CHARACTERISATION OF THE ELASTIC PROPERTIES OF SOILS IN SOME PARTS OF LAGOS WETLANDS FOR ENGINEERING PURPOSES

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ABSTRACT

The results obtained from the evaluation of elastic properties of some part of Lagos Wetlands were presented for the determination of the competent soil for engineering structures. The study area falls within the reclaimed part of the Lagos wetlands signifying the presence of unstable geological materials. The study area is characterized with alluvium sediments which comprises of materials of low shear strength. Five (5) seismic profile lines were established via the ground rolling technique of Multi-Channel Analysis of Surface Waves (MASW). The data acquisition was carried out with twenty-four (24) channels 4.5Hz vertical geophones connected to the ABEM Mark 6 Terraloc Seismograph. The acquired MASW data were processed using SeisImager to obtain the two-dimensional (2-D) shear wave velocity (V_s) profiles which gives the contrast in the distribution of the velocity along each profile. In addition, dynamic parameters such as rigidity modulus, poisson ratio were estimated for further classification of the geo-earth materials in the study area. In the study area, the shear wave velocity (V_s) values obtained ranged between 94 – 1320 m/s representing different sediments such as saturated loose sand (163 – 204 m/s), loose silty sand (165- 225 m/s), medium – dense sand (220 – 350 m/s), medium dense sand (400 – 700 m/s) and dense-coarse sand (900 - 1380 m/s). However, based on these classification, it is found that saturated loose sand and loose silty sand are not competent for founding layer of engineering structures. Therefore, deep foundation inform of piling system is recommended for engineering structure that will devoid unexpected collapse and partial and differential settlement. The study has revealed that the area is generally comprise of problematic soil(s) that are inimical to construction of engineering structures.

INTRODUCTION

The design and construction of foundations for sensitive engineering structures require evaluation of the dynamic elastic properties of the subsurface soil. The dynamic moduli (such as Young's modulus, shear modulus, bulk modulus and Poisson's ratio) are measures of elastic stiffness of geo-earth materials in which the foundation are situated on (Fjaer, 2019). Being the derivatives of seismic velocities (shear wave and compressional wave velocity), they customarily give detailed subsurface information prior to the construction process. The incessant rate at which incompetent soils has contributed to engineering failures cannot be underestimated. Likewise the incongruous number of casualties reported from this menace required detailed investigation in order to avert the rate at which lives and property are being loss to collapse of engineering structures. Several authors have reported other causes of building collapse such as use of sub-standard materials, age of the building, poor supervision, bad design among others (Akintorinwa & Adesoji, 2009) (Ayolabi et al., 2012; Oyedele & Okoh, 2011).

Wetlands part of Lagos are mainly areas with sand reclamation from water bodies. These areas are described with geological sediments that are mechanically and structurally unstable for engineering construction. They comprises of sediments which are unfavorable to the founding layer of construction work such as impermeable soil layers (peat and clay) and loose sand (Ayolabi et al., 2012). To ascertain suitable foundation system for engineering constructions in this area, detailed elastic properties of the subsurface need to be assessed.

Several authors have used different parameters such as electrical resistivity or conductivity, subsurface geology and acoustic properties in describing the detailed subsurface geological information in wetlands area (Adepelumi et al., 2009; Adewoyin et al., 2017). Although, the deployment of elastic parameters in characterising the coastal soils in wetlands area has recorded limted attention. Several authors do elude the mathematical procedure involve in estimation of the elastic parameters. Nevertheless, the procedure do provide comprehensive information inform of sediment thickness, horizontal and vertical lithologic extents, depth to water table, fault zones among others.

The afore-mentioned parameters offer valuable information about the subsurface sediments thereby helping in solving geo-mechanical problems of the reclaimed sediments. The science of the dynamic elastic properties of soil have found to be worthwhile during investigation of geotechnical information. These methods have been useful in obtaining the resonance of the vibrating devices on the constructed structures, thereby testing its durability and its ingenuity. Elastic parameters are regarded as crucial factors used in studying the dynamic response analysis and soil–structure interaction problems, likewise, these parameters have been found to play an important role in the study of liquefaction potential under seismic loading (Oladunjoye et al., 2019; Maurer et al., 2014). Thus, they are useful for the characterization of soils in terms of geotechnical and mechanical (Emujakporue & Ekine, 2009; Fjaer, 2019).

Generally, elastic properties of rocks are determined using static (high strain) and dynamic (low strain) methods (Anbazhagan & Sitharam, 2006). While static methods are usually conducted in the laboratory with collected soil samples, dynamic methods use compressional and shear wave velocities as input parameters substituted into Hookean equations. The former method make use of specimens that are usually compressed within the equipment until failure is observed within the compression. Conversely, the dynamic properties of geo-earth materials are determined from the stress–strain curves that are interpreted with computer software. Generally, geophysical measurements involving seismic techniques are being increasingly used to determine the elastic properties. This is because the tests are carried out in situ at an appropriate strain rate. Geophysical methods used to obtain in situ seismic velocities include crosshole seismics, multi-channel analysis of surface waves (MASW) and surface refraction surveying techniques. However, due to their environmental, time and cost ineffectiveness, surface non-invasive seismic methods have become more favoured.

To this end, this study was embarked upon to determine the stiffness and shear strength of soil towards the construction of engineering structure in Badore part of Lagos wetlands. The study is expected to delineate the presence of any/all problem soils that can be disparaging to the foundation layer. These problem soils are exclusively include but not limited to loose - very loose sand, alluvium/saturated sand, peat/clay, etc. The characterization of sediments in the study area were carried out through the estimation of rigidity modulus and poisson ratio from shear wave velocity. The values of these parameters are prominent in determine the soil stiffness due to some mutual features. The study area is one of the reclaimed part of Lagos wetland with unstable geological sediments. Many collapsed engineering structures have been reported in the study area while some have underwent partial and differential settlement. It is believed that the study will unravel the causes of these menace while it will reveal the geophysical and geo-mechanical characteristics of the geo-earth materials in Badore and its environ.

LOCATION AND GEOLOGICAL SETTINGS OF THE AREA.

Lagos wetland is part of the coastal plain sand formation of the Dahomey Basin (Adepelumi & Olorunfemi, 2000; Oyedele et al., 2012). Lagos metropolis have been described with wet equatorial climate with mean annual rainfall that is more than 1800 mm with two main seasons, namely; the rainy season and dry season. These seasons span between April to October and October to March respectively. Lagos experiences an average temperature of 27°C. The vegetation cover is dominated by swamp forest, wetlands and tropical swamp forest comprising of fresh waters and mangrove. Generally, the pattern of relief in Lagos reflects the coastal location of the state. Water and wetlands cover over 40% of the total land area within the state and an additional 12% is subject to seasonal flooding (Iwugo et al., 2003).

The litho-stratigraphic sequence of the sediments in Lagos wetlands have been described to be from the youngest to the oldest comprising the Coastal Plain Sands, Ilaro Formation, Oshosun Formation, Akimbo Formation, Ewekoro Formation, and Abeokuta Formation in descending order (Obaje, 2009). These sediments were been underlain by Precambrian Basement Complex of Nigeria (Omatsola & Adegoke, 1981). The previous studies has described the coastal plains sands in this region to fall within the age range of Pleistocene to Oligocene. The Litho-stratigraphic of the coastal plain sands reveals that it consists of unconsolidated dry and wet sand intercalated with clay deposits (Adepelumi et al., 2009; Oyedele et al., 2012; Adeoti et al., 2016). The sediments range in size from coarse to medium grained, clean, white, loose sandy soil.

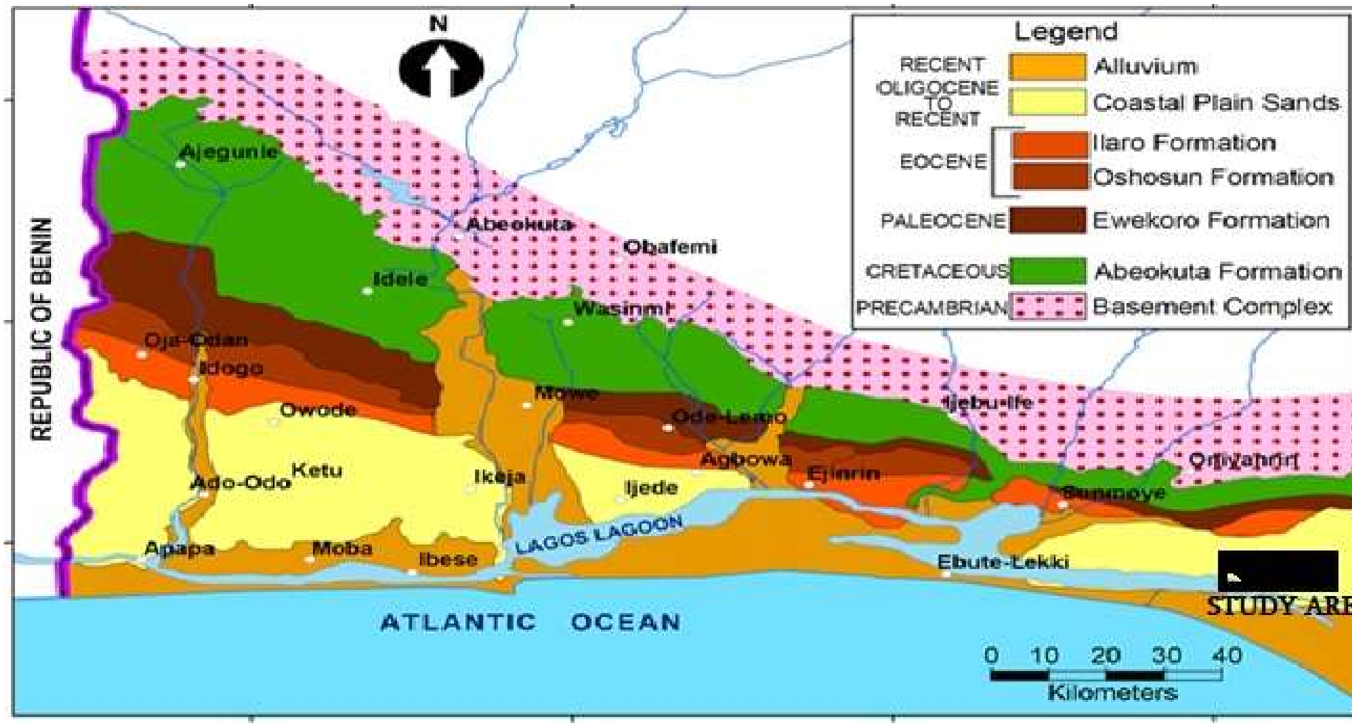

Figure1: Geology Map of Dahomey Basin indicating the Study Area

MATERIALS AND METHODS

For the purpose of this study, seismic refraction method was conducted along five (5) traverses within the study area using Multi-Channel Analysis of Surface Waves (MASW) technique. The technique has the proficiency to provide the parameters that can be used to estimate the elastic properties of the soil. Soil stiffness as a function of soil competency was generated from shear wave velocity values and its derivatives as estimated from MASW data (Xia et al., 2002; Wang et al., 2015). Ground - roll configuration of Multi-Channel Analysis of Surface Waves (MASW) technique was employed for the purpose of this study. The technique assist in determining the phase velocities from multi-shot data directly by using cross correlated traces at midpoint gathers (Stokoe et al., 2018). The MASW data was acquired with a 24-channel ABEM Terraloc Mark 6 seismograph with its sophisticated accessories. The accessories comprise of seismological geophones, geophone cables, trigger cable, source of energy (weight drop), supporting stand, battery, connecting cables, pen and recording sheet. The active source technique was employed in this study. The source was made to produce lower frequency so as to generate longer wavelength for the investigation purpose as presented in equation 1 (Xia et al., 2002; Xia et al., 2007).

$$\lambda = \frac{v}{f} \tag{1}$$

Where v is the velocity; f is frequency and λ is the wavelength.

The geophones were aligned in a linear array with equal interval based on the geophone spacing considered for each traverse. The choice of geophones intervals was to allow the optimum coverage of the study area and probing the relevant layers without masking out useful information that may aid the output of the study. The geophones were planted at equidistant measurement of 3 - 5 m along the entire line, to record shots made by the weight-drop in the study areas. The receiver spacing (dx) is related to the investigated shortest wavelength (λ_{min}) in the survey and therefore determines the shallowest resolvable depth of investigation (Xia et al., 2002; Lu, 2017).

$$Z_{min} = kdx(0.3 \leq k \leq 1.0) \tag{2}$$

The survey array lengths were made to give a reliable sampling wavelength associated with desirable frequency components of the investigation. Using the customary assumption, the array length (L) is at least equal to the maximum desired wavelength, which corresponds to more or less twice the desired investigation depth (Z). The source offset (x_1) needs to change in proportion to the maximum depth of investigation as presented in Eq. 3 (Lu, 2017)

$$X_1 \geq 0.5Z_{max} \quad (3)$$

The receiver spacing (dx) may need to be slightly dependent on the average stiffness of near-surface materials. However, a rule of thumb shows that $dx \leq 0.1Z_{max}$ (Stokoe et al., 2018). This led to the use of geophone spacing (dx) values that range between 3.0 – 5.0 m for the survey. This is adequate enough to give detailed subsurface information along the profile up to 30 m depth. Data were acquired along several parallel lines in all the locations of the study area. The data were recorded and vertically stacked with a minimum of four (4) impacts using the earlier discussed weight-drop in order to improve the signal to noise ratio. The acquisition areas are dry, free from wet alluvium and is mainly comprised of sand sediments. The standard roll-along technique was used to acquire about fifteen (15) shots along each line. The acquisition sites were properly chosen to devoid of domestic noise such as moving traffic, human activities, vibration from industrial activities. The spread of the seismic lines in the study area is presented in Figure 2.

The acquired data were processed systematically to obtain 2-D shear wave velocity profile through the generation of dispersion curves. The procedure consists of three steps, namely, the preliminary detection of surface waves, construction of the dispersion curves (image) and back-calculation the V_s variation with depth from the extracted dispersion curve. All these steps were fully automated using software called SeisImager. The software provides the result in the most accurate evaluation of the shear - wave velocity at the expense of more intensive field operations and the burden of securing a wide-open space for the array. The software provides the results in two dimensional (2-D) profiles comprising of vertical and horizontal elastic variations.

Figure 2: Base Map of the Study Area showing the Seismic Traverses.

Evaluation of Rigidity Modulus

Rigidity modulus is among the parameters deployed for the characterization of the geo-earth materials. It is derivatives of shear wave velocity (V_s) which measure the rate at which geo-earth materials responds to shear deformation and further information as regards the degree of material to shear deformation. Rigidity modulus as measured in Pascal (Pa) and multiple units of Giga-pascals (GPa) are expressed in terms of shear wave velocity and density as related in Equation (4) (Anbazhagan & Sitharam, 2006; Anbazhagan & Sitharam, 2008)

$$\mu = V_s^2 . \rho \quad (KPa) \tag{4}$$

where ρ is the density of the medium, which had a slight variation with depth (Hanumantharao & Ramana, 2008).

Evaluation of Poisson Ratio

The Poisson's ratio represents the lateral extension to longitudinal contraction. It is a measure of the geometrical change in the shape of an elastic body. Its value is 0.5 for fluids, and it approaches 0 for very hard indurated anisotropic rocks. Poisson's ratio can be determined using the following equations (5-6). Thus, Poisson ratio (σ) may be expressed as

$$\propto = \frac{V_s^2}{V_p^2} \tag{5}$$

$$\sigma = \frac{1-2\alpha}{2-2\alpha} \tag{6}$$

Table 1: Classification of Sand Sediments based on elastic parameters (After (Anbazhagan & Sitharam, 2008)

Sediments	**Poisson Ratio Value** (σ)	**Young Modulus (E)**
Loose Sand	0.20 – 0.40	10 - 25
Medium Dense Sand	0.25 – 0.40	15 - 30
Dense Sand	0.30 – 0.45	35 - 55
Silty Sand	0.20 – 0.40	10 – 20
Sand & Gravel	0.15 – 0.35	70 - 170

RESULTS AND DISCUSSION

The results of the data acquired through the seismic refraction in the study area are presented as two dimensional (2-D) shear wave velocities (V_s) profiles (Figures 15 – 17). The inverted 2-D (V_s) profiles described the variations of the shear wave velocity across the lithologic units in the study area. Likewise, the elastic dynamic parameters such as modulus of rigidity, poisson ration were estimated for the delineation of the stratigraphic sequence.

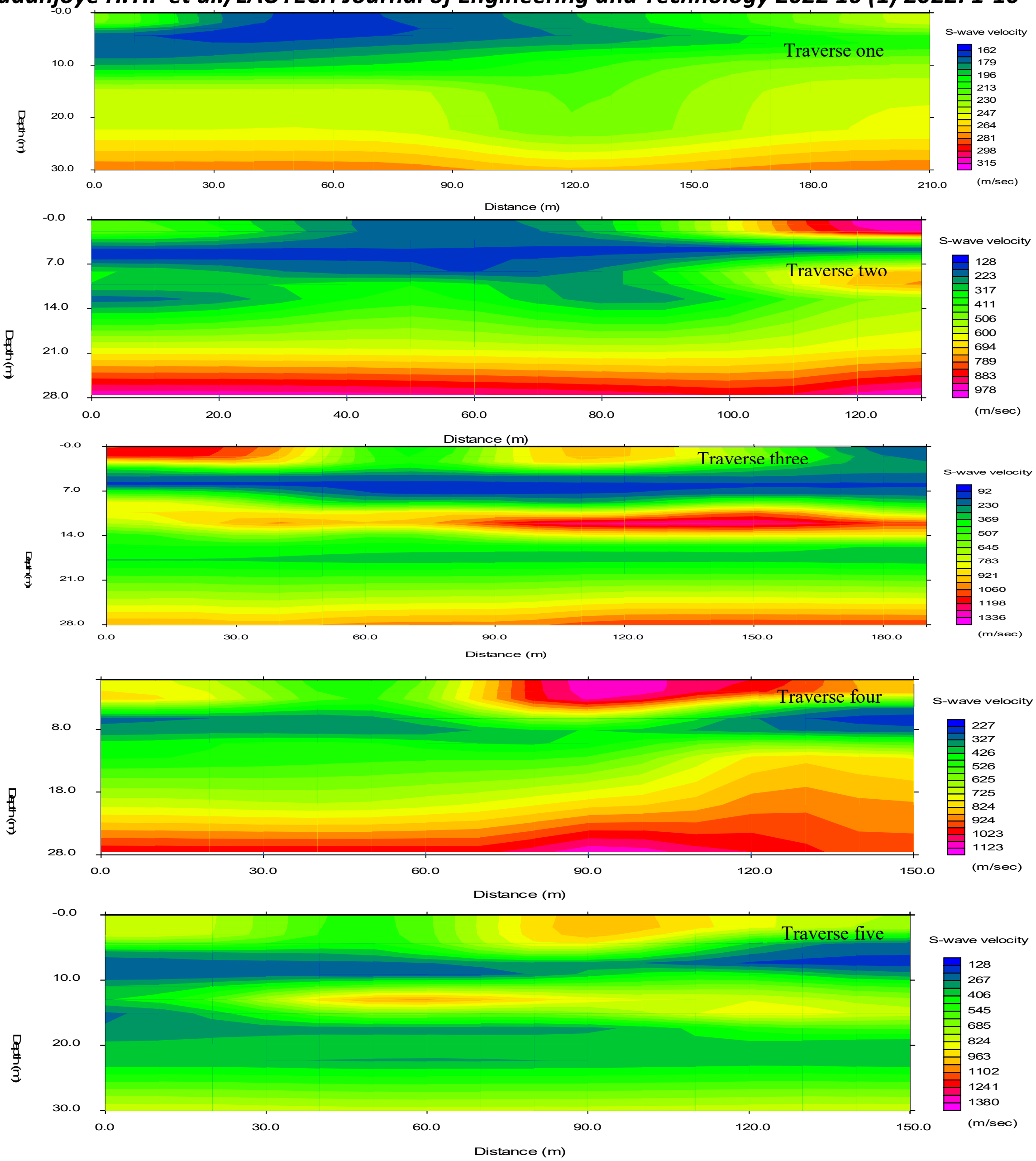

Figure 3: 2-D Shear Wave Velocity profiles across the Study Area

The shear wave velocity (V_s) values obtained along the traverse one in the study area ranged between 163 – 314 m/s within the corresponding depth value of 28.0 m from the sub-surface. The estimated shear wave velocity (V_s) values obtained in this traverse described the presence of loose sand, medium-dense sand with traces of saturation. The outlined topsoil is described with V_s values that varies between 221 – 224 m/s with thickness value of about 3.09 m. The second geologic layer showed the presence of saturated loose sand with V_s values ranging from 163 – 186 m/s with thickness value of about 7.81 m. The third and fourth geologic layers along the traverse are described with V_s values of 200 – 204 m/s and 242 – 246 m/s with corresponding depth values of 10.9 – 12.9 m and 12.9 – 22.3 m respectively. The lithology of these layers comprise of medium – dense and dense sandy layer.

The shear wave velocity V_s values estimated in traverse two and three ranged between 164 – 959 m/s and 94 – 1161 m/s with corresponding depth values of 23.0 m and 24.8 m depicting five (5) layers as shown in Figure 2. The 2-D V_s profile showed that the topsoil comprises of sediment with V_s values that loiter between 424 - 461 m/s and 466 - 1161 m/s with thickness values of 3.1 m and 3.5 m. The topsoils are underlain with sediments of low shear rigidity with V_s values of 164 – 179 m/s and 94 - 287 m/s with corresponding depth values of 3.1 – 8.1 m and 3.5 - 7.3 m respectively. The third geologic layer along these traverses comprises of medium-dense silty sand with V_s values ranging between 400 – 464 m/s and 760 - 934 m/s within the depth values of 8.1 – 10.2 m and 7.3 – 12.0 m correspondingly. It was found that sediments of low shear wave velocity with V_s values that spanned 168 – 225 m/s was delineated beneath the third geologic layer of traverse two with depth values of 10.2 – 20.5 m. On the contrary, the third geologic layer outlined in traverse three is medium-dense silty sand layer with V_s values that varies between 760 – 937 m/s with depth values that loiters 12.0 – 24.8 m. However, the fourth geologic layer obtained in traverse two depicts the presence of dense – coarse sandy layer with V_s values that varies between 900 – 959 m/s within the depth values of 20.0 – 23.0 m.

The 2-D shear wave velocity profile (V_s) obtained from the traverse four and five were presented as shown in Figure 2. The 2-D shear wave velocity showed that the lithology of the sediment varied from saturated loose – medium dense sand having shear wave velocity V_s values that ranged between 315 – 1012 m/s. The stratigraphic sequence outlined in this profile showed intercalation of medium dense sand and dense sand. The topsoil comprises of dense sand with V_s values that varies between 759 – 797 m/s with thickness value of about 4.5 m. The topsoil was underlain by sediments with medium dense silty sand having V_s values that loiters between 315 – 532 m/s spanning between depth values of 4.5 – 12.5 m. The third geologic layer along this profile is characterized with shear wave velocity values of ranging between 900 – 1012 m/s representing the dense sand with high degree of stiffness. Likewise, the traverse five showed the intercalation of sediments such as medium dense sand - saturated sand- silty sand. The Vs values outlined in this traverse ranged between 160 -1380 m/s within the depth values 30.35 m. The topsoil with thickness of 4.3 m with V_s values that ranged between 799 – 817 m/s. The topsoil was underlain with medium dense sand characterized with V_s values of 380 – 385 m/s spanning between depth values of 4.3 – 5.8 m. The third and fifth geologic comprises of sand layer with varying degree of saturation. The estimated V_s values outlined in this area are 160 – 236 m/s and 277 – 300 m/s with corresponding thickness values of 5.1 m and 9.4 m respectively. On the contrary, the sixth geologic comprises of sediments with dense sand having the V_s values of 1200 – 1380 m/s within depth values of 22.3 – 30 m.

Elastic Dynamic Parameters.

Bulk modulus and Poisson ratio values were estimated for further characterization of the stratigraphic sequence in the study area. These parameters were presented in Table 2. These parameters were estimated using eqtn 3 – 4, whereas, the stratigraphic characterization was achieved using table 1.

The bulk modulus and poison ratio values evaluated in the study area varies between 3.8 - 51.6 and 0.35 – 0.48 describing the sediments within Loose Silty, Medium Silty and Dense - Coarse Sand with varying degree of saturation. From table 2, traverse 1 showed the presence of saturated Loose sand within the depth values of 3.09 – 12.90 m with bulk modulus and Poisson ratio values of 3.8- 4.0 and 0.35 respectively. The third and fourth geologic layer showed the presence of competent geo-earth materials with bulk modulus that ranged between 12.4 and 22.7; 30.0 and 36.0 with corresponding Poisson ratio of 0.48. These layers depicts the presence of medium-dense sand and dense sandy layer. Similarly, the third and fourth geologic layer in traverse two represent the stiff layer suitable for engineering structure. They are described with bulk modulus values of 18.1 – 24.1 and 30.0 – 38. 2 with equivalent Poisson ration value of 0.38.

Traverse	Depth (m)	Vs (m/s)	Bulk Modulus (E) (MN/m^2)	Poisson Ratio (v)	Inferred Lithologic Unit
Traverse 1	0.00 – 3.0	221 – 224	18.2 – 20.0	0.48	Topsoil
	3.0 – 12.9	163 – 204	3.8 – 4.0	0.35	Saturated Loose Sand
	12.9 – 22.3	242 – 300	12.4 – 22.7	0.48	Medium - Dense Sand
	22.3 – 30.3	300 – 314	30.0 – 36.0	0.48	Dense Sandy Layer
Traverse 2	0.00 – 3.10	424 – 461	13.5 – 15.7	0.46	Topsoil
	3.1 – 8.1	164 – 179	3.7 – 3.8	0.36	Saturated Loose Sand
	8.1 – 10.2	400 – 460	15.0 – 25.9	0.40	Medium Dense Sand
	10.2 – 12.5	168 – 225	18.1 – 24.1	0.48	Loose Silty Sand
	12.5 – 20.0	900 – 959	30.0 – 38.2	0.40	Dense – Coarse Sand
Traverse 3	0.00 – 2.5	1120 – 1162	19.3 – 20.2	0.37	Topsoil
	2.5 – 4.6	287 – 466	15.2 – 26.1	0.48	Medium Dense Silty Sand
	4.6 – 7.3	94.0 – 181	13.9 – 18.9	0.49	Loose Silty Sand
	7.3 – 17.8	308 – 760	18.5 – 20.0	0.41	Loose – Medium Dense Silty Sand
	17.8 – 24.2	1100 – 1162	40.0 – 50.2	0.37	Dense – Coarse Sand
Traverse 4	0.00 – 4.5	759 – 797	14.9 – 17.4	0.42	Topsoil
	4.5 – 10.2	315 – 353	16.8 – 19.1	0.48	Silty Sand
	10.2 – 20.0	405 – 532	22.3 – 30.2	0.45	Medium Dense Silty Sand
	20.0 – 24.0	900 – 1012	40.2 – 51.6	0.39	Dense – Coarse Sand
Traverse	**Depth (m)**	**Vs (m/s)**	**Bulk Modulus (E) (MN/m^2)**	**Poisson Ratio (v)**	**Inferred Lithologic Unit**
Traverse 5	0.00 – 4.3	799 – 817	17.5 – 18.7	0.41	Topsoil
	4.3 – 10.9	160 – 300	3.7 – 5.0	0.49	Saturated – Loose Silty Sand
	10.9 – 12.9	500 – 525	19.0 – 29.7	0.45	Medium Dense Silty Sand
	12.9 – 28.0	277 – 385	12.0 – 15.0	0.48	Loose – Medium Silty Sand
	28.0 – 30.0	1200 – 1380	30.0 – 31.7	0.34	Dense – Coarse Sand

CONCLUSION

The elastic properties of soils within some parts of Lagos Wetlands have been evaluated using MASW. The 2-D shear wave velocity (V_s) were obtained across all the traverses in the study area. Also, the dynamic parameters were evaluated in order to corroborate the estimated stiffness as evaluated from 2-D profile. The study revealed the presence of sand sediments with varying grades and traces of saturation.

The integrated approach showed that the study area are generally comprises of sand sediments of varying degrees but intercalated at different depth interval. These sediments are mainly the loose sand, loose silty sand, medium to dense sand, dense sand and dense to coarse sand. The traverses in the study area demonstrated the presence of stiff layer competent for engineering structures with third and fourth geologic layer. These layers were outlined from the depth values of 10.0 m indicating that founding layer should not be shallower than this depth in order to provide adequate support for the engineering structure.

The estimated elastic parameters obtained from this study demonstrated a dynamic and useful approach for characterizing subsoil and thus providing detailed information towards the preparation of construction foundation of any engineering structures. Although, geotechnical method has been proven to be more effective in obtaining strength of subsoil prior to erection of engineering structure, but, the dynamic parameters of the subsoil as evaluated from seismic method offer the shear strength parameters vis-à-vis the stiffness with respect to the depth in the study area. Similarly, this approach is advantageous over geotechnical method. It is less expensive, the survey area extends to larger area when compared to geotechnical method which is mainly point test. Conclusively, the competent sediment for high rise structure in some part of Lagos wetlands are found to be within the depth values of 10 m downward. The saturated loose sand has to be evaded in order to avoid quick sand or settlement of the founding layer. Therefore, it is advisable that dewatering technique should be carried out and the foundation should be allowed to rest on deep foundation in form of piling system.

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