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Investigation to determine the vulnerability of reclaimed land to building collapse using near surface geophysical method

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 Abstract. Adequate knowledge of the geology and the structures of the subsurface would assist engineers in the best way to carry out constructions to avoid building collapse. In this study, near surface seismic refraction method was used to determine the geotechnical parameters of the subsurface, the results obtained were correlated with the result of borehole data drilled in the study area. The results of seismic refraction method delineated mostly two distinct layers with the first layer having the lower geotechnical parameters. It was observed that in the first layer, the Young's modulus ranged from 0.168 to 0.458 GPa , shear modulus ranged between 0.068 and 0.185 GPa, the bulk modulus ranged between 0.106 and 0.287 GPa while the bearing capacity ranged from 0.083 to 0.139 MPa. On the other hand, in the second layer, the Young's modulus ranged between 3.717 and 7.018 GPa, shear modulus ranged from 1.500 to 2.830 GPa while the bulk modulus ranged from 2.383 to 4.449 GPa. Significantly, the formation of the second layer appeared to be more competent than the first layer, therefore engineering construction in this geological setting is recommended to be founded on the second layer at depth ranging between 7 and 16 m.

1. Introduction
The alarming rate of building failure has necessitated the knowledge about the structure of the subsurface especially in area where lands are recovered from water bodies for the purpose of construction. This type of land is known to contain geologic formations [1], which are mechanically unstable for founding an engineering structure [2]. Therefore, adequate approach of investigation must be employed in order to study this type of terrain giving consideration to the high number of casualties that would be recorded and the worth of resources that would waste if the result obtained does not properly represent the condition of the subsurface [3,4]. Geophysical techniques are in high demands lately because of their relevance in hydrological and geotechnical investigations [1,5]. They have the advantage that they are capable of providing information about the spatial and/or temporal distribution of the features of the subsurface [6,7]. Prominent among the geophysical methods used for geotechnical studies is the seismic refraction method [8,9,10]. This technique is highly useful in many applications such as engineering, environmental, groundwater, hydrocarbon, and industrial-mineral exploration [11].It is used to characterize the subsurface structure and geological condition. This method divides the subsurface structure into different layers and it gives information on the engineering parameters of each layer and their thicknesses [12]. Seismic refraction method operates on the principle that the speed of propagation of seismic energy varies with the medium of propagation. It is on this basis that the first arrival is of utmost importance in the analysis of seismic data because it is

used to determine the distribution of underground seismic velocities. It provides 2-dimensional profiles including depth and distance that simplified the characterization of relatively large volumes of the subsurface [3].

Various geomechanical properties can be measured by the propagation of seismic energy through soil deposits. Some of the soil properties that could be obtained by this method include Young's modulus, shear modulus, bulk modulus and Poisson's ratio. All these geotechnical parameters require the knowledge of both p and s-waves to determine their values. This method has been used to obtain in-depth information on different geological formation, previous studies revealed that this method can be successfully applied for site characterization [3,13]. Martinez and Mendoza [7] were able to show that this method would give quality image of the subsurface for site characterization. In a recent development, Grelle and Guadagno [14] established the applicability of seismic refraction method for groundwater level determination. This method has also been used to determine the ground role motion in soil. Seismic refraction method has been found to be very useful in the characterization of the subsurface for geotechnical engineering applications [14]. The advantage of seismic refraction method in seepage study was noted by Osazuwa and Chinedu [15]. Percussion drilling test is often conducted to obtain physical information on the geology of the study area in order to corroborate the results obtained by geophysical methods [16,17].

In order to prevent loss of lives and cost suffered in the cases of building collapse, it is important to understand the subsurface characteristics and the geologic condition of reclaimed land before they are recommended for construction purposes. Therefore, it is on this note that seismic refraction method was engaged in the present study to determine the condition of the subsurface and to correlate the result with borehole lithologic log of the area in order to determine the depth to the most competent layer in the area of study.

2. Description and Geological Setting

The study area is located in Lagos Island area of Lagos State, southwestern Nigeria Coastal zone, a zone of coastal creeks and lagoons developed by barrier beaches associated with sand deposition [18]. The topography is gentle with elevation averaging about 2 m above mean sea level. This area is situated within the Nigerian sector of the Benin-basin, and near the eastern margin of the basin. The geological formations of the study area are composed of sediments laid down under fluviate, lascustrine and marine environments. These sediments grade into one another and vary widely in lateral extent and thickness [18,19]. In this region, six lithostratigraphic formations are present, which are Abeokuta, Ewekoro, Akinbo, Oshosun, Ilaro and Benin Formations (arranged sequentially from the oldest to the youngest. The local geology is predominantly Coastal Plain Sands which consist of poorly sorted clayey sands, reddish mud/mudstone, clay and sand lenses, and sandy clay with lignite of Miocene to Recent (Figure 1).
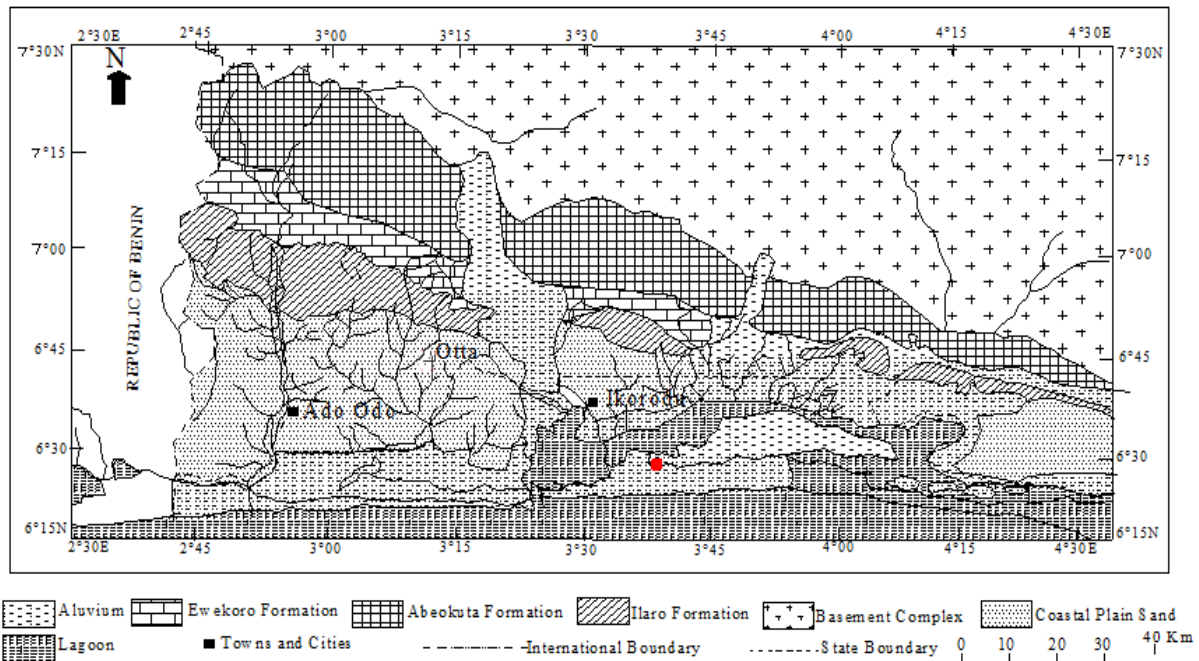
Figure 1. Geological map of the study area, with the area of study marked in red (Modified after [19])

3. Methodology

Seven seismic refraction profiles were surveyed in order to obtain adequate data for this study. Each profile length extended between 50 and 150 m as a result of space. The inter-geophone spacing of 2 m was used and the shot-to-first geophone spacing was also 2 m. A total number of 24 geophones were used on every 50 m profile length. A 24 Channel ABEM MK 6 Terraloc seismogram [20] was used for the data acquisition and energy source engaged was a 15 kg sledge hammer and a metallic base plate. Multiple shots were taken at each location and the data stacked about 8 times in order to increase the data quality. On each 50 m profile length, shots were taken at the offset location, between the sixth and the seventh geophones, between the twelfth and thirteenth geophones and mid-point between the eighteenth and nineteenth geophones and finally at 2m after the last geophone. This was done in order to adequately cover the refractor layer in the subsurface and to improve the quality of the image. High consideration was given to possible sources of noise such as machinery, daily human activities, traffic and other similar factors so as to improve the signal-to-noise ratio. From the seismic refraction method, p-wave velocity of each layer was used to determine the some engineering parameters for the two layers using some theories that exist in literature [21].

A borehole was drilled to a depth of 30 m in the study area using Shell and Auger percussion boring techniques with a Pilcon Wayfarer rig to bore through the overburden in accordance with the code of practice for soil investigations [2,13,22]. This is used to produce a borehole lithologic log for the surveyed area which formed a basis for the correlation of the results of seismic refraction method.

4. Results and discussion

The first arrival travel times of all recorded traces were picked, and then the picked travel times were inverted using a software code called seisImager. The seismic tomography section revealed two geologic layers in the study area (Figure 2). The p-wave velocity of the first layer ranged between 340 and 554 m/s while in the second layer, the velocity was between 588 and 2012 m/s. Other geotechnical parameters were determined, the Young's modulus varied between 0.168 and 0.458 GPa and it ranged between 0.518 and 7.071 GPa. Relatively, the bulk modulus ranged between 0.106 and 0.287 GPa in the first layer while the values lied between 0.326 and 4.455 GPa in the second layer. In another

measurement, the shear modulus ranged between 0.068 and 0.185 GPa in the first layer while it was between 0.210 and 2.862 GPa in the second layer. Further, the allowable bearing capacity was discovered to vary between 0.083 and 0.139 MPa while it was between 0.149 and 0.593 MPa in the second layer. The depth of the first layer was about 8 m from the topsoil while in the second layer the thickness measured was about 11 m. Geotechnically, the geologic formation with higher values of geotechnical parameters are considered for engineering construction purposes as was observed in the second layer.
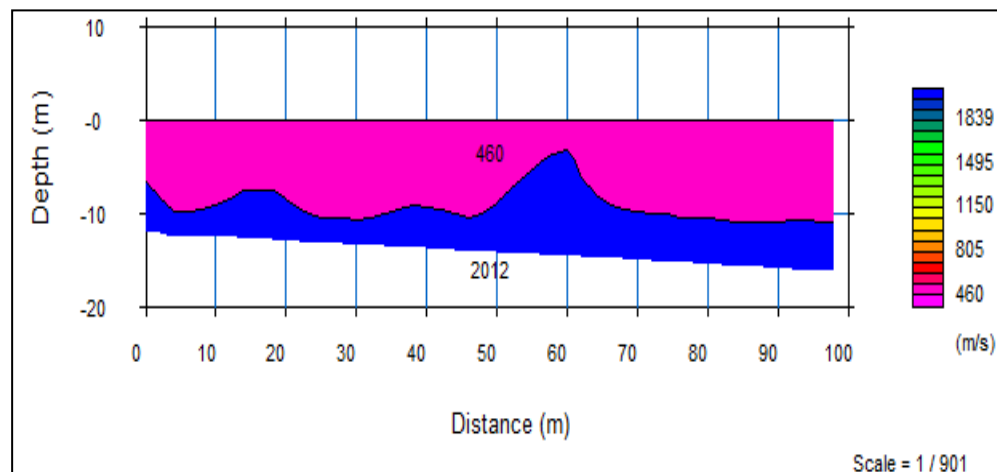

Figure 2. 2D seismic refraction section of the study area, indicating the number of layers and the values of the p-wave velocities

The result revealed that the first layer is predominantly composed of unconsolidated geologic formation which was responsible for the lower values of geotechnical parameters observed. This result was established by the borehole lithologic log of the study area which revealed the geologic formation from the topsoil to a depth of about 1.5 m as a geologic formation that is composed of peaty clay (soft geomaterials). This layer was underlain directly by wet sand deposit that is about 2.0 m in thickness. The two earlier mentioned geologic deposits were later underlain by clay and sandy clay of soft to medium-dense consistencies to a depth of 7 m in the subsurface. This type of depositional pattern is typical of a zone of coastal creeks and barrier beaches that characterize the study area. The second layer was found to have higher geotechnical parameters than the first layer. The borehole lithologic log revealed that the geologic formation in this layer is composed of sandy clay of medium dense to dense consistency. The geologic formation in this layer was found to be more competent than the first layer as this layer was found to possess high shear strength and low compressibility potential.

Geologically, the study area is located in the alluvium deposit, which is a prominent formation of a coast line area. The composition of the first layer is more recent in age of deposition than the second layer, which explained why the first layer was characterised by unconsolidated geologic formation. The weak geologic formation observed in the first layer might also be because there was no direct pressure from other geologic formation on top of this layer that could assist to hasten the consolidation of the soil deposit in this layer. Also, the second layer was found to be composed of more consolidated geological formation than the first layer, which might be because of the age of deposition, which allowed it to be compressed by the presence of other recent deposit lying on it. The pressure exerted on this layer by other geological formation lying on it helped to improve its geotechnical capability. It is worthy of mentioning that the results obtained in the present study correlated with the results of Pegah and Liu [23], in Manjil city of northern Iran, which is a similar terrain to the study area.

Therefore, the depth to the most competent geologic formation was found to be between 7 and 16 m corresponding to consolidated layer in the subsurface. This is the portion of the subsurface recommended for siting the foundation for the purpose of engineering construction. This study revealed that in any reclaimed land having similar geology, as in the study area engineering construction that is designed to provide safety and stand the test of time should be founded on the depth from the second layer.

5. Conclusion

In this study near surface seismic refraction method was used to explore the geological condition and engineering parameters of the subsurface. The observed results were correlated with the borehole lithologic log of the study area. Two different subsurface layers were revealed by the seismic method in the study area. The engineering parameters were observed to be higher in the second layer than in the first layer. The second layer corresponded to a consolidated layer on the borehole lithologic log obtained from the borehole drilled in the area, which is found to be sandy clay of medium to dense consistency. This layer was found at a depth between 7 and 16 m. It is therefore recommended that the foundation of any engineering construction that is intended to stand the test of time and offer protection to lives and property should be founded on the consolidated layer. This study revealed that in any part of the world with similar geological formation, the layers beneath the first layer should be considered for the foundation of engineering structures.

Acknowledgements

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