation assessment and geotechnical engineering designs.

INTRODUCTION

Seismic waves are pulses of energy caused by the sudden breaking of rocks within the earth or an explosion (Grant and West, 1995). These waves are the energy that propagates through the earth. As seismic waves propagate through soil media, their amplification and attenuation is mainly dependent on the fundamental period of the soil deposits. The fundamental period, in turn, depends on the mechanical and geometrical characteristics of the soil deposit (Sheriff, 1989).

Geophysical testing has increasingly been used for geotechnical investigations to identify subsurface irregularities such as fill, cavities and variable strata (Budhu and Al-Karni, 1993; Furnal and Tinsley, 1985). Since input motion characteristics greatly affect dynamic structures, quantification of these vital information and necessary exercise is useful for foundation assessment and geotechnical engineering design (Coffey, 2005). This work is based on utilization of seismic refraction survey for determination of mechanical and elastic properties of soil which is useful in engineering foundations. The combination of compressional and shear wave velocities give a better resolution of the quality of rocks or geomaterials in which they have propagated through (Rosyidi, 2007; Sarma and Lossifelis, 1990).

The fundamental period of a soil deposit is dependent on its thickness, low strain stiffness and density (Scott *et al.,* 1968). The fundamental period is widely used in site classification. Soils condition at site is categorized into three groups in earthquake design standard. The first group is called "bed rock site" whose fundamental period (T) is less than 0.2 second; the second group is called "stiff soil site" whose fundamental period is from 0.2 second to 0.6 second; the third group is called the "soft soil site" whose fundamental period is more than 0.6 seconds (Sawada, 2004).

The study of propagation of elastic waves through the earth shows that waves of disturbance spread out from a source point some moving through the body of the solid (body waves) and others (surface waves) being constrained to follow any surface discontinuity (Tezcan *et al.,* 2006; Keceli and Ozdemir, 2006; Bullen and Bruce, 1993). This study is restricted to the propagation of the two types of body waves: compressional waves (P-waves) and shear (S-waves) through the earth. When both types of waves are generated simultaneously, pulse of the compressional waves arrives first on the surface while those of the shear waves arrive later (Sheriff, 1989).

An important deduction which can be made from the study of wave propagation through a material medium such as a rock is the fundamental period analysis computed to show properties of a soil deposit which is very useful in geotechnical engineering soil structure interactions, estimation of earthquake response to local soil deposit. When a load is applied to rock/soil, deformation occurs which causes breakdown of cementation and structure leading sometimes to the rearrangement of the solid grains which in turn affects the strength of the material. Therefore, it is then very necessary that foundation rocks/soil materials be tested and certified before construction commences.

Bedrock is relatively hard, solid rock beneath surface materials such as soil and gravel and can also underlie sand and other sediments on the ocean floor. It allows buildings to have solid foundations. Stiff is a soil that is resistance to pressure which is not capable of movement. Soil is a soft spot in the terrain that can be used for planting seeds. The exploitation of these properties of seismic waves has given rise to the existence of building, civil engineering, geotechnical engineering and estimation of earthquake response to local soil deposit. The estimation of the fundamental period is crucial in response analysis for existing building and for their assessment and retrofitting. A reliable estimation of the fundamental period is an important aspect both in classic (Forced Based Design, FBD) and in more recent design procedures (example pushover analysis, displacement-based design). The dynamic response of a horizontal sand bed (soil deposit) depends on the stiffness of the soil and the material damping in the soil. The stiffness of a soil deposit (element) depends on the void ratio and confining pressure which it is subjected.

Location and Geology

Eket local government area is located in the southeastern part of Niger Delta, Nigeria within latitudes $4^{0}00^{I}$ to $4^{0}30^{I}$N and longitudes $7^{0}45^{I}$ to $8^{0}00^{I}$E (Figure 1). The area is characterized by two distinct seasons: rainy (March - October) and dry season (November - February). The mean monthly rainfall during rainy season is about 135mm and this falls to 65mm during dry season (George *et al.*, 2010).

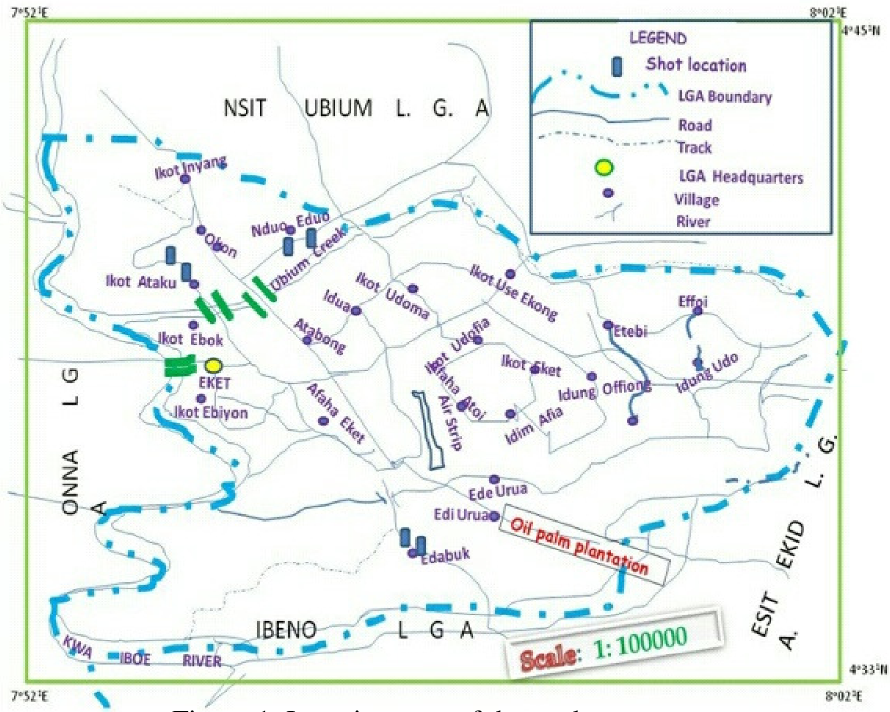

Figure 1: Location map of the study area

Geologically, the study area has a thick sequence of Neogene-Quaternary deposits. The Niger Delta is the youngest Sedimentary basin within the Beune Trough system. The Niger Delta began after the Eocene tectonic phase, up to 12.0km of silicic high energy deltaic deposits and shallow marine sediments have accumulated in the basin. The Niger and the Benue Rivers are the main suppliers of sediments. Three lithostratigraphic units are distinguished in the Tertiary Niger Delta. The basal Akata Formation which is predominantly marine prodelta shale is overlain by paralic sand/shale sequence of the Agbada Formation. The topmost section, which overlies the Agbada Formation, is the continental upper deltaic plain sands-the Benin Formation in which the top soil is investigated for elastic constants.

The universal relations among Bulk Modulus, Poisson's ratio, Shear Modulus μ and Young's Modulus E are given in equation 1 and equation 2 respectively.

$$K = \frac{2\mu(1+\sigma)}{3(1-2\sigma)} \quad 1$$

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

(Dowbrin and Sarit, 1988).

In terms of compressional and shear wave velocities, Poission's ratio

$$\sigma = \frac{\left[\left({V_P}/{V_S}\right)^2-2\right]}{\left[2\left(\left({V_P}/{V_S}\right)^2-2\right)\right]} \quad 3$$

Additionally, the existing relation between μ and V_S is as given in equation 4.

$$\mu = \rho {V_S}^2 \quad 4$$

The natural frequency (fundamental period) of the dry soil bed (top soil) may be obtained in terms of the shear wave velocity in the soil. If V_S is the shear wave velocity in the soil then the fundamental period may be obtained as:

$$\omega_n = \frac{\left(n+\frac{1}{n}\right)\gamma V_s}{h} \quad 5$$

Where ω_n is the natural frequency in the nth mode, V_S is the shear wave velocity in the case of a saturated sand bed, h is the height. The fundamental Period of soil layer of thickness H, having an average shear wave velocity V_S is approximately expressed as in equation 6.

$$T = \frac{4H}{V_s} \quad 6$$

For the fundamental time period T_n in the nth mode

$$T_n = \frac{4H}{(2n-1)V_S} \quad 7$$

Where n = 1, 2, 3, …

For n = 1,

$$T = \frac{4H}{(2(1)-1)V_S} \quad 8$$

The shear wave velocity V_s is given as

$$V_s = \sqrt{\frac{\mu}{\rho}} \quad 9$$

μ is the soil shear modulus, ρ is the soil density.

MATERIALS AND METHOD

The materials used include: sledge hammer, 12 channel signal enhancement seismograph, geophones and metal plates for generation of seismic waves. Other accessories used are measuring tape, extension cables, battery, switch and Global Positioning System receiver. The electromagnetic geophones were coupled with the earth, which received and transformed the seismic energy generated by the source to electrical voltage. The geophones for P-waves and S-waves were arranged in line from the source. A sledge hammer and metal plate were used to generate seismic waves in this study. A P-wave was generated when the hammer was struck vertically on the metal plate while S-wave was generated when the hammer was struck horizontally. The generated energy enters into the ground and was refracted off at the various interfaces corresponding to geological boundaries and consequently returned to the surface at latter time and was detected by the geophones. The seismic waves received by the geophones were converted into electrical pulse and amplified by preamplifier. The desired output was then recorded as photographic trace of moving light spot on the seismograph, an analogue plot of the time of wave arrived against source-receiver separation (Figure 2). Pickwin and IX Refrax software were used to pick the arrival time in the seismic trace and to plot the arrival time milliseconds (ms) against the geophones separations. The inverse of slope (velocity) and the mean depth of the penetrations were obtained for each plot as shown in Table 1.

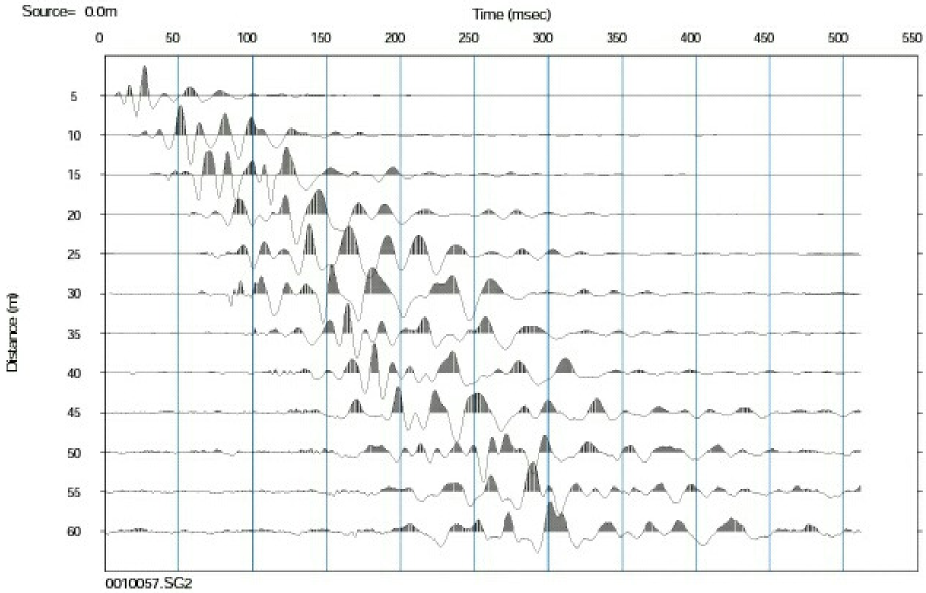

Figure 2: A typical seismogram obtained in location $4^{0}66^{1}$N and $7^{0}91^{1}$N

RESULT, DATA ANALYSIS/DISCUSSION

The result of this work is presented in Table 1.

Table 1: Summary of the Result.

Location Lat/Long (°N)/(°E)	Layers	Mean V_p (m/s)	Mean V_S (m/s)	V_p /V_S	Shear Modulus $\mu x 10^8$ N/ M^2	Young's Modulus $Ex10^8$ N /M^2	Bulk Modulus $Kx10^8$ N/ M^2	Mean Depth X_s (m)	Fundamental Period T(s)
4.676/ 7.9256	1	355.5	342.5	1.0380	2.5807	-25.6005	-0.6605	6.25	0.07299
	2	551.0	399.5	1.3792	3.6708	6.9437	2.0882		
4.6800/ 7.9303	1	288.0	276.5	1.0416	1.6819	-14.7627	-0.4178	10.45	0.15118
	2	393.0	339.5	1.1576	2.6510	0.1559	0.0177		
4.6667/ 7.9147	1	333.0	195.0	1.7077	0.8366	2.0733	1.3245	6.60	0.13538
	2	470.0	395.0	1.1899	3.5886	2.1367	0.2962		
4.6636/ 7.9156	1	399.5	380.5	1.0499	3.1852	-21.5836	-0.7359	8.80	0.09251
	2	572.5	482.0	1.1878	5.3435	3.0244	0.4141		
4.6206/ 7.9325	1	315.0	201.0	1.5672	0.888	2.0561	0.9982	13.30	0.26475
	2	584.0	416.0	1.4038	3.9803	7.8412	2.5371		
4.6125/ 7.9419	1	334.5	214.0	1.5631	1.0075	2.3243	1.1180	9.25	0.17290
	2	433.0	315.0	1.3746	2.2822	4.2810	1.2693		

From the average shear velocity V_s (m/s) and the mean depth which is the height of the soil deposit, the fundamental period was calculated using equation 6. The fundamental periods of these soil deposits were computed as shown in Table 1. It is dependent on soil deposit thickness, low strain stiffness and density (Scott *et al.,* 1968). These soil deposits can be classified according to the earthquake design standard as bed rock site, stiff soil site or soft soil site. The values of the fundamental periods for these soil deposits as they relate with shear wave velocities are shown in the Table 2.

Table 2 shows that the highest value of the fundamental period of 0.26475s at 4.6206 ^oN and 7.9325 ^oE and the lowest value of 0.07299s at 4.676 ^oN and 7.9256 ^oE. The result shows that fundamental period of the soil deposits lies between 0.007299s to 0.26475s in the South Eastern part of Niger Delta which can be classified as either stiff soil site or bedrock site. Figure 3 shows that the shear wave velocity is inversely proportional to the fundamental period.

Table 2: The relationship between T and V_s

Location Lat/Long ($^oN/^oE$)	Mean V_s (m/s)	Mean Depth X_s (m)	Fundamental Periods T (s)
4.676/7.9256	342.5	6.25	0.07299
4.6800/7.9303	276.5	10.45	0.15118
4.6667/7.9147	195.0	6.60	0.13538
4.6636/7.9156	380.5	8.80	0.09251
4.6206/7.9325	201.0	13.30	0.26475
4.6125/7.9419	214.0	9.25	0.17290

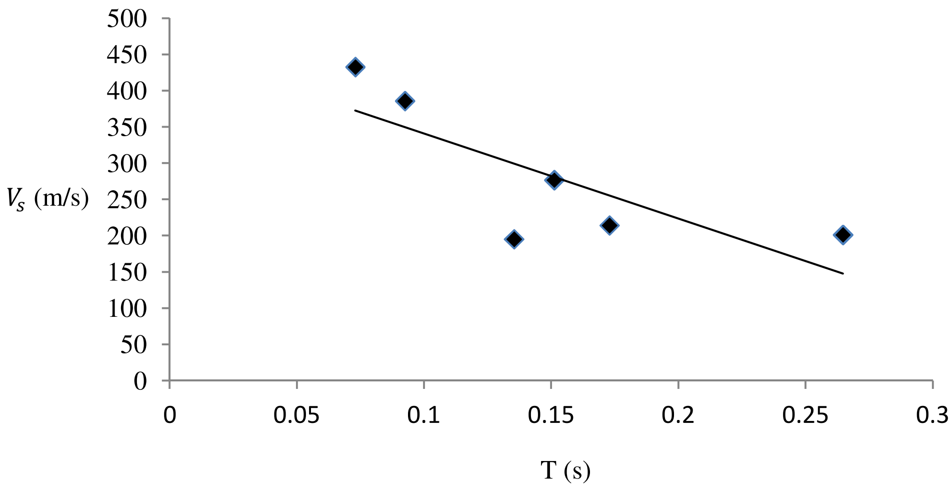

Figure 3: Relationship between Mean V_s and the Fundamental Period for each location.

CONCLUSION

The fundamental period, the mean depth X_s and P-waves velocities were determined for the porous; air filled and weathered top soil by carrying out seismic refraction survey. The values of the fundamental period range from 0.07299s to 0.26475s which indicates a soft soil site. The values of the V_p/V_s ratio indicates that the top soil is air filled porous which could be the major cause of road failure in the area. Also, it can be deduced that these locations are not good sites for engineering foundation and infrastructural construction. The area with the highest value of fundamental period T = 0.26475s (Ikot Ataku) at latitude 4.6206^{0}N and longitude 7.9325^{0}E is a stiff soil site. This is a soil that is resistance to pressure. Other locations have fundamental periods less than 0.2; this indicates bedrock site. Bedrock is a relatively hard, solid rock beneath surface materials such as soil and gravel. It allows building to have solid foundations.

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