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Application of Shallow Seismic Refraction Method and Geotechnical Parameters in Site Characterization of a Reclaimed Land

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Abstract

The recent incessant cases of building collapse have made it necessary for building site to be characterized before they are developed especially when the land is reclaimed from water bodies. On the basis of the above, both geophysical and geotechnical methods are engaged to determine the subsurface structure of a land for construction purposes. In this research effort, near surface seismic refraction method together with relevant geotechnical methods were used to characterize the subsurface condition of the study site. Nine seismic refraction profiles were surveyed with some of the profiles laid parallel and some others overlain one another. The result of this study revealed three geologic layers in the site with varying geotechnical parameters. The Young's modulus, bulk modulus and shear modulus all have values that ranges from 0.071-25.685, 0.083-30.042 and 0.0286-10.395 *GPa* respectively in the site. From these results, it can be concluded the third layer having the highest value of geotechnical parameters is the most competent and this layer is between 7.5 m and 18 m into the subsurface. The information obtained from other geotechnical methods in the site confirmed the results of this study. Thus, near surface seismic refraction method is recommended for a non-invasive, non-cumbersome and reliable site characterization.

Keywords: Characterization, Geotechnical Parameters, Reclaimed Land, Shallow Seismic Refraction, Subsurface Structure

1. Introduction

The risk that may be associated with constructions on lands reclaimed from water bodies which is a trending innovation in the world today is the area of interest for this research article. This is because some developing nations including Nigeria, now follow this trend without consideration for the in-depth studies and state of the art engineering techniques that go into this practice in the developed world. If we consider the rate of building collapse in Nigeria and the number of lives and resources that are lost in the process, measures must be taken to ascertain the safety of lives before construction begins on lands reclaimed from water bodies. Therefore, there is need to characterize the subsurface conditions of this site using the appropriate techniques before they can be considered safe for people to stay.

Often times when a building collapses, attentions are shifted to factors such as sub-standard building materials, age of the building and poor experience of the contractors as the cause of the collapse. The factor that is rarely considered is the subsurface settings of the land on which the building is cited[1]. Land reclaimed from water bodies usually contains certain mechanically unstable geological formations which are harmful to the foundation of engineering structures on it[2,3]. This is because, the subsurface structure of this kind of land are often composed of impermeable soil layers such as clay or peat and as a result, they are naturally flooded. Therefore, in order to ensure a proper foundation system for buildings within this type of area, adequate information about the subsurface is necessary. As a result of this, a comprehensive subsurface investigation must be planned and this will require adequate geophysical and

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geotechnical methods[1,4]. This would provide information on the local geology, interpretation of the land forms of the area and the correct application of the characteristics of the various soil deposits and rock formations.

Geophysical techniques are used to study the contrast in the physical properties of the different units in the subsurface such as velocity, electrical resistivity, acoustic properties, subsurface geology and the environmental conditions[5,6] and they can provide some of the information required to delineate those materials in the subsurface space such as the overburden thickness, horizontal and vertical lithologic extents, depth to water table and fault zones[7,23].The geophysical method that was employed in this study is the near surface seismic refraction technique. This method utilizes the refraction of seismic waves on geologic layers and rock/soil units in order to characterize the subsurface geologic conditions and geologic structure. It operates on the principle that seismic waves have differing velocities in different types of soil/rock, in addition the waves are refracted when they cross the boundary between different types/conditions of soil/rock[8,9].Geotechnical investigations on the other hand are conducted as a ground truthing investigation in order to assist in accurate interpretation of geophysical data[10,22]. It is often done by using intrusive methods which normally extend to a total depth of less than several hundred feet or more where necessary. The most readily available geotechnical investigation methods are the light cable percussion boring test, the Cone Penetration Test (CPT) and the Standard Penetration Test (SPT)[5,11].

This present study engaged near surface seismic refraction method and information on the cone penetration and percussion drilling tests to determine the subsurface structure of a site reclaimed from water body for building/construction purposes.

2. Location, Geology and Hydrogeology of the Study Area

The area under investigation is located between latitude 6^0 26^1N and 6^0 32^1N and Longitude 3^0 35^1E and 3^0 45^1E in Lagos Island area of Lagos State as indicated in Figure 1. The choice of the study area is based on the fact that most part of Lagos Island and its environs are water logged and sand filled. The area of study is in the coastal region of Lagos which is the area of land around the only inlet of the sea into the extensive lagoon system. The area under investigation lies within a part of the geologically termed alluvium deposits of Southwestern Nigeria Basin, which is an integral part of the Dahomey embayment.

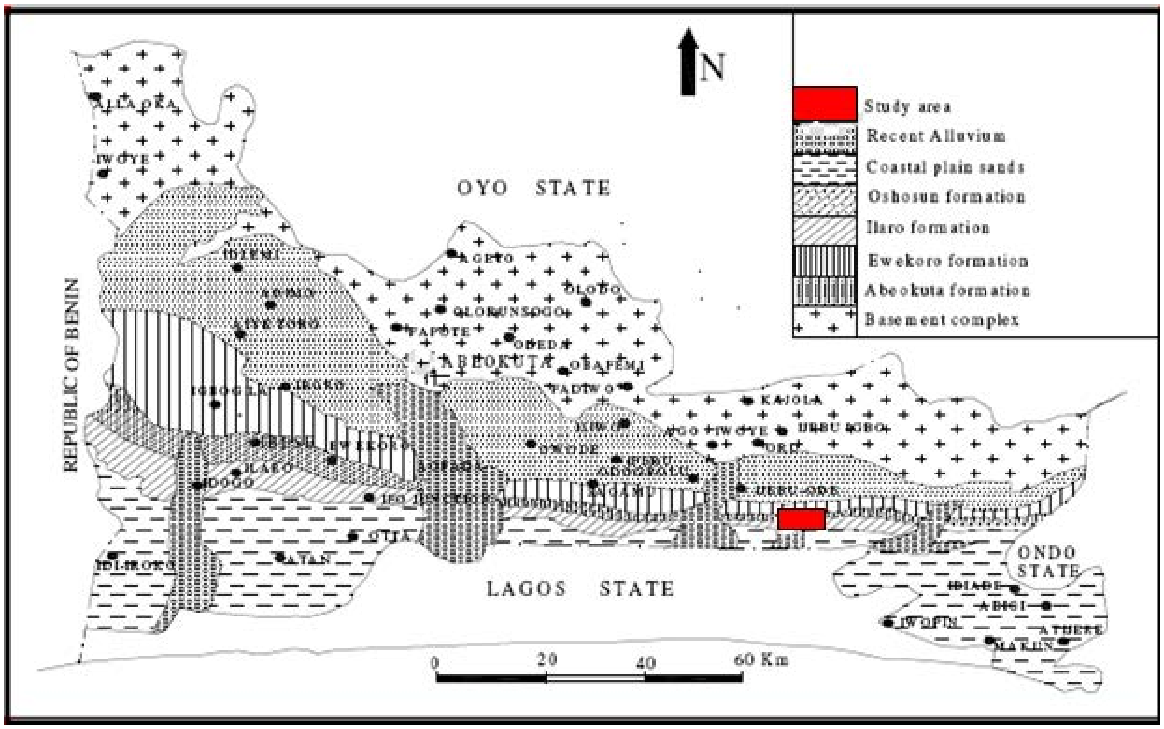

Figure 1. Geological map of Lagos state with the study area circled with red.

The superficial materials of the general area under investigation are silts, sands and clays with fibrous peat at the surface in some places. The Dahomey sedimentary Basin extends from the eastern part of Ghana through Togo and Benin Republic to the western margin of the Niger Delta. The eastern half of the basin occurs within the Nigerian territory. The base of the basin consists of unfossilerous sandstones and gravels weathered from underlying Precambrian basement. The vegetation at the study area has given way to fens and other water loving shrubs and herbs[12]. Basically, Lagos State is a sedimentary area located within the western part of Nigeria. It is located in a zone of coastal creek and lagoon[13]. The subsurface geology reveals two basic lithologies; clay and sand deposits. In some places, these deposits may be interbedded with sandy clay or clayed sand. Occasionally, there are deposits of vegetable remains and peat. The water bearing strata of Lagos State consists of sand, gravel or a mixture from fine through medium to coarse sand gravel[14,24]. Four major aquifer units are being tapped for the purpose of water supply in the Lagos metropolis. The aquifers occur at depths ranging between 10 m below ground level to 450 m below the sea level.

3. Methodology

3.1 Seismic Refraction Method

Data acquisition and field procedure

Seismic refraction was carried out in the study area, nine profiles were surveyed using a 24-Channel ABEM Terraloc Mark 6 seismogram (Figure 2). The length of each seismic profile ranges between 50 m and 200 m. Seismic refraction method requires the use of a seismogram, 12V-DC battery, a roll of trigger cable, 2 seismic cable reels, a 15 kg sledge hammer, a metal base plate, 24 geophones of 14 Hertz frequency, a log book and measuring tapes. The geophones were connected to the 2 seismic cable reels which are signal cables which were in turn connected to the seismogram. The seismogram was placed at the middle of the survey line on each profile. Geophone spacing of 2 m was used so as to obtain quality data and a good depth of penetration[15]. The trigger cable reel connected the sledge hammer to the equipment and each time there was a shot, the seismogram recorded a seismic event. Shots were taken at the following points: 2m to the first geophone, between the 6th and 7th geophones, between the 12th and 13th geophones, between the 18th and 19th geophones and 2m after the 24th geophones. These shot points were termed the offset, quarter spread, mid-spread, three quarter spread and off-end shots respectively. The purpose of these multiple shots along a profile was to obtain adequate coverage of the refractor surface and to provide adequate lateral resolution[16]. After the equipment was set up, the background noise level was monitored on the seismograph by the operator to be sure there was no noise at all. The seismic waves generated

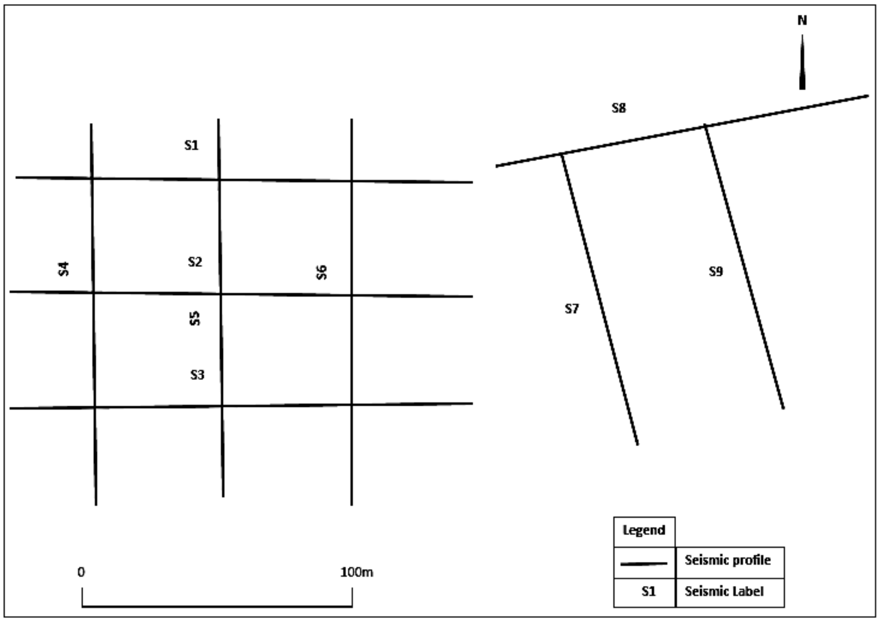

Figure 2. Base map of the study site.

by this shot travelled down and along different refractor boundaries, only the refracted energies are detected by the geophones[17,21]. From the data obtained, the time–distance graphs were plotted with software, from the data of first arrival of p–waves. The essence of employing seismic refraction method is to obtain information on the depth to the most competent layer in the subsurface and to determine the strength and competence of each subsurface layer for the purpose of construction.

3.2 Data Processing

The seismic data acquired were first arranged in different folders according to the number of shot points. The seisImager/2D™ was used for the data analysis. The software is composed of five different packages but the Pickwin and the Plotrefa are the most relevant to this study. The Pickwin package was first used to select the first arrival or the first breaks. After picking the first breaks for all the seismic events (Figure 3), the Plotrefa package was used for the second stage of this interpretation. This package was used to carry out the time term inversion in order to generate the 2-D seismic section of the surveyed area. This inversion employs a combination of linear least square and delay time analysis to invert the first arrival for a velocity section. This process enabled us to assign the number of layers as depicted by the distance-time graph. After the layers were assigned, a 2D image of the profile studied was produced showing the number of layers and the primary wave velocities of each layer. The information provided by the 2D image are used to obtain other geotechnical information as they relate to the study site using standard equations in theory.

4. Theory

The primary and the shear wave velocities were used to determine the densities and the elastic moduli for each layer delineated in the study area using equations (1)-(7) below respectively.

$$V_p \approx 1.7V_s \quad (1)$$

From which we can also determine the remaining acoustic parameter. That is, the density by using equation (2)

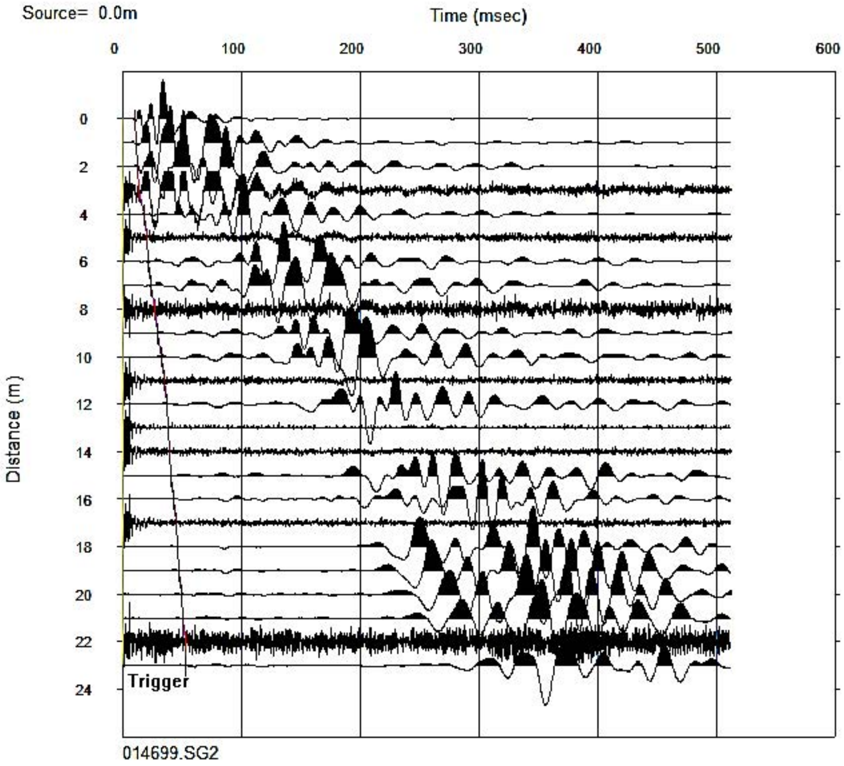

Figure 3. Sample of first break picks on a seismograph.

$$\rho_b = \frac{\gamma}{g} \tag{2}$$

where, γ is the unit weight of the soil and g is the acceleration due to gravity which is given by 9.8 m / s^2. The unit weight of the soil relates with P-wave velocity V_p as shown in equation (3) below.

$$\gamma = \gamma_o + 0.002 V_p \tag{3}$$

where, γ_0 is the reference unit weight values in KN / m^3 for soil and rock types. The value of γ_0 is 16 for loose, sandy and clayey soil[1,18,19]. Also, other geotechnical parameters can be calculated, such as the Poisson's ratio, υ using equation (3).

$$\nu = \frac{\left[\left(\frac{V_P}{V_S}\right)^2 - 2\right]}{\left\{2\left[\left(\frac{V_P}{V_S}\right)^2 - 1\right]\right\}} \tag{4}$$

The Young's modulus can also be obtained using equation (5).

$$E = \frac{\rho_b V_P{}^2 (1-2\nu)(1+\nu)}{(1-\nu)} \tag{5}$$

The bulk modulus can be calculated using equation (6).

$$B = \rho_b V_p{}^2 \tag{6}$$

Finally, the shear modulus can also be obtained by using equation (7).

$$G = \frac{E}{[2(1+\nu)]} \tag{7}$$

5. Results and Discussion

5.1 Geophysical Method

The results obtained from the data acquired for the seismic refraction method in the study area revealed mostly 3 geological layers with the velocity of each layer increasing with depth, this may be as a result of the variation in the composition of the subsurface structures with depth (Figure 4). The primary wave velocity of the first layer ranges between 258 m/s and 454 m/s while the p-wave velocity for the second layer ranges between 642 m/s and 979 m/s while in the third layer the primary wave velocity ranges between 1000 m/s and 3544 m/s. The shear wave velocity of the first, second and third layers' ranges between 151.76 m/s and 267.06 m/s, 377.65 m/s and 575.88 m/s and 588.24 m/s and 2084.71 m/s respectively. The change in velocity may largely be as a result of the variation in lithology, texture, grain size, the rate of cementation, the level of saturation and the changes in compaction[20,24]. The results of the p-wave velocities of the first layer characterize a loose dry geomaterial while the second layer may be a saturated formation while the sharp contrast in the velocity of the third layer may be as a result of the presence of a highly compacted/cemented geologic formation.

The densities of the first, second and third layers ranges between 1242.4 kg / m^3 and 1431.0 kg / m^3, 1560.4 kg / m^3 and 1734.0 kg / m^3 and 1743.3 kg / m^3 and 2391.9 kg / m^3 respectively. A linear relationship was observed between the density and the velocity of each layer. The Young's modulus E was also determined and it was observed to be increasing with depth, though this was not

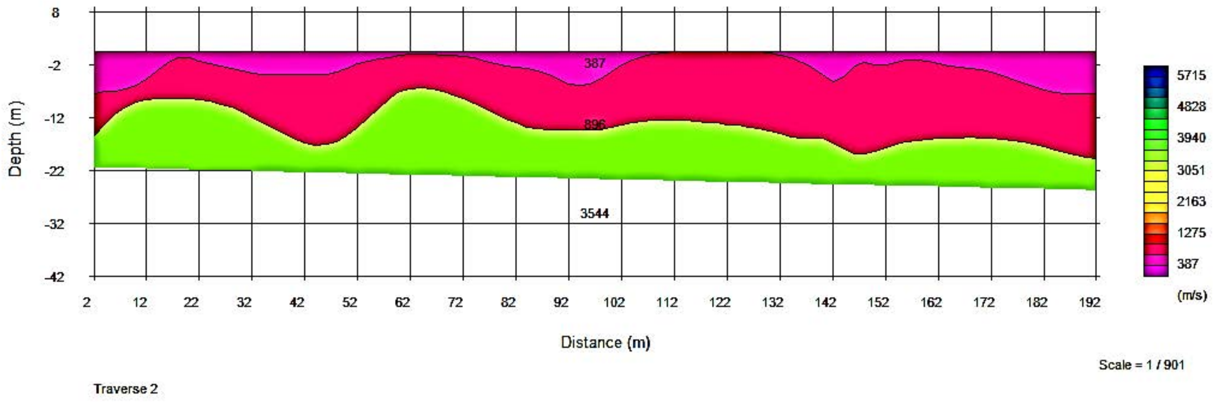

Figure 4. 2D seismic refraction section of the study area.

uniform across the study area. The Young's modulus for the first layer ranges between 0.0707 *GPa* and 0.2522 *GPa*, for the second layer, the Young's modulus ranges between 0.5499 *GPa* and 1.4209 *GPa*. The third layer on the other hand, has a Young's modulus that ranges between 1.4905 *GPa* and 25.6856 *GPa*. It can be seen from these results that of the three layers, the third layer having the highest Young's modulus may be the strongest of the layers delineated by the seismic refraction method.

The bulk modulus B was also estimated and the results are as follows: The first layer has bulk modulus that ranges between 0.0827 *GPa* and 0.2950 *GPa* while the second layer on the other hand has a bulk modulus that ranges between 0.6431 *GPa* and 1.6619 *GPa* and the bulk modulus of the third layer ranges between 1.7434 *GPa* and 30.0421*GPa*. From this estimation, the third layer has the highest bulk modulus, which implies that this layer will not undergo change in volume under stress. This result confirms the third geologic formation as the strongest in the area of study.

The Shear modulus G which is also a measure of strength/stiffness was determined, the shear modulus for the first layer ranges between 0.0286 *GPa* and 0.1021 *GPa* for the second and the third layers, their shear modulus ranges between 0.2225 *GPa* and 0.5751 *GPa* and 0.1552 *GPa* and 10.3952 *GPa* respectively. From this, the shear modulus of the third layer was the highest implying that the third layer has the most strength in the study area. These different parameters confirmed the third layer to be most competent for construction purposes in the study area and this layer is in the depth of 7 m and 18 m in the subsurface.

5.2 Geotechnical Methods

The data presented in Table 1, correlated the results of two cone penetrometer tests and one percussion drilling test acquired in the site studied. From this correlation, three distinct layers were delineated. The first layer spans from the ground level to a depth of 0.75 m, having a stratum thickness of 0.75 m. The cone resistance values, q_c of this layer ranges between 2 kg / m^2 and 11 kg / m^2. This value classifies the layer as very loose sandy soil. Thus, the topmost geomaterial is cohesionless, non- plastic and drains fast. It has a poor geotechnical property, low shear strength and high compressibility potential. The second layer has a stratum thickness of 4.50 m with depth that ranges between 0.75 m and 5.25 m. The cone resistance values within this stratum ranges between 7 kg / m^2 and 185 kg / m^2. According to the information provided by the borehole log, the material is clayish in nature and its cone resistance value puts it in the class of hard geomaterial. The clay property of this material suggests that it is plastic in nature, slow draining and very slow compression rate. All these conditions show that this material can be inimical to construction because its compression may be uneven and this can result in differential settlement and this can cause major damage to the engineering structure on it. The third layer ranges between 5.25 m and 7.50 m in depth. The cone resistance values, q_c range between 66 kg / m^2 and 168 kg / m^2. The borehole log depicts this layer as a soft geological formation. Based on the above stratigraphic profile, it can be seen that the depth to the most competent layer lies between 7.5 m and 15 m. This region is composed of soil composition that has high shear strength potential, low compressibility and good geotechnical properties.

It is obvious from the results of the geophysical analysis and geotechnical results that it would be difficult to have the foundation of a building at this depth. Therefore, some form of arrangement must be made to transfer the load of the building to the subsurface materials at this depth to avoid collapse as geomaterials above this depth are not mechanically stable to support a building that will stand the test of time.

Table 1. Stratigraphic profile of the study site

From (m)	To (m)	Stratum Thickness (m)	Generalised Stratum Description	SPT N-Values	q_c (Kg/cm^2)
0.00	0.75	0.75	Dark brownish silty fine SAND	-	2-11
0.75	5.25	4.50	Soft becoming firm light yellowish sandy CLAY	-	7-185
5.25	7.50	2.25	Soft dark grey organic silty CLAY	-	66-168
7.50	10.50	3.00	Loose becoming medium dense light grey silty SAND	10-13	-
10.50	14.25	3.75	Firm dark grey organic CLAY	-	-
14.25	15.00	0.75	Light grey coarse SAND	-	-

6. Conclusion

Geophysical and geotechnical surveys, which included seismic refraction methods and percussion drilling and cone penetration tests have been conducted in order to determine the competence of the study site for construction purposes. Seismic refraction method delineated the third layer as the most competent layer, having recorded higher values of geotechnical parameters than the other layers. This most competent layer is between the depth of 7.5 m and 18 m into the subsurface. The percussion drilling test confirmed the geologic formation within this depth to have high shear strength and low compressibility potentials thus, confirming its competence. The cone penetration test also revealed the geologic formation in the topmost layers to be of low compressibility potential. Therefore, it is recommended that engineering construction on this site should be founded on the most competent layer using pile foundation.

7. References

1. Hunt RE. Geotechnical engineering investigation handbook. 2nd edition; 2005. p. 1–3.
2. Ayolabi EA, Enoh IJE, Folorunsho AF. Engineering site characterisation using 2-D and 3-D tomography. Earth Science Research. 2012; 2(1):133–42.
3. Shirzadyan J, Talkhablou M. Using GIS software for identification and zoning of the areas prone to liquefaction in the bed soil of the Dams. Indian Journal of Science and Technology. 2015; 8(59):62–66.
4. Burger HR. Exploration geophysics of the shallow subsurface: Prentice Hall, New Jersey; 1992.
5. Akintorinwa OJ, Adesoji IJ. Application of geophysical and geotechnical investigations in engineering site evaluation. International Journal of Physical Sciences. 2009; 4(8):443–54.
6. Coker JO, Makinde V, Mustapha AO, Adesodun JK. The application of geophysical methods in foundation failure investigation, a case study of Metro Hostel camp area, Abeokuta, Southwestern Nigeria. Nature and Science. 2013; 11(11):103–9.
7. Oyedele KF, Olorode DO. Site investigation of subsurface conditions using electrical resistivity method and cone penetration test at Medina estate, Gbagada, Lagos, Nigeria. World Applied Science Journal. 2010; 11(9):1097–104.
8. Soupios PM, Papazachos CB, Vargemezis G, Fikos I. Application of seismic methods for geotechnical site characterization. International Workshop in Geoenvironment and geotechnics; 2005. p. 163–70.
9. Fitzallen A. An improved approach to site characterization combining geophysical and geotechnical data. Australian Geomechanics. 2010; 45(1):77–88.
10. Robertson PK, Cabal KL. Guide to cone penetration testing for geotechnical engineering. Gregg Drilling and Testing Inc., U. S. A., 4th edition; 2010. p. 6–15.
11. Baldi G, Belloti R, Ghionna VN, Lo Presti DCF. Modulus of sands from CPT and DMT. Proceedings of the 12th International Conference on soil mechanics and Foundation Engineering. 1995; p. 165–70.
12. Adegbola RB, Badmus GO. Estimation of shear wave velocity for near-surface wave characterisation; case study: Ifako/Gbagada area of Lagos State, S. W. Nigeria. British Journal of Applied Science and Technology. 2014; 4(5):831–40.
13. Elueze AA, Ntom ME. Organic geochemical appraisal of limestones and shales in part of eastern Dahomey basin, Southwestern Nigeria. Journal of Mining and Geology. 2004; 40(1):29–40.
14. Adeleye DR. Nigeria late cretaceous stratigraphy and palaeography. American Association of Petroleum Geologists Bulletin. 1975; 59(12):2302–13.
15. Sayeed SRM, Adel MEM, Abd El-Aal AK. Applicability of near surface seismic refraction technique to site characterization of south Marsa Matrouh and Sedi Abd El-Rahman, Western desert, Egypt. Journal of Applied Geophysics. 2007; 6(2):77–85.
16. Reynolds JM. An introduction to applied and environmental geophysics. Wiley, United Kingdom; 1998. p. 417–50.
17. Shearer PM, Orutt JA. Surface and near-surface effects on seismic waves theory and borehole seismometers results. Bulletin of the Seismological Society of America. 1987; 77(4):1168–196.
18. Altindag R. Correlation between p-wave velocity and some mechanical properties for sedimentary rocks. The Journal of the Southern African Institute of Mining and Mettalurgy. 2012; 112(3):229–37.
19. Dehbashi M, Asl MM. Determining parameters of simple geometric shaped self-potential anomalies. Indian Journal of Science and Technology. 2014; 7(1):79–85.
20. Bremmer CN. Developments in geomechanical research for infrastructural projects. 12th European Conference on Soil Mechanic and Geotechnical Engineering. Geotechniek Special Issue; 1999. p. 52–5.
21. Adeyemo IA, Omosuyi OG. Hydrogeologic, electrical and electromagnetic measurements for geotechnical characterization of foundation beds at Afunbiowo, near Akure, Southwestern Nigeria. Indian Journal of Science and Technology. 2012; 5(2):2017–22.
22. Obasi RA, Ikubuwaje CO. Analytical study of rainfall and temperature trend in catchment states and stations of the Benin-Owena river basin, Nigeria. Journal of Environment and Earth Sciences. 2011; 2(3):9–21.
23. Oyedele KF, Okoh C. Subsoil investigation using integrated methods at Lagos. Nigeria. Journal of Geology and Mining Research. 2011; 3(7):169–79.
24. Mohd HZA, Fauziah ARS, Devapriya CW, Mohamed FTB. Seismic refraction investigation in near surface landslides at the Kindasang area in Sabah, Malaysia. Sciverse Science Direct, Procedia Engineering. 2012; 50(2012):516–31.