



# **Estimation of Shear Wave Velocity for Near-surface Characterisation; Case Study: Ifako/Gbagada Area of Lagos State, S.W. Nigeria**

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## **Authors' contributions**

*This work was carried out in collaboration of the authors. Author BAR designed the study correlated the results and made the first draft. Author OBG made the literature review, managed the analyses of the study and literature searches and made the final draft. Both the authors read and approved the final manuscript.*

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## **ABSTRACT**

Near-surface shear-wave velocity profiles were acquired at four locations; these at strategic stations in Ifako/Gbagada a sub-urban area in Lagos State. The geophysical surveyed obtained the shear-wave velocity data using Multichannel Analysis of Surface Waves (MASW) technique. These data were acquired with a view to delineating the existing or potential hazards relating to subsidence, distressing and weakening of structures above the earth which is important to public safety, mitigation of property damage and to see the effectiveness of MASW technique in engineering site investigation. The processing method was fully automated by software called SURFSEIS. The study showed that the entire profiles depicted a very low shear-wave velocity (~80m/s to 160m/s) region down to 15m, a signature of saturated peaty/clayey formation. Thus, subsidence, distressing and weakening of structures were inferred to probably resulted from the loose nature of the subsurface soil.

**Keywords:** *Geophysical; near-surface; MASW; subsidence; Ifako/Gbagada.*

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## **1. INTRODUCTION**

A number of geophysical methods have been proposed for near-surface characterization, borehole logging is generally considered the standard for obtaining shear wave velocity ( $V_s$ ) data [1] but such measurements are not cost effective and environmentally friendly because several boreholes need to be drilled and this tends to cause difficulties in urban areas. This has led to the development of numerous surface acquisition techniques to obtain shallow shear wave velocity. Geophysical imaging methods provide solution to a wide range of environmental and engineering problems: protection of soil and groundwater from contamination, geotechnical site testing for underground vault [2]. It has been a well-established fact that a detailed dynamic analysis and design of built environment that takes into account the behaviour of local soil deposits reduces the loss of life and damage to infrastructure.

Described a high-resolution seismic reflection as a good tool for detecting fracture zones in granitic rocks [3]. The combination of P- and S- velocity information enables calculation of Poisson's ratio and if an estimate of density is available the dynamic elastic constants may be calculated directly from a number of well-known equations [4].

In his shear-wave refraction study were able to trace the course of the vallum between March Burn and the Fort [5]. Thus, there was a good velocity contrast between the overburden and the bedrock. Recently, interest in the large amount of information contained in surface waves has increased. However, the use of surface waves on an intermediate scale is diffused engineering. Shear wave velocity or shear modulus at very low strains is the most important input parameter in the analysis of engineering problems. It is widely accepted that the shear wave velocity profile of a site is a fundamental parameter to estimate specific amplification factor [6].

Surface waves exist only in media with a free surface and they propagate in a limited layer close to the surface, the layer having a thickness that is roughly equal to one wavelength. Hence, in same medium, waves of different wavelength affect different depth. If the medium is not homogeneous, they propagate with different velocities and different attenuations in different materials [7]. Therefore the velocity of propagation can be strongly frequency-dependent (dispersion) according to geometric distribution of the soil properties [8].

Surface waves can also be used for locating and detecting near-surface objects [9,10].

The determination of acoustic parameters of rock, particularly the elastic moduli has important application in assessing the response of structures to static and dynamic loads [11,12]. In general, the dynamic elastic moduli determined by Multi-Channel Analysis of Surface Wave technique, tend to yield higher values than those determined by static method [13].

The advent of Multichannel surface wave recording has opened way for developing another method of measurement of shear-wave velocity. The shear wave velocity ( $V_s$ ) is one of the most important input parameter to represent the stiffness of the soil layers. Surface wave techniques are the simple and efficient tool to measure shear wave velocity in the field as compare to other in situ methods. In most geotechnical investigation programs, dynamic in situ tests are usually not conducted due to cost considerations, point evaluation and lack of specialized personnel. The  $V_s$  profiles (1D, 2D) are generated by carrying out MASW (Multichannel Analysis of Surface Waves) tests at four locations in the study area.

MASW technique was developed to overcome the shortcomings of Spectral Analysis of Surface waves (SASW) in the presence of noise [14]. The simultaneous recording of 12 or more receivers at short (1-2m) to long (50-100m) distances from an impulsive or vibratory source gives statistical redundancy to the measurements of phase velocities.

Overall, MASW method is environmentally friendly, non-invasive, low cost, rapid and robust. Also, it consistently provides reliable shear wave velocity profiles within the first 15 m below the surface [15]. This technique is adopted in this study to show the likely course of general occurrence of subsidence, distressing and weakening of structures at Ifako/Gbagada a sub-urban area in Lagos, Nigeria (Fig. 1).

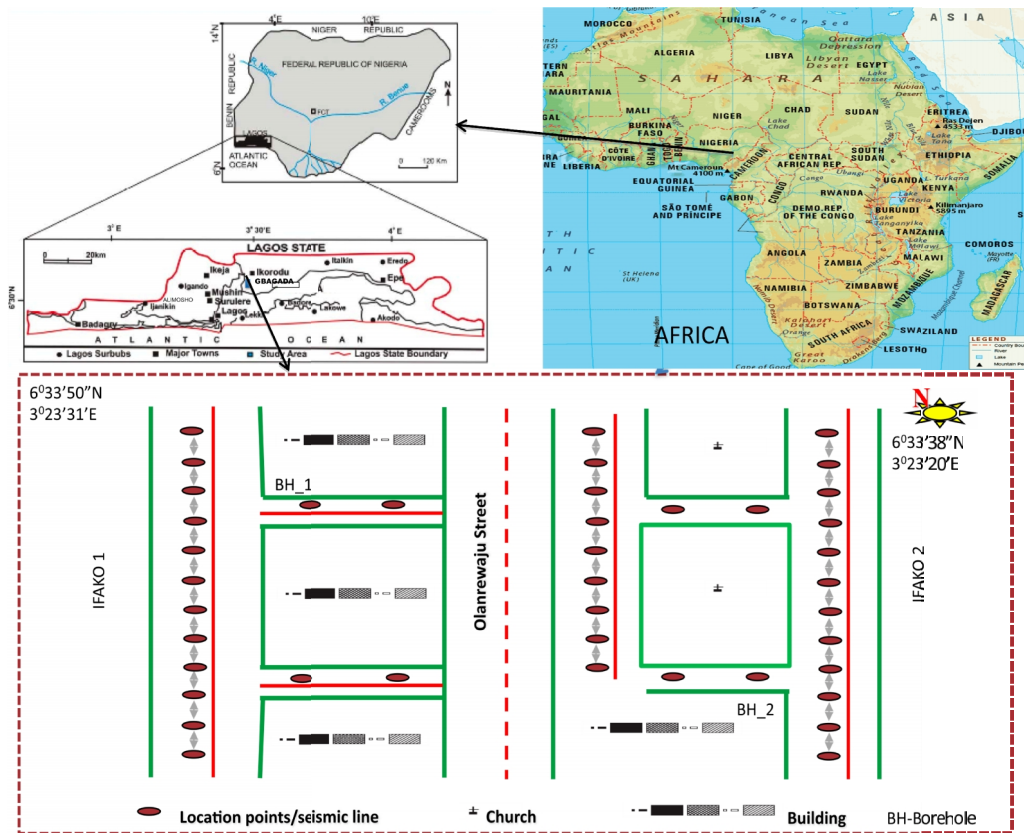


Fig. 1. Map of Nigeria showing Lagos State and the location of study area (Gbagada/Ifako)

### 1.1 Study Location and Geology

Lagos State is situated in the South-western part of Nigeria. It belongs to the coastal plain sand formation which is made up of loose sediment ranging from silt, clay and fine to coarse grain sand. The exposed rock unit in the area consists of poorly sorted sands with lenses of clays. The sands are in part cross-bedded and show transitional to continental characteristics according to [16,17,18]. Lagos State lies within Dahomey sedimentary Basin; this 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 unfossiliferous sandstones and gravels weathered from underlying Precambrian basement [19]. The vegetation at the study area has given way to fens and other water loving shrubs and herbs. Mangrove swamps, water lily are found at the eastern side while at the north-eastern side, thick rainforest can be found with liners and ropes forming the undergrowth. These soils are mainly alluvial and in most places they look like metamorphosed quartz and laterite (Fig. 2).

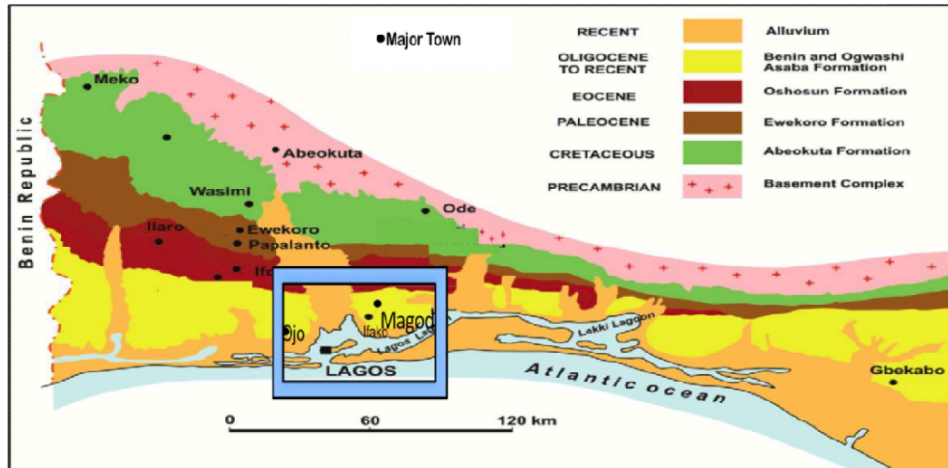


Fig. 2. Geological map of Lagos State showing the study areas

Recently, problem of collapse, weakening and sinking of structures in the study area were observed. MASW is being used as a method with a view to addressing the problems by analysing the subsurface characteristics.

## 2. MATERIALS AND METHOD OF STUDY

Geophysical seismic methods are based on the fact that the velocity of propagation of a wave in an elastic body is a function of the modulus of elasticity, Poisson's ratio and density of material [20]. Methods employing wave propagation principles in determining shear-wave velocity ( $V_s$ ) variation with depth is either intrusive or non-intrusive. Multi-Channel Analysis of Surface Waves using seismic refraction technique is a non-intrusive and non-destructive method which is adopted in this study.

This is the most common type of survey that can produce a 2-D shear-wave velocity ( $V_s$ ) profile. The field acquisition system comprises of a fairly heavy sledge (10 Kg) hammer, with an impact plate of about  $0.6 \text{ m}^2$ . Vertical stacking of five stacks was adopted with a view to suppressing the ambient noise. Twenty-four channel geophones of low frequency (10Hz) were used with 2 m geophone interval. The source to the nearest-receiver offsets was 2 m, this makes length of receiver spread to be 48 m. A source-receiver configuration (SRC) of 2 m was adopted in all the profiles.

The data acquired were processed systematically. Firstly, the preliminary detection of surface waves which examine the recorded seismic waves in the most probable range of frequencies and phase velocities (Fig. 3a). Secondly, construction of the dispersion image and extracting the signal dispersion curve. At this stage several transformations had taken place, which has eliminated all the ambient and source-generated noise.

The dispersion image panel (Fig. 3b) shows the relationship between phase velocity and frequency for those waves propagated horizontally directly from the impact point to the receiver line. Finally, the extracted dispersion curve is used as reference to back-calculate the Vs variation with depth in 1D profile (Fig. 3c). A 2-D map is constructed from the processed multiple number of 1D Vs profiles generated (Fig. 3d). The above processing method was fully automated by software called SURFSEIS, data processing software that takes into account methodological development user friendly and save tremendous time.

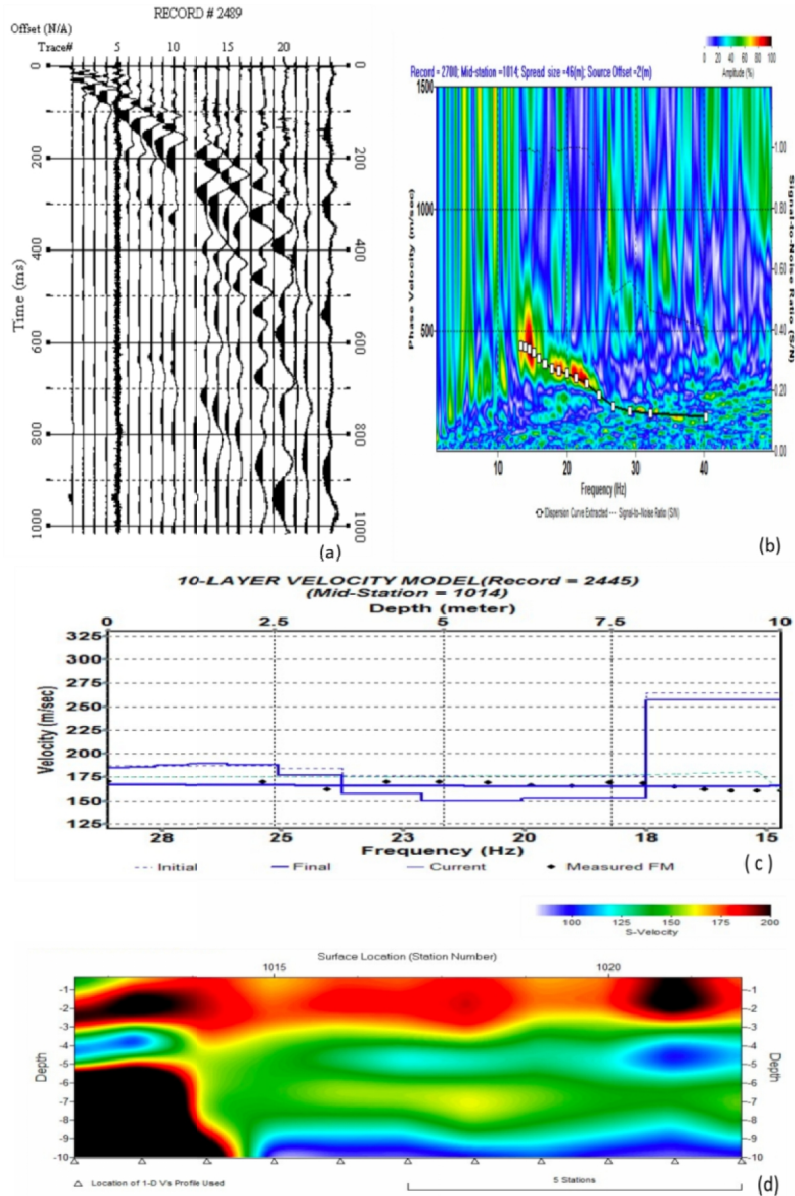


Fig. 3. (a) Typical seismic waves recorded at the survey area, (b) Dispersion curve, (c) 1-D Shear wave velocity profile and (d) 2-D Shear wave velocity profile

### 3. RESULTS AND DISCUSSION

From four locations studied, the shear wave velocity structures from the ground surface down to depth (0-15m) were presented in Fig. 4, a correlated well log data tables, which were obtained prior to the study (Table 1 and 2) and a table showing soil properties with depth at Ifako/Gbagada (Table 3) were also presented. Ten-layered model was used for the inversion. The profiles generally show undulation and non-uniqueness of the sediments both vertically and horizontally. Though, low velocity layers were signatures in all the profiles.

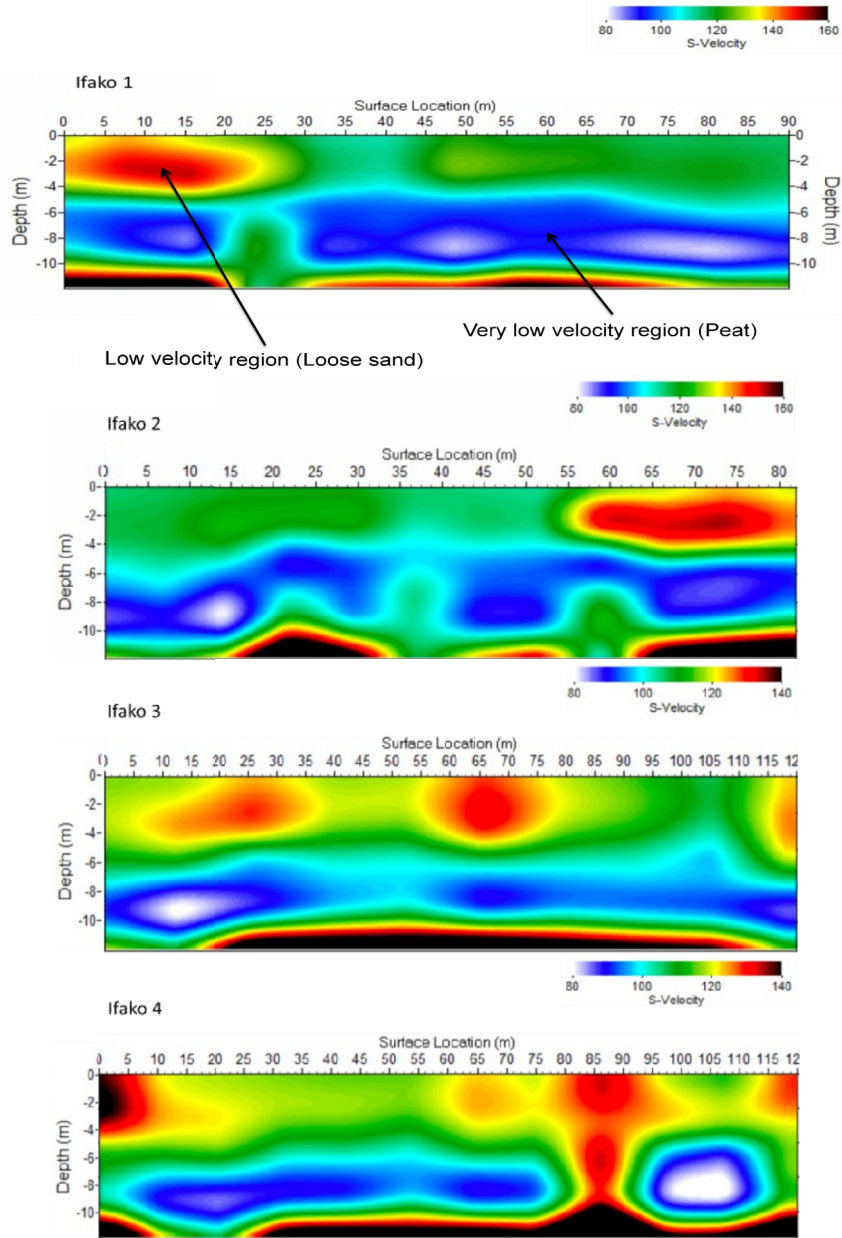


Fig. 4. Shear wave velocity-depth models for the study area

The best way to classify the sediments along the profile to depth is to use additional information from other source [21]. The study used Borehole log information (This was done at a locations very close to the survey area) earlier carried out by consulting firm Geo-vision limited.

**Table 1. Summary of lab result 1 (Penetrometer Test)**

Depth (m)	Description
0-0.15	Fibrous Peat
0.15-9	Silty peaty organic clay
09--21	Silty peaty organic clay
21-22.5	Silty sandy clay
22.5-26.5	Fine medium and coarse sand with some gravel

Source: Geo-vision Limited (2006)

**Table 2. Summary of lab result 2 (Penetrometer Test)**

Depth (m)	Description
0-2	Silty sandy clay (lateritic fill)
2-10	Clayey peat
10-20	Soft to firm silty clay
20-30	Firm moulted silty clay

Source: Geo-vision Limited (2007)

**Table 3. Typical soil properties with depth at Ifako/Gbagada**

Depth (m)	Vs (m/s)	Inferred sediments
0 - 4	120 - 140	Lateritic soil/Alluvial clay
4 - 12	80 - 110	Peat/ Organic clay
>12	>140	Silty Clay

The shear-wave velocity section for the four profiles is shown in Fig. 4. It shows a velocity-depth model that depicts variations of shear wave velocity with depth.

The distribution of shear wave velocity in the subsurface soil of the survey area shows a wide variation of velocity of soil at different depth along each profile line, starting from a low value of less than 80 m/s to a higher value of about 160 m/s.

The results of 2D profile have been presented as Ifako 1-4. For instance, the maximum velocity obtained in Ifako 1 was about 160m/s. This is a probable indication that, low velocity materials dominated the entire survey area. The acquired velocities were categorized into four regions. The topmost layer has thickness varying from 0-5m. It has shear wave velocity ranging from 110-130m/s, a relatively higher velocity region was observed between positions 0-25m which extends down to about 5m, this may probably be a result of filling (lateritic) material that was used for reclamation. The second layer has thickness ranging from 5-9m with shear wave velocity ranging from 80-110m/s. The first two layers composed of peaty organic clay with rigidity modulus in the range 13 to 34N/m<sup>2</sup>. Underlying this very low velocity region is a thin zone of very loose sediment of shear wave velocity 110-130m/s with a thickness of 9-11m and forms an interface between the low and relatively higher velocity (140-160m/s) region and extend from about 10m down to a depth of about 15m. The

subsurface characteristics observed at these surveyed area exhibits a very similar trend and match well with the borehole logs information available (Tables 1 and 2).

The shear wave velocity values obtained from the MASW profiles for different layers falls within the recommendations of National Earthquake Hazard Reduction program (NEHRP) "Vs" soil classification of site categories [22] and site classification by [23].

Averaging the results obtained from Ifako (1- 4) and comparing these with the soil properties with depth Information available (Table 3), the top soil/ first layer has shear wave velocity between 120 and 140m/s with thickness of about 4m, this layer composed of alluvial clay or lateritic materials. Underlying this layer was very loose sediments that can be classified as peaty/organic clay having shear wave velocity in the range 80-110m/s. This showed that the affected structures were located/erected on very loose sediments. Beneath this layer, a higher shear wave velocity (>140 m/s) starts to emerge, a region considered to composed of silty clay materials. This region also falls to category of low velocity region. However, these categories of velocities provide essential information for foundation design, soil and ground-water conditions for the engineers.

#### **4. CONCLUSION**

The four 2-D Vs maps has depicted that the entire land mass of the surveyed area is underlain by materials of very low shear-wave velocity values below 80m/s from ground surface to depth of 15m at maximum velocity of about 160m/s which is interpreted as peat/ organic clay. This was supported by borehole log information available that had been carried out before the study. Therefore, the geologic conditions of entire Ifako/Gbagada area up to the depth of investigation showed saturated peaty/clay formation. Thus, subsidence, distressing and weakening of structures are products of loose nature of the subsurface soil. The study had vindicated practically that Multichannel Analysis of Surface Waves (MASW) can be used to characterize the subsurface soil; this eventually will be useful for engineering investigation. Hence obtaining realistic and competitive tenders based on adequate foreknowledge of the ground condition saves money.

#### **COMPETING INTERESTS**

Authors declare that there are no competing interests.

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