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Analysis of Geotechnical Parameters from Geophysical Information*

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Search and Discovery Article #70254 (2017)**
Posted April 10, 2017

*Adapted from extended abstract prepared in conjunction with oral presentation given at AAPG/SPE 2016 International Conference & Exhibition, Barcelona, Spain, April 3-6, 2016

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Abstract

In our part of the world where legislations related to site investigations before constructions are not strictly enforced, it may be difficult to carrying out a comprehensive geotechnical investigation to characterize a site because of the expenses and the time involved. Another factor that can discourage a developer is the fact that most of the geotechnical tests procedures utilized during site investigations, to a certain extent, alter the existing environment of the site. This study suggests a quick, non-destructive, and non-intrusive method of obtaining key subsoil geotechnical properties necessary for foundation design for proposed engineering facilities. Seismic wave velocities generated from near surface refraction method was used to determine the bulk density of soil, Young's modulus, bulk modulus, shear modulus, and allowable bearing capacity of a competent layer that can bear structural load at the particular study site. Also, regression equations were developed in order to directly obtain the bulk density of soil, Young's modulus, bulk modulus, shear modulus, and allowable bearing capacity from the compressional wave velocities. The results obtained correlated with the results of standard geotechnical investigations carried out.

Introduction

The high cost of geotechnical investigation is a major factor that discourages many building developers from carrying out site characterization especially in a country where there is no strict law enforcing such. These have made many private developers carry out various construction projects without undertaking proper site investigation. One of the consequences of this is its significant contribution to the incessant building collapse experienced in many developing countries. An attempt to simplify, reduce the cost, and reliably estimate the geotechnical parameters needed for proper foundation design will be a major contribution to the field of geotechnical engineering. Using geophysical techniques to predict the required geotechnical parameters has the potential to make this contribution. Typically, the results of geotechnical tests are for point measurements but geophysical investigation techniques can give volumetric measurement and produce image of the subsurface without physically disturbing the subsoil (Mohd et al., 2012). Some geophysical techniques such as seismic refraction has the potential to provide quick test, to characterize and model a site, and recommend regions recommended for detailed geotechnical investigation, when employed. Altindag, (2012) studied the relationship between p-wave velocity and mechanical properties of sedimentary rocks. He used an already acquired data and simple regression analysis. All the data were later subjected to multi-regression analysis. He also derived some empirical equations with high correlation coefficients which would be useful for rock engineers (Soupios et al., 2005). The compressional wave is the only wave that is paramount in this study. In order to determine the zones of structural weakness in the basement and analyze the stability of the subsurface and obtain the mechanical properties of rocks, there will be need to evaluate seismic velocities, Vp and Vs obtained during the field survey (Uyanik, 2010). In this study, near surface seismic refraction method will be used to determine geotechnical parameters such as the Poisson ratio, Young's modulus, shear modulus, oedometric modulus, and allowable bearing pressure.

Geology and Location of Study Area

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). The superficial materials of the general area under investigation are silts, sands, and clays with fibrous peat at the surface in some places. The vegetation at the study area has given way to fens and other water loving shrubs and herbs (Adegbola and Badmus, 2014). The study area lies between latitude 06^0 26' N and 06^0 32' N and longitude 03^0 35' E and 03^0 45' E in Lagos Island area of Lagos State. The choice of Lagos Island as the study area is based on the fact that most part of this area is reclaimed from water using sand. The Nigeria coastal zone is within the tropical climate area which has two seasons: the rainy season and the dry season. The rainy season is between April and November, while the dry season is between December and March. The amount of annual rainfall varies between 2030 mm and 2540 mm (Obasi and Ikubuwaje, 2012).

Theory

V_P and V_S in meter/second (m/s), are readily obtained in the field. They were used to compute the following engineering properties such as the Young's modulus, Bulk modulus, shear modulus, and the Poisson ratio which are used to determine the degree of stiffness of a material. The resistance of the body to deformation under an applied force is referred to as stiffness (Nastaran, 2012). The higher the elastic moduli, the greater the stiffness of the material. These elastic moduli are presented in Atat et al. (2013) and Tezcan et al. (2009).

$$\rho_b = \frac{\gamma}{g} \qquad (1)$$

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 (2) below.

$$\gamma = \gamma_o + 0.002V_p \qquad (2)$$

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 (Atat et al., 2013; Tezcan et al., 2009). Also, the relationship between shear wave and primary wave velocities is expressed in (8).

$$V_p \approx 1.7V_s \tag{3}$$

Where, E is the Young's modulus (N/m^2), G is the shear modulus (N/m^2), B is the bulk modulus (N/m^2), ρ_b is the bulk density (Kg/m^3) and ν is the Poisson's ratio. Also, the subgrade coefficient (K_s), ultimate bearing capacity (q_f) and the allowable bearing capacity (q_a) can be determined using the following equations respectively.

$$K_s = 4\gamma V_s \tag{4}$$

$$q_f = \frac{K_s}{40} \tag{5}$$

$$q_a = \frac{q_f}{n} \tag{6}$$

Where n is the safety factor and n = 4 for soils. Equations (4)-(6) further confirms the strength of the soil being considered for construction purpose.

Materials and Methods Applied

Seismic refraction method was carried out, using a 24-Channel ABEM Terraloc Mark 6 seismogram (ABEM Instrument, 1996). This method requires the following for its functionality: 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. Four (4) traverses were marked forming a square shape (Figure 2). The geophones were planted at 2 m interval to each other and then connected to the equipment. The length of the traverses ranged between 100 m and 150 m. The geometry used for the data acquisition consisted of 5 shots fired between geophones and at 2 m off each end of the spread. The p-wave energy source was a 15 kg sledge hammer. SeisImager software was used to produce the 2D seismic image of the data collected (Figure 3). Each traverse showed two geological layers with the topmost layer being characterized with low p-wave velocities which may be as a result of the loose and soft nature of the soil.

The second layer on the other hand showed materials of relatively higher velocities which may be due to saturation and compression of the material in the subsurface. The significant change noticed in the elastic properties of the two layers may be due to change in the composition of the subsurface, uneven saturation, and changes in the unit weight of the soil.

Results and Discussion

The results obtained are presented in Table 1. Two geologic layers were delineated by the SeisImager software (SeisImager, 2009). The first geologic layer has the lower seismic wave velocity while the second geologic layer has the higher seismic wave velocity. The bulk density of the first layer ranges between 1708.8 kg/m^3 and 1745.7 kg/m^3. The bulk density of the second layer ranges between 1752.7 kg/m^3 and 2043.3 kg/m^3. This result showed that the second layer is more compressed than the first layer. This may be as a result of the soil composition, level of saturation, and level of cementation of the geologic formation. It was also observed that the density of the subsurface increases in direct proportion with the seismic wave velocity and these two parameters increased with depth.

The ultimate bearing capacity and the allowable bearing pressure were estimated to buttress the results provided by the elastic moduli. The ultimate bearing capacity for the study area ranges between 0.3674 MPa and 0.5575 MPa while it ranges between 0.5941 MPa and 2.3699 MPa in the second layer. This confirmed the second layer to have more bearing capacity than the first layer. Also, the allowable bearing pressure ranges between 0.0919 MPa and 0.1394 MPa in the first layer while it ranges between 0.1485 MPa and 0.5925 MPa in the second layer. The result also showed that the second layer is more competent than the first layer. The result showed that the depth to the most competent layer ranges between 7 m and 15.7 m. This result is in agreement with the results obtained from the borehole log and the cone penetrometer tests earlier carried out in the study area.

Analysis of Geotechnical Parameter from Seismic Refraction Data

This study aimed at obtaining model equations from the correlations of the primary wave velocities and the different geotechnical parameters studied. This is to obtain direct relationships between the p-wave velocity and the geotechnical parameters. These equations can be used for the speedy evaluation and inexpensive estimation of the various geotechnical parameters. The graphs of the geotechnical parameters were plotted against the primary wave velocities. The regression equations and their coefficient of determinations were obtained.

Also the graph of unlimited bearing capacity was plotted against the primary wave velocity (Figure 4) and the correlation equation is given as

$$q_f = 1\times10^{-7}V_p{}^2 + 0.0009V_p - 8\times10^{-5} \quad (7)$$

The correlation equation derived from the graph of allowable bearing capacity versus the primary wave velocity (Figure 5) is

$$q_a = 3\times10^{-8}V_p{}^2 + 0.0002V_p - 6\times10^{-5} \quad (8)$$

The coefficient of determination is also 1.

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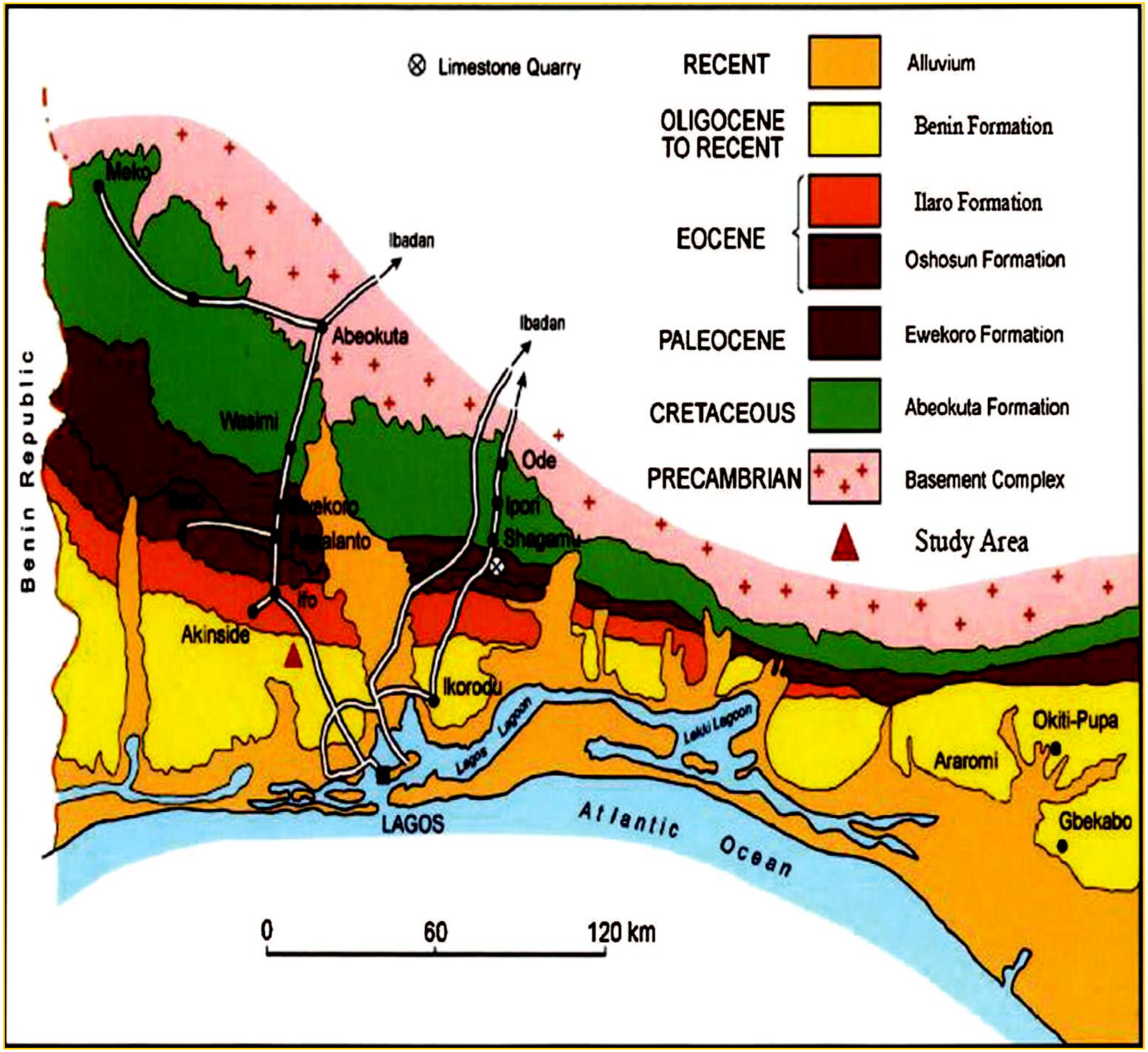

Figure 1. Geological map of Nigeria, showing the Nigerian part of the Dahomey Basin.

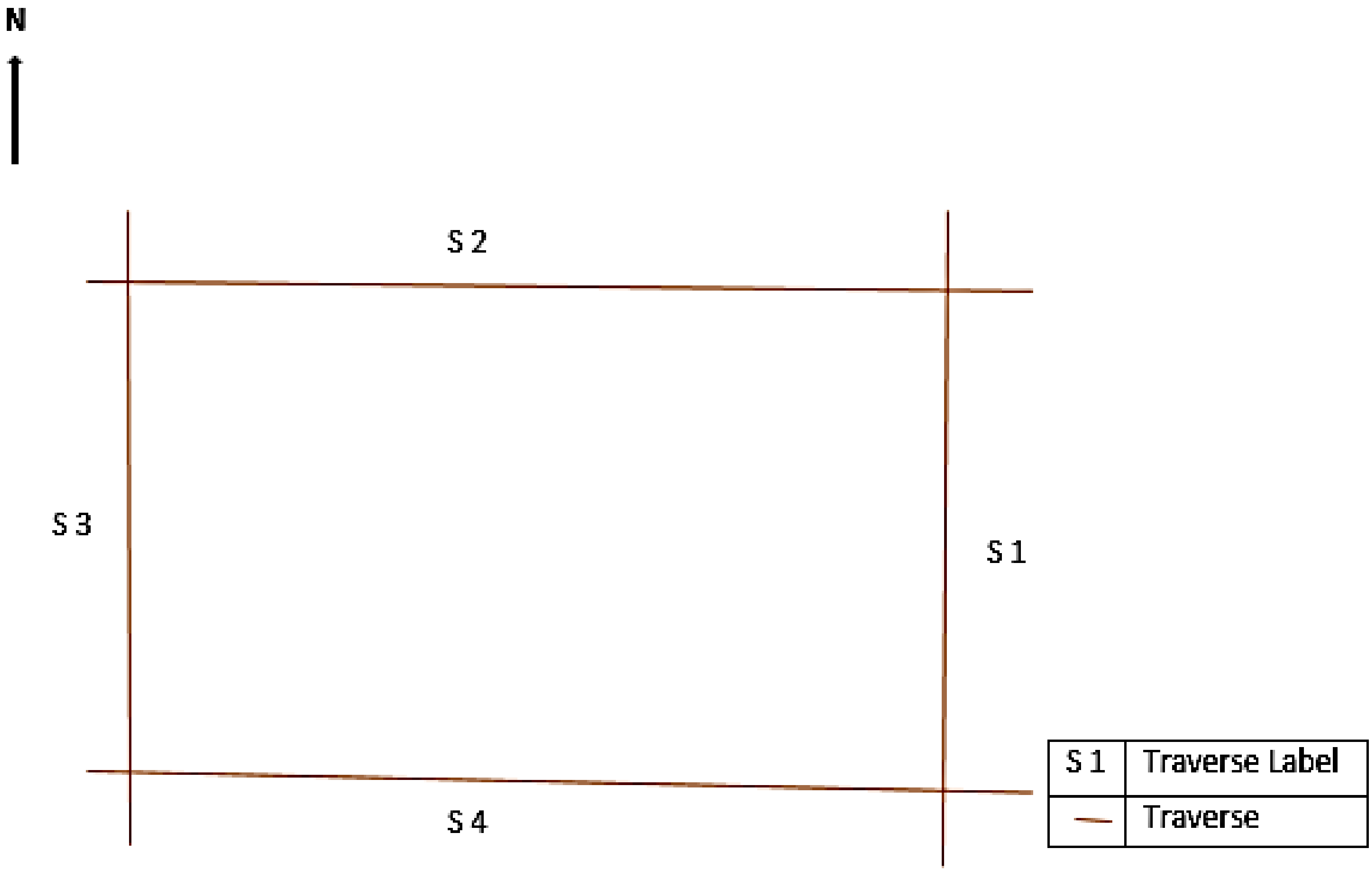

Figure 2. Base map of the study area.

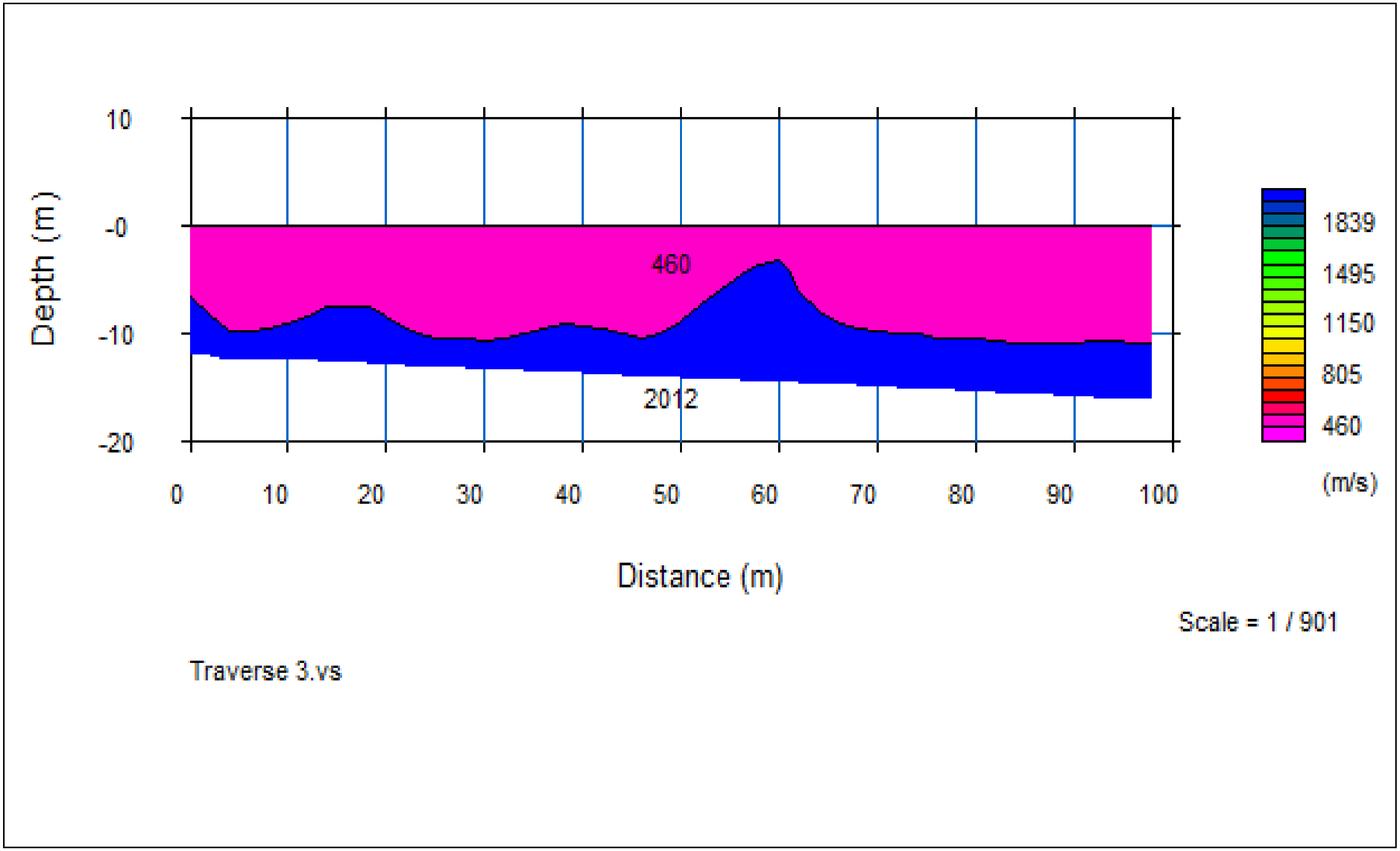

Figure 3. 2D seismic refraction image of the study area, indicating the number of layers, p-wave velocity of each layer, and depth of investigation.

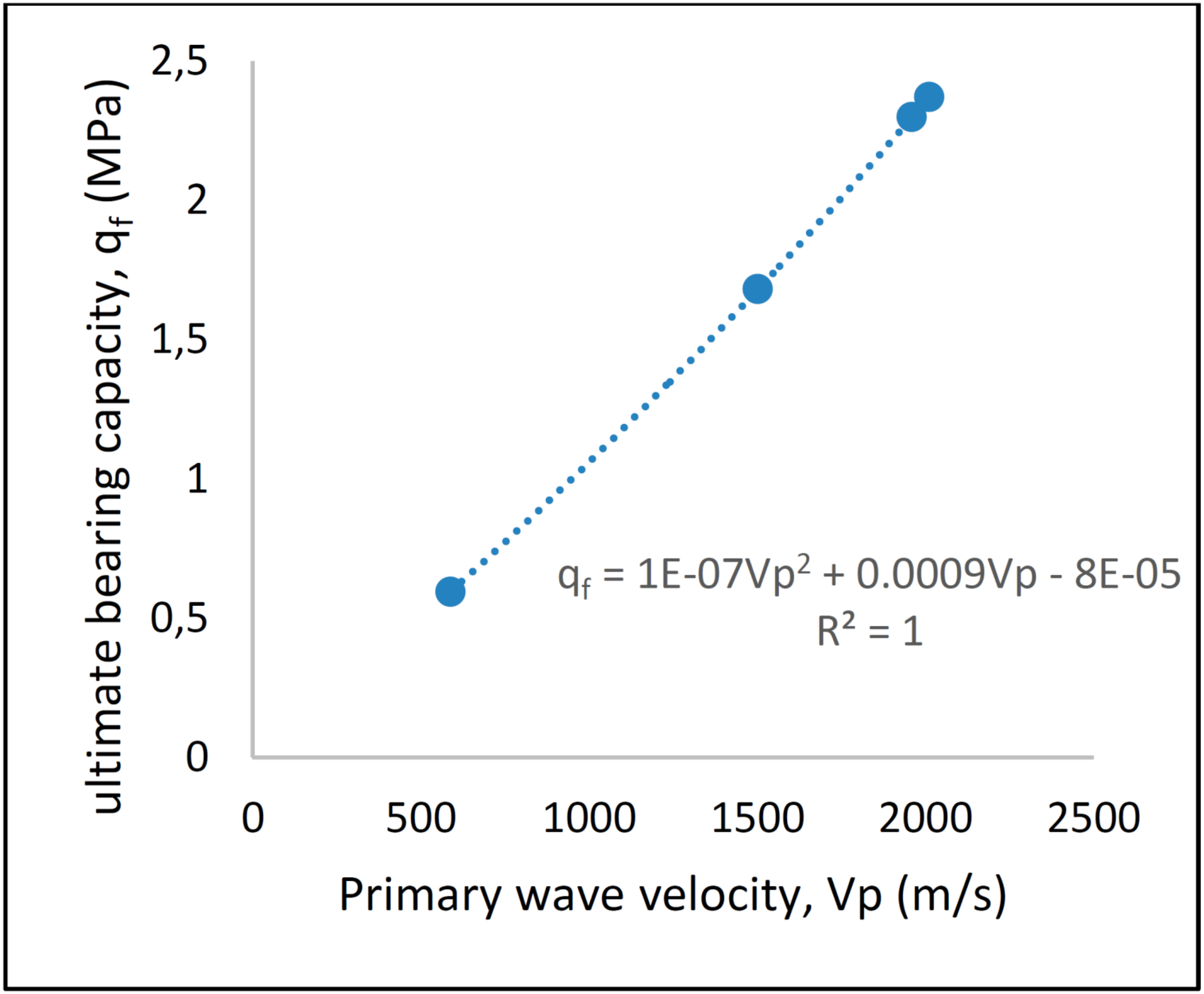

Figure 4. The graph of ultimate bearing capacity (*MPa*) against Primary wave velocity (m/s).

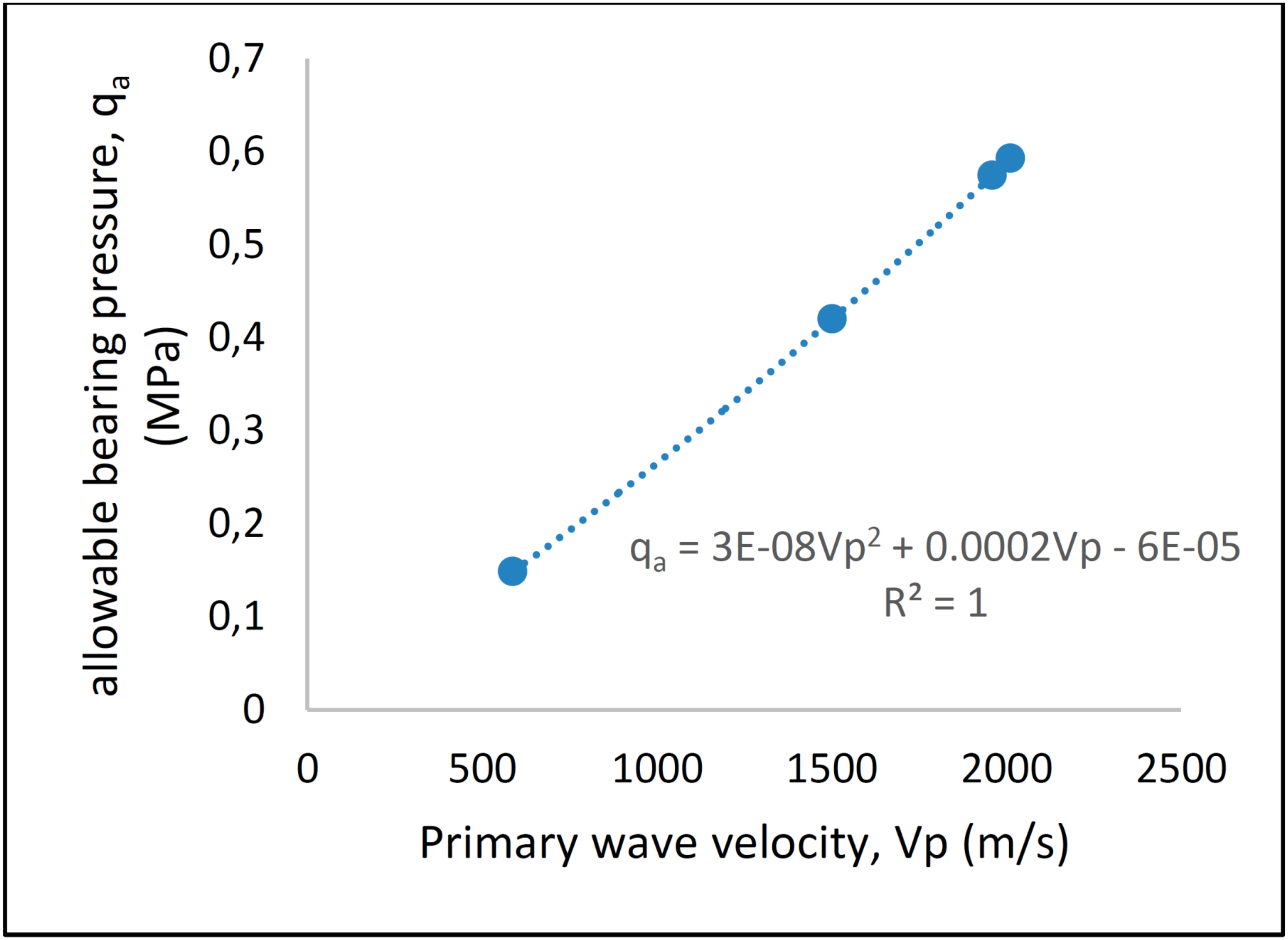

Figure 5. The graph of allowable bearing pressure (*MPa*) against Primary wave velocity (m/s).

Sides	V_p (m/s)	V_s (m/s)	ρ (kg/m^3)	Depth (m)	ν	E (GPa)	E_c (GPa)	B (GPa)	G (GPa)	K_s $(MPas)$	q_f (MPa)	q_a (MPa)
S1	498	292.94	1734.3	7.6	0.2355	0.3677	0.4301	0.2317	0.1488	0.0199	0.4979	0.1245
	1961	1153.53	2032.9	15.7	0.2355	6.6837	7.8174	4.2108	2.7050	0.0919	2.2981	0.5745
S2	554	325.88	1745.7	8.7	0.2355	0.4581	0.5358	0.2886	0.1854	0.0223	0.5575	0.1394
	1503	884.12	1939.4	10.9	0.2354	3.7458	4.3811	2.3598	1.5160	0.0672	1.6804	0.4201
S3	460	270.59	1726.5	7.9	0.2354	0.3124	0.3653	0.1968	0.1264	0.0185	0.4578	0.1145
	2012	1183.53	2043.3	11.4	0.2354	7.0719	8.2714	4.4553	2.8621	0.0948	2.3699	0.5925
S4	373	219.41	1708.8	7.0	0.2355	0.2033	0.2377	0.1281	0.0823	0.0147	0.3674	0.0919
	588	345.88	1752.7	10.3	0.2355	0.5181	0.6060	0.3264	0.2097	0.0238	0.5941	0.1485

Table 1. Seismic wave velocities for each traverse and their geotechnical parameters.