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Building Distress Evaluation Using Seismic Refraction and Multichannel Analysis of Surface Waves: A Case Study of Millennium Estate Araromi, Gbagada, Lagos, South-Western, Nigeria

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ABSTRACT

Integration of Seismic refraction and Multichannel Analysis of Surface Waves (MASW) was used to assess the subsurface information in order to establish the causes of sinking and tilting of buildings at Millennium Estate Gbagada, Lagos. Four traverses of equal length of 69 m were picked oriented in the north to south. Seismic data were collected using the ABEM Terraloc Mk.6 with a 24channel recording system. Forward and reverse shooting as well as Multichannel Analysis of Surface Waves (MASW) using split spread shooting methods were carried out within the study area. Each collected shot record of the surface wave was quality controlled and processed using the Seisimager software. The results indicate the presence of three subsurface layers with the first layer having velocity 300 m/s and thickness 1.0 – 6.0m, representing topsoil (clayey materials). The second refractive layer is composed of dry loose sandy soil with thickness 6.0 – 13.0 m and velocity 580 – 700 m/s. The third refractive layer consists of saturated clay materials (clay and shale) with a velocity of 1000 m/s. The delineated refractive layers are characterized by an increase in velocity with depth. The results of both approaches reveal that the topsoil (Clay), loose sand, and saturated clay/shale unit are incompetent materials, thus leading to the sinking and tilting of buildings within the study area. This study has been able to use integrated methods of geophysical investigation to provide an understanding of the subsurface condition for evaluating building distress.

1. Introduction

Building is a universal problem that has eaten deeply into the fabrics of the construction industry, of which very little has been done to curb the menace. Nigeria like many other countries is witnessing the collapse of engineering structures at an alarming rate in many of its cities across the country (Olagunju *et al.*, 2013). Once a building is properly constructed, they are expected to be in use for a long time. Although every society has its own problems and Nigeria is not an exception yet the very recent challenges of buildings collapsing in various locations in the country

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are giving the various arms of government and the people of Nigeria source of concern in view of the enormous loss of huge investments in housing, properties and human life.

Some key factors to be observed in building construction include durability, adequate stability to prevent its failure or discomfort to the users, resistance to weather, fire outbreak and other forms of accidents (Oloyede *et al.*, *2017*). Therefore, a detailed investigation of the subsurface material of the proposed site is an important task needed to be considered before the erection of any structure to avoid foundation failure and undue loss of lives and properties.

The seismic refraction surveying method is normally used to locate refraction interfaces separating layers of different seismic velocities. The method is well suited for estimating the stiffness of the soil for engineering purposes and estimation of rock rip-ability. Multi-channel Analysis of Surface Waves (MASW) is a very useful method for investigating the shallow geological structures and, in particular, the relative shear strength of subsurface materials. By incorporating density values for the local bedrock and overburdened sediments it is possible to derive their shear modulus often referred to as dynamic ground stiffness (Mario *et al.*, 2020).

Extensively, several studies have been carried out on the evaluation of building distress using the integrated geophysical and geotechnical approaches. Some of the geophysical methods used include multi-channel analysis of surface wave (MASW), ground-penetrating radar (GPR), and 2-D electrical resistivity tomography (ERT). These methods are used around the affected building to help detect possible causes of deterioration (Fathy *et al.*, 2012). Building distress evaluation has been investigated with the seismic refraction method. Sangodiji and Olorunfemi, (2013) applied seismic refraction survey at part of Mowe along Lagos/Ibadan expressway Southwest, Nigeria, and its engineering significance Anukwu *et al.* (2017) evaluate the potency of the multichannel analysis of the surface wave techniques in a geological composite terrain. The application of MASW for site characterization has helped to delineate zones suitable for construction, and the site classification based on National Earthquake Hazard Reduction Provision (NEHRP) (Abubakar *et al.*, 2020). A number of principal engineering problems which include dams, bridges, reservoirs, huge and heavy constructions that can cause the failure of engineering structures have been identified in which geophysical methods find their application (Aigbedion, 2007). This is as a result of the unique window in which geophysics offers into the earth as a means of detecting subsurface conditions. For the past two decades, geophysics has proved quite relevant in building and site investigations and several of these engineering and geological problems have been successfully solved by geophysical methods (Nelson and Haigh, 1990, Adiat *et al*. 2009).

The study area investigated, exists within the Gbagada axis of Lagos. The site is a consulting firm currently undergoing construction and is situated around residential zones. At the time of this study, some major tilting and foundation depressions which will, in turn, lead to building failure were observed on the scene, and being a residential area in one of the fastest-growing cities in the world, there is a high demand for shelter to meet the demand of the ever shooting population. In this study, Seismic refraction and MASW were used to access the cause of building distress at Millenium Estate Araromi, Gbagada, Lagos State, south-western, Nigeria.

1.1 Study Area

The study area is located at Owolabi Salis Cresent, Millennium Estate, Gbagada, Lagos State. Nigeria. The location falls within the Dahomey Basin Figure 1 and is characterized by alternating wet and dry seasons. It is a residential area with uneven topography. The topography is low lying the site is located within the sub-equatorial climate belt with tropical rain forest vegetation. Table 1 shows the Stratigraphy of Nigeria eastern sector of Dahomey Basin (Nfor *et al.*, 2007).

Table 1: Stratigraphy of Nigerian eastern sector of Dahomey Basin (Omatsola and Adegoke, 1981)

Age	Formation	Lithology
Pleistocene-Oligocene	Coastal Plain Sands	
Eocene	Ilaro, Oshosun	
Palaeocene	Akinbo, Ewekoro	
Maastrichtian-Neocomian	Araromi, Afowo, Ise	
Precambrian	Crystalline Basement	

The vegetative cover of Lagos is characterized by two main types of vegetation, the swamp forest of the coastal belt and the dry lowland rain forest. The swamp forest in the state area is a combination of mangrove forest and coastal vegetation developed under the brackish conditions of the coastal areas and the swamp of the freshwater lagoons and estuarine. Figure 2 shows the location chat of the study area (Nfor *et al.*, 2007).

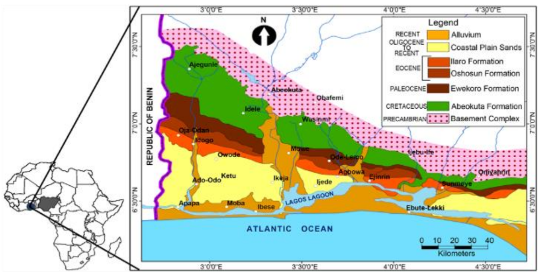

Figure 1: Map of Africa showing the location of Nigeria and the generalized geological map of the eastern Dahomey Basin (Gebhardt *et al.*, 2010)

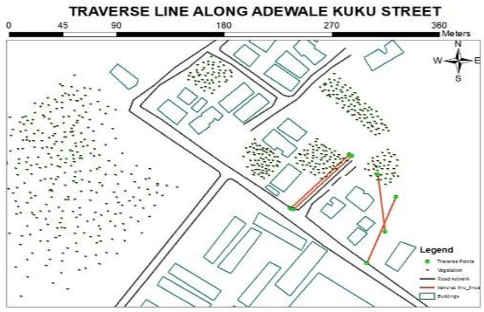

Figure 2: Location Chat of the study area

2. Methodology

2.1 Basic Theory of Seismic Refraction Method

The seismic method makes use of the properties of the velocity of sound. The method involves a geophysical principle governed by Snell's Law, which it describe the relationship between seismic wave angles of refraction when passing through a boundary between two different isotropic media, like soil to bedrock for instance (Xia *et al.*, 1999).

The velocity of propagation of a body wave in any material is given by V,

$$V = \left[\frac{Appropriate\ elastic\ modulus\ of\ the\ material}{Density\ of\ the\ material}\right]^{1/2} \quad (1)$$

Where the velocity of compressional wave V_p is given by;

$$Vp = \left[\frac{\varphi}{\rho}\right]^{1/2} \quad (2)$$

$$\varphi = [k + 4/3\mu] \quad (3)$$

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

Where, ρ = density; μ = shear modulus (stiffness),

K = bulk modulus; φ = axial modulus

The multichannel analysis of surface waves (MASW) is a non-invasive and environment-friendly method that is suitable for the estimations of shear-wave velocity as a function of depth (Xia *et al.,* 1999). The travel time is represented by equation 5, where the frequency is represented in hertz and the phase difference is in radians.

(5)

The wave velocity, V can then be measured by relating the known distance between the receivers spread and travel time, as presented in equation 6

(6)

2.2 Data Acquisition

A total of four (4) seismic refraction profiles were mapped within the study area. These profiles were taken at different locations in order to have an optimum coverage of the study area. In the field configuration for the seismic refraction, the twenty four geophones are positioned symmetrically along a straight line. Forward, reverse and midpoint shots were carried out at each location with a single spread of 69 m and a spacing of 3 m. The data acquired for surface wave analysis using the MASW technique were generally with offsets designed based on target dimensions and depths. The suggested parameters for the set of MASW survey are presented in Table 1 and the relationship between soil type, and P-wave and S-wave velocities in Table 2.

2.3 Data Processing

The acquired seismic Refraction Tomography data were processed and interpreted using the software package SeisImager/2D The first stage involved accurate picking of the first breaks from the seismic signal by using Pickwin program for every shot record to obtained time-distance curves. The time-distance curves constructed was based on the distance along the survey line, geophone spacing, source location and the first arrival time. The second stage was to analyzed time-distance curves which were generated from each seismic line by using Plotrefa program. These curves were corrected and checked for the exact estimation of the P-waves velocity. The third stage was the modeling of the velocity-depth profiles from the observed seismic velocity by a tomographic inversion method provided by Plotrefa program. Finally, the depth-velocity models which is represented in 2D form converts the tomogram to a layered model to better represent the layered nature of the geology.

In like manner, the acquired MASW data were processed and interpreted using Seisimager/SW software to determine shear wave velocity (V_s). The first step in the analysis was making the file list in which all waveform files and source receiver configurations were mentioned and then cross correlation CMP gather were calculated. Dispersion curves were also calculated by converting them into frequency domain through Fourier transformation of data and then checked. Generation of a dispersion curve is one of the most critical steps for generating an accurate shear wave velocity profile. Dispersion curves are generally displayed as phase velocity versus frequency. The 1D shear wave velocity profiles are calculated using non-linear least square method using the dispersion data. The sequence of processing is shown in Figure 3.

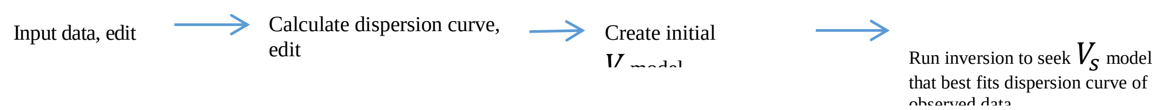

Figure 3: Processing Sequence of MASW (Park, 2013)

Table 1: Suggested parameters for setup of MASW survey (Parker *et al.*, 2007)

Material type	Optimum geophone (Hz)	Optimum source (Kg)	Recording time (ms)	Sampling interval (ms)
Very soft (Vs.<100)	4.5	25.0	1000	1.0
Soft (100<Vs.<300)	4.5	25.0	1000	1.0
Hard (200<Vs.<500)	4.5 – 10.0	25.0	500	0.5
Very hard (500<Vs.)	4.5 – 40.0	25.0	500	0.5

Table 2: Showing relationship between soil type, and P-wave and S-wave velocities (Avseth et al, 2005).

Type of formation	P-wave velocity (m/s)	S-wave velocity (m/s)	Density (g/cm^3)
Scree, vegetal soil	100-700	100-300	1.7-2.4
Dry sands	400-1200	100-500	1.5-1.7
Wet sands	1500-2000	400-600	1.9-2.1
Saturated shales and clays	1100-2500	200-800	2.0-2.4
Marls	2000-3000	750-1500	2.1-2.6
Saturated shale and sand sections	1500-2200	500-750	2.1-2.4
Porous and saturated sandstones	2000-3500	800-1800	2.1-2.4
Limestones	3500-6000	2000-3300	2.4-2.7
Chalk	2300-2600	1100-1300	1.8-3.1
Salt	4500-5500	2500-3100	2.1-2.3
Anhydrite	4000-5500	2200-3100	2.9-3.0
Dolomite	3500-6500	1900-3600	2.5-2.9
Granite	4500-6000	2500-3300	2.5-2.7
Basalt	5000-6000	2800-3400	2.7-3.1
Gneiss	4400-5200	2700-3200	2.5-2.7
Coal	2200-2700	1000-1400	1.3-1.8
Water	1450-1500	-	1.0
Ice	3400-3800	1700-1900	0.9
Oil	1200-1250	-	0.6-0.9

3. Results and Discussion

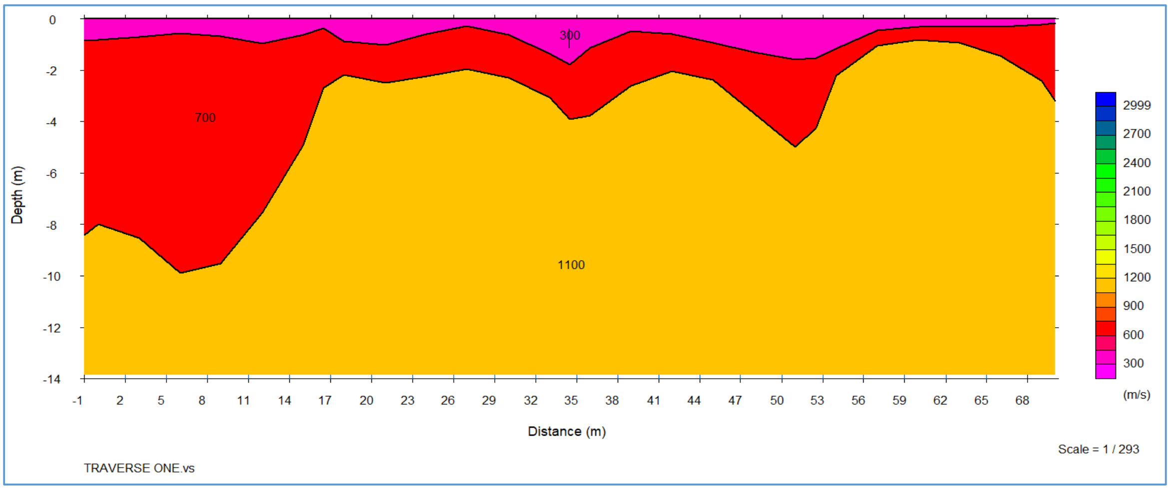

Figure 4: Compressional wave velocity result across traverse one

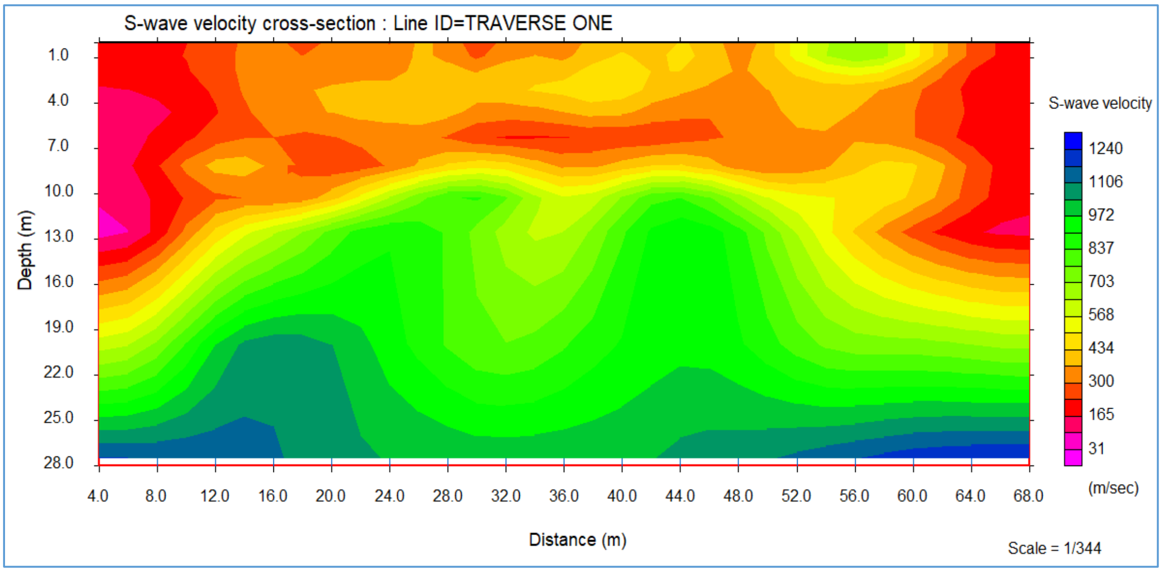

Figure 5: Shear Wave Velocity Model of Traverse One in the Study Area

Figure 5: Shear Wave Velocity Model of Traverse One in the Study Area.

Figure 4 shows the velocities with respective thicknesses of the various layers and the dip interface between the layers along Traverse One. The traverse line reveals three layers with average velocities of 300 m/s, 700 m/s, and 1100 m/s for the first, second and third layers respectively. The velocities indicate that the first layer which is the topsoil (clayey materials) which extends to an average depth of 1 m, the second layer dry loose sand extending to 8 m deep and the third layer may be made of saturated clay material which covers to the depth of about 14 m across the traverse line.

Figure 5 shows the inverted shear wave velocity model of Traverse One probing to about 28 m deep. From the surface to depth of about 16 m, the shear wave velocity is ranging from about 31 –330 m/s depicting dry sands. Underneath the dry sands to the depth of about 25 m lies the saturated shale and clays with a shear wave velocity of range 350 – 950 m/s. Then below the saturated shale and clays to the depth of about 28 m are the marls with shear wave velocity ranging from about 900 – 1240 m/s.

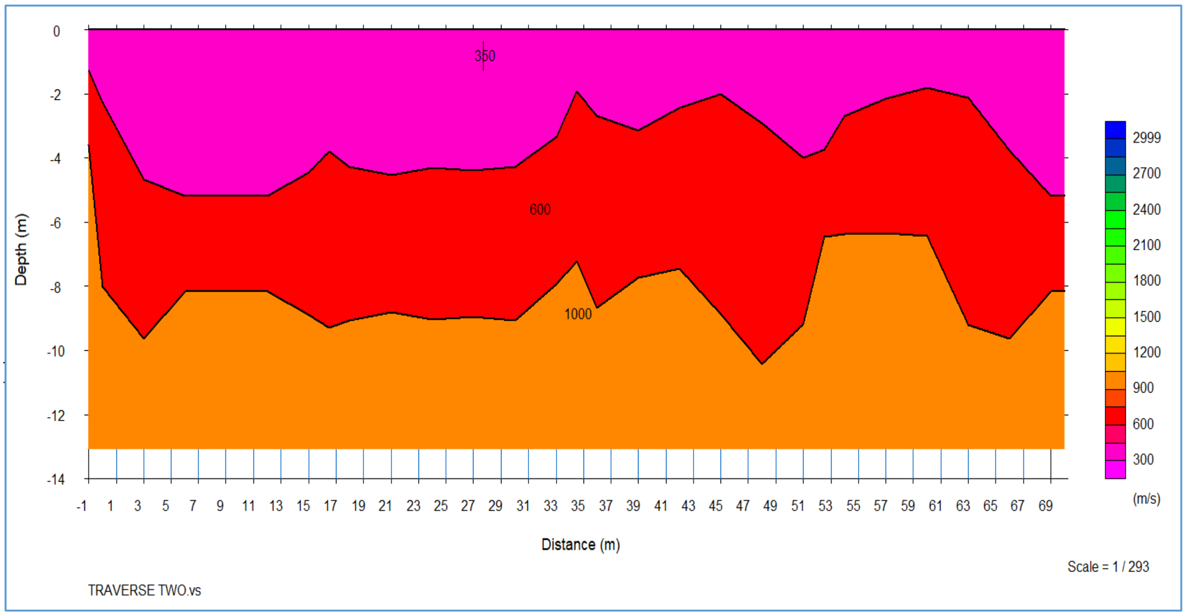

Figure 6: Compressional wave velocity result across traverse two

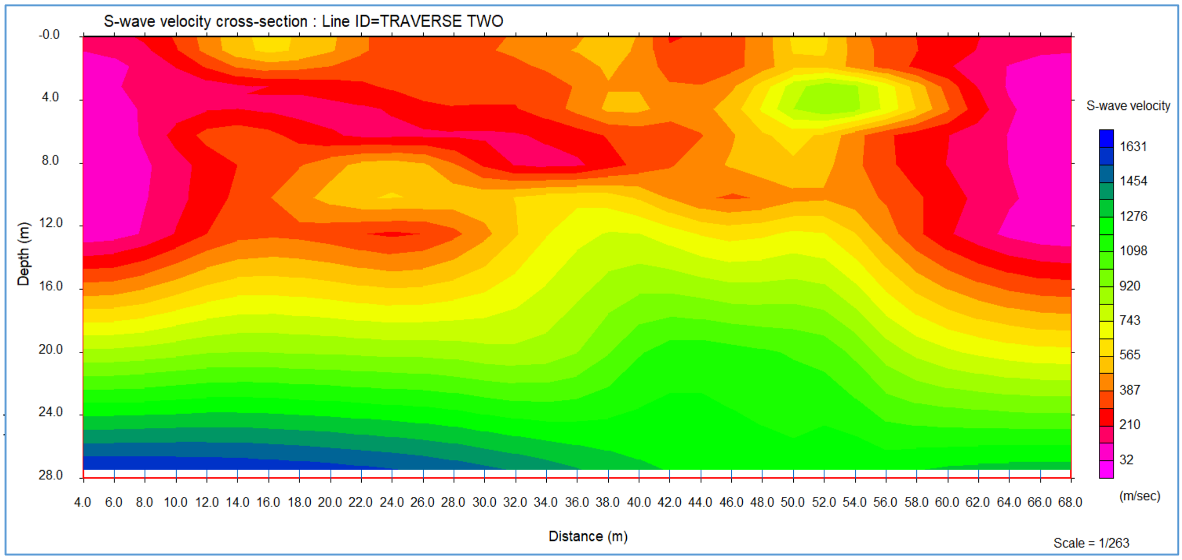

Figure 7: Shear Wave Velocity Model of Traverse Two in the Study Area.

Figure 6 shows the velocities with respective thicknesses of the various layers and the dip interface between the layers along Traverse Two. The traverse line reveals three layers with average velocities of 300 m/s, 600 m/s, and 1000 m/s for the first, second and third layers respectively. The velocities indicate that the first layer which is the topsoil (clayey materials), the second layer dry loose sand and the third layer may be made of saturated clay material.

Figure 7 shows the inverted shear wave velocity model of Traverse Two probing to about 28 m deep revealing the distribution of the subsoil across the traverse line. From the surface to depth of about 16 m, the shear wave velocity is ranging from about 30 –387 m/s depicting loose dry sands with pocket of saturated shale and clay with range of 387 – 800 m/s. Underneath the loose dry sands to the depth of about 28 m lies the saturated shale / clays and marls with a shear wave

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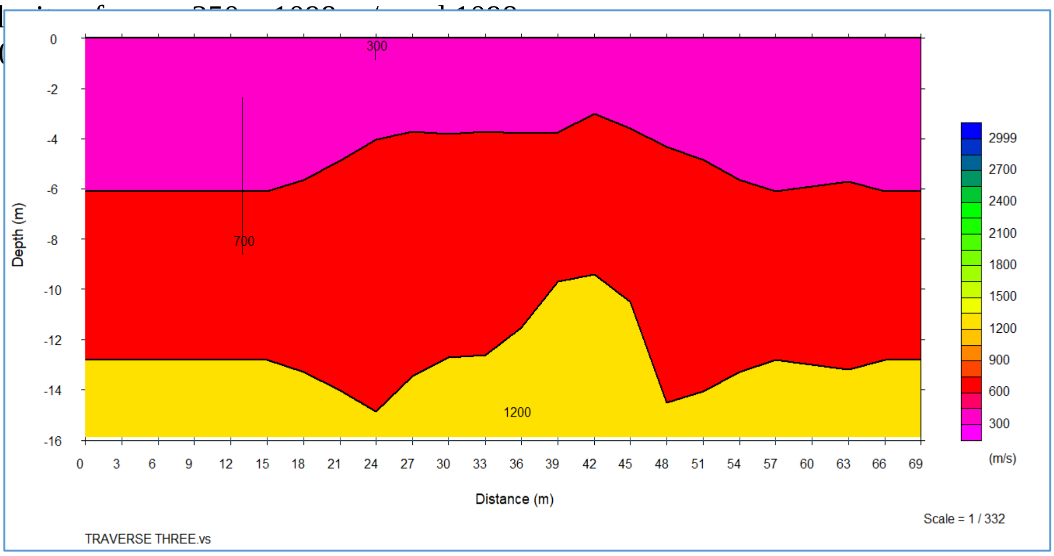

Figure 8: Compressional wave velocity result across traverse three

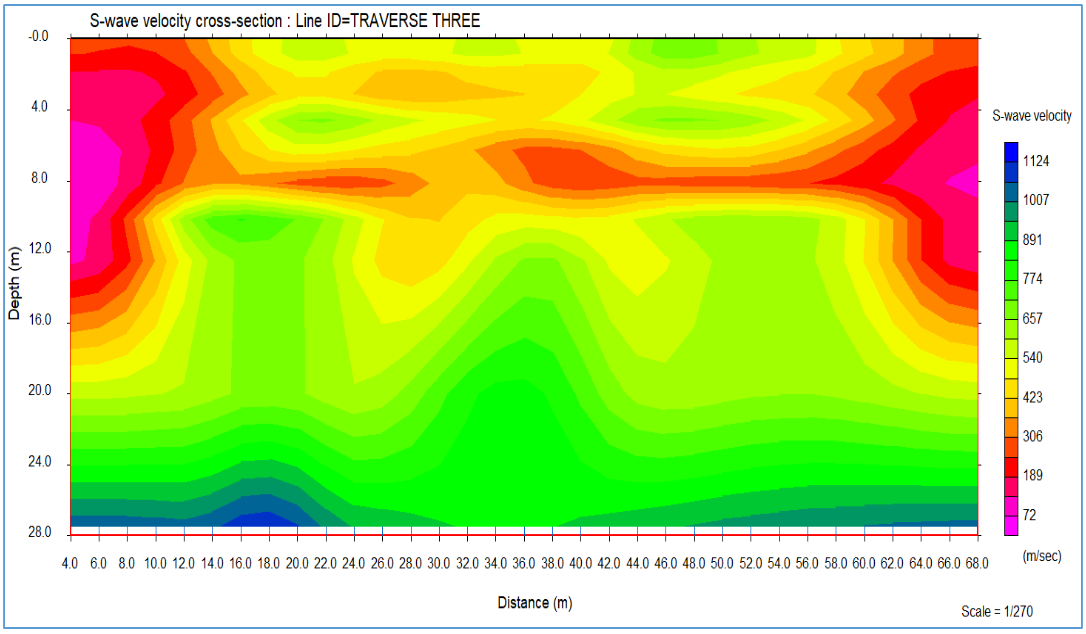

Figure 9: Shear Wave Velocity Model of Traverse Three in the Study Area.

Figure 8 shows the velocities with respective thicknesses of the various layers and the dip interface between the layers along Traverse Three. The traverse line reveals three layers with average velocities of 300 m/s, 700 m/s, and 1200 m/s for the first, second and third layers respectively. The velocities indicate that the first layer which is the topsoil (clayey materials) which extends to an average depth of 6 m, the second layer dry loose sand extending to about 13 m deep and the third layer may be made of saturated clay material which covers to the depth of about 14 m across the traverse line.

Figure 9 shows the inverted shear wave velocity model of Traverse Three probing to about 28 m deep. From the surface to depth of about 16 m, the shear wave velocity is ranging from about 30 – 300 m/s depicting dry sands with a large expanse laterally, within the distance of 14 – 62 m, of saturated shale and clay with shear wave velocity ranging from 310 – 660 m/s. Underneath the dry sands to the depth of about 25 m lies the saturated shale / clays and marls with a shear wave velocity of range 310 – 1124 m/s

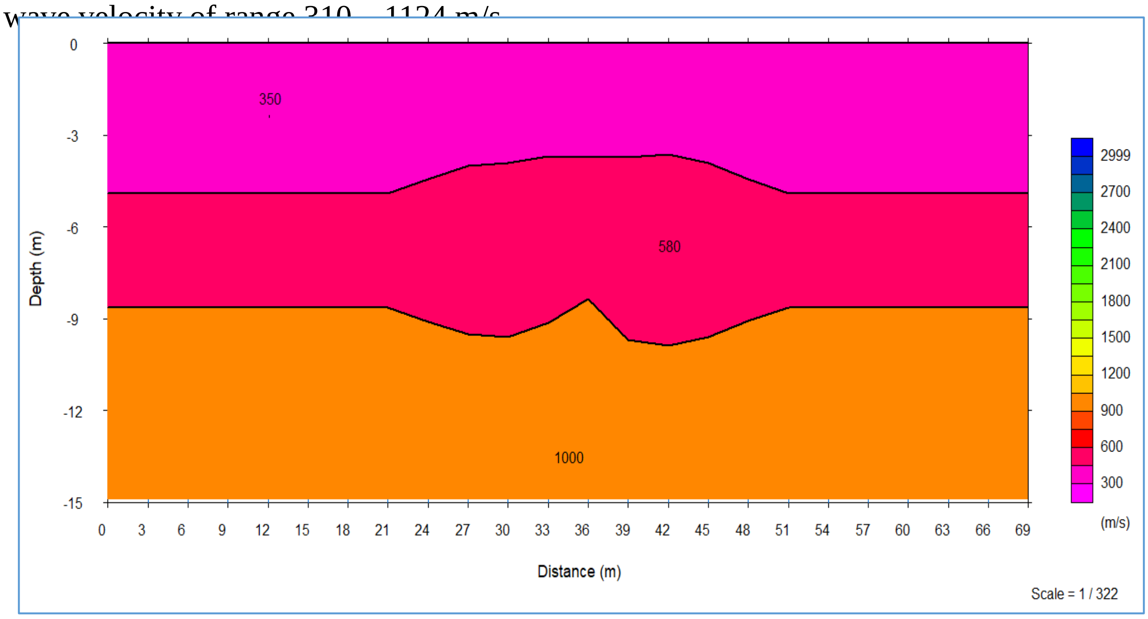

Figure 10: Compressional wave velocity result across traverse four

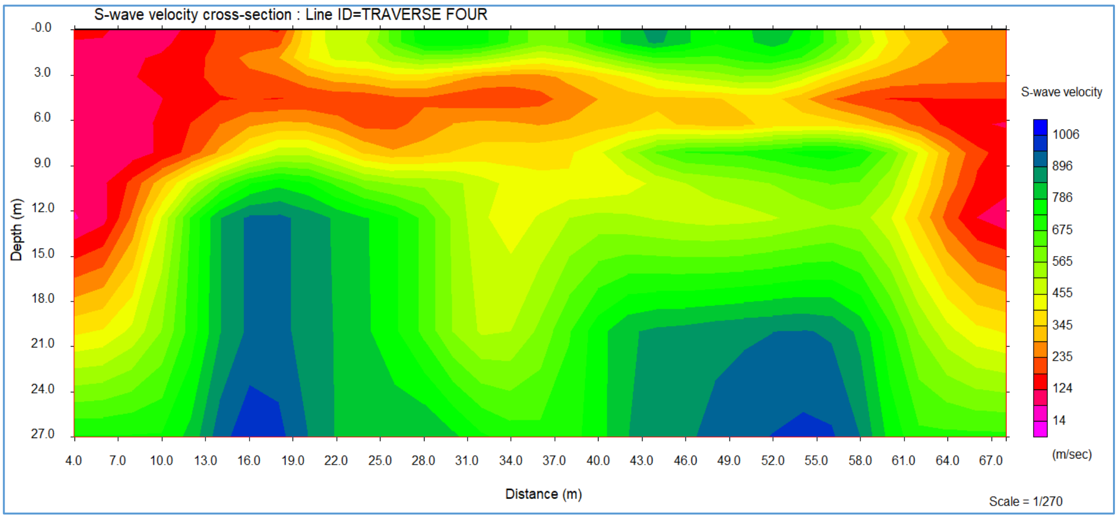

Figure 11: Shear Wave Velocity Model of Traverse Four in the Study Area

Figure 10 shows the velocities with respective thicknesses of the various layers and the dip interface between the layers along Traverse One. The traverse line reveals three layers with average velocities of 300 m/s, 580 m/s, and 1000 m/s for the first, second and third layers respectively. The velocities indicate that the first layer which is the topsoil (clayey materials) which extends to an average depth of 5 m, the second layer dry loose sand extending to 8.5 m deep and the third layer may be made of saturated clay material which covers to the depth of about 15 m across the traverse line.

Figure 11 shows the inverted shear wave velocity model of Traverse Four probing to 27 m deep. From the lateral distance of 0 – 19 m and 61 – 68 m on land from the surface to the depth of about 16 m, the shear wave velocity is ranging from about 31 – 125 m/s depicting loose dry sands while in-between this section lies the saturated shale and clays which exist from the surface to the depth of about 5 m with shear wave velocity of range 345 – 800 m/s. Underneath this layer lies the saturated shale / clays which extends to the depth of about 25 m with a shear wave velocity of range 345 – 800 m/s but there exist portions of marls with shear wave velocity of range 800 – 1000 m/s.

4. Conclusion

This study revealed that the subsurface geology of the area is made up of three (3) layers comprising clayey materials, Dry loose sand, Clay and Shale. The soil types in this area do not favor building construction as clay/shale tends to shrink and swell, leading to differential settlement. This unstable seasonal behavior of the clay makes foundation to lose its integrity within a short time after construction of buildings.

Results from this geophysical survey identified the most probable causes of failure to include; the top soil (Clay) is a very porous and possesses low permeability. As a result of its poor pore connectivity, it has the ability to retain a lot of water and swell. This would lead to deformation which would eventually result in foundation failure. The soil type in the area is the reason for the differential settlement, as most of the buildings are tilting to the point of contact.

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