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Foundation Settlement Determination: A Simplified Approach*

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Search and Discovery Article #70256 (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

The heterogeneous nature of the subsurface requires the use of factual information to deal with rather than empirical or generalized equations. Therefore, there is need to determine the actual rate of possible settlement in the soil before structures are built on it. This information will help determining the type of foundation design and the kind of reinforcement that will be necessary in constructions. This paper presents a simplified and a faster approach to determining foundation settlement in the soil using real field data acquired from seismic refraction techniques and cone penetration tests. This approach was also able to determine the depth of settlement of each strata of soil. The rate of settlement for the four profiles was found to vary between 0.019 m and 0.035 m. The results obtained revealed the different depth of possible settlement.

Introduction

The problem of foundation settlement due to dynamic load has attracted the attention of researchers since the sixties (Prakash et al., 2014). Determination of the level of settlement of a foundation in soil layer is one of the major challenges confronting the building industry as this may be one of the factors contributing to some of the building collapses rampant in our country of late (Amadi et al., 2012; Oyedele et al., 2012). Since the subsurface is not homogeneous, it may be difficult for engineers to access the condition of the subsurface with traditional geotechnical techniques because of their limitations Kuo et al., (2004). Efforts have been made by early researchers to determine the rate of settlement of a foundation. These methods are mainly theoretical and as such may be difficult and not be apply to all cases. Chobbasti et al., (2010) confirmed the possibility of numerically evaluating the bearing capacity and settlement of ring footing. Kuo et al., (2004) examined the settlement of footing founded on two-layered soil profile. Also, Shahnazari et al., (2013) showed that it is possible to predict the settlement of shallow foundations on cohesionless soils. In this study both seismic refraction method and cone penetrometer test were combined. Seismic refraction method is a geophysical method of investigating the subsurface condition and this method uses the surface-sourced seismic waves for its operation (Altindag, 2012; Reynolds, 1998). The cone penetrometer test (Dutch cone test) on the other hand is a geotechnical test that is used to determine the engineering properties of the subsurface and assessing the subsurface stratigraphy (Hunt, 2005; Soupios et al., 2005).

Foundation settlement assessment requires that detailed information on the soil profile, pore water regime, influence of fills, loads from other foundations, excavation, and changes in groundwater table are well established (Akintorinwa and Adesoji, 2009; Das, 2007). This process may be cumbersome and take a lot of time. Therefore, it will be of great advantage if engineers can easily determine the rate of settlement possible by soil layers so as to inform their decision on the type and the kind of materials required for foundations and the depth at which foundations must be erected.

Location of the Study Area

The study area is located at Eti-Osa local government in the southeastern part of Lagos State. It lies between latitudes 6° 30' 37" and 6° 30' 18" N and longitude 3° 36' 3" and 3° 35' 34" E in southwestern Nigeria. This area is in the zone of coastal creeks and lagoons developed by barrier beaches associated with sand deposition. It is situated in the Nigeria sector of the Benin Basin and near the eastern margin of the basin. The geological formation of the study area is composed of sediments that are typical of the marine environments which is an intercalation of sand and clay. These sediments also grade into one another and vary widely in both lateral extent and thickness (Adepelumi et al., 2009; Adepelumi and Olorunfemi, 2000).

Theory

The seismic refraction method readily gives both P and S wave velocities. These velocities are required to compute the following engineering properties such as the dry density, shear modulus, Young’s modulus, and the Poisson’s ratio. These quantities make the determination of the bearing potential of the subsurface possible.

The dry density is related to the p-wave velocity by the relation

$$\gamma = \gamma_0 + 0.002V_p \qquad (1)$$

and the unit is kN/m^3. γ_0 = 16 for loose, sandy, and clayey soil (Atat et al., 2013; Tezcan et al., 2009).

The shear modulus on the other hand relates with shear wave velocity as expressed in equation (2).

That is,

$$\mu = \frac{\gamma V_s^{\ 2}}{g} \qquad (2)$$

Where g is the acceleration due to gravity and it is equal to $9.8m/s^2$. The equation for the Young's modulus and Poisson's ratio are expressed in (3) and (4) below respectively.

$$E = 2\mu(1+\sigma) \tag{3}$$

and

$$\alpha = \left(\frac{\alpha - 2}{2(\alpha - 1)}\right) \tag{4}$$

where $\alpha = \left(\frac{V_p}{V_s}\right)^2$ and the relationship between V_p and V_s is given in (5) as

$$V_p \approx 1.7V_s \tag{5}$$

In the same vein the results of the cone penetrometer test provides information on the bearing capacity (q_f) which is given as

$$q_f = 2.7 \times q_c \tag{6}$$

where q_c is the cone penetration resistance. Thus, the average bearing capacity is given by

$$_a q_f = \frac{\sum_{n=1}^{i} q_f}{n} \tag{7}$$

In equation (7), n is the number of 0.25 m division present in a stratum of soil. In Tezcan et al., (2009),

$$H = V_s t \tag{8}$$

Where H is the profile depth parameter and t is an unknown time parameter. Thus, d which is the depth of settlement is given by

$$d = \frac{_a q_f}{E} \times V_s t \tag{9}$$

Data acquisition and Processing

Seismic Refraction Method

In this study, a total of four seismic profiles were surveyed and the data acquired. A 24-Channel ABEM Terraloc MK 6 seismogram was used for the data acquisition. The profile varied in length between 50 m and 100 m as a result of accessibility (Egwuonwu and Osazuwa, 2011; Bery and Saad, 2012). 2 m geophone spacing was adopted for better coverage of the refractor surface, multiple shots were taken at each shot point along the profile with the aid of a 15 kg sledge hammer, and the resulting shots were stacked so as to produce clearer images of the subsurface. For the purpose of this study, the seismic survey was conducted in a rectangular shape across the site (Figure 1). The seismic shots were taken in this order: at 2 m before the first geophones, between the sixth and the seventh geophones, between the twelfth and the thirteenth geophones, between the eighteenth and nineteenth geophones, and 2 m after the twenty-fourth geophones respectively.

Discussion of Results/Conclusion

The data acquired were interpreted with the use of seisImager software package (Sayed et al., 2012; SeisImager, 2009) which produced 2D images of the subsurface area surveyed. The 2D image gives information on the number of layers, the thickness of each layer, and the p-wave velocity of each layer Figure 2.

Cone Penetrometer Test

A 2.5 ton Shell and Auger cone penetrometer was used for the test, four cone penetrometer tests (CPTs) were conducted and each one terminated at the point at which the anchors of the equipment were pulling out of the ground. This technique tests the subsurface at an interval of 0.25 m and also provides information on the bearing capacity of soil layer at this interval. In this study, each CPT was conducted along the seismic profile so as to easily validate the results obtained (Figure 1). The data acquired were plotted and the graphs are presented (Figure 3). From the graphs, we can obtain information on the depth of penetration and the allowable bearing capacity. In this research, only the first layers provided by the seismic refraction method were considered because they correlated with depth of investigation provided by the CPT method. Also, it will be much easier to compare the responses of the geologic formation within this layer for the methods of investigation. The result in this first layer provides information on the average bearing capacity, the Young’s modulus, Poisson’s ratio, the dry density, and shear modulus using equations (1)-(8). Some of the results are presented in Table 1.

In the four seismic profiles surveyed in the study area, the seismic refraction method revealed two geologic layers. The depth of investigation of the first layer was correlated with the depth of penetration of the CPTs. The velocity of the first layer ranges between 373 m/s and 554 m/s. Also, the shear wave velocity ranges between 219.41 m/s and 325.94 m/s. The variation in the velocities observed showed that the subsurface is heterogeneous in the studied site. The depth of coverage of the seismic refraction method ranges between 7.0 m and 8.7 m. The variation in the depth of penetration showed the variation in the responses of the geologic formation of the site to the passage of elastic energy. The dry density

γ ranges between 16.746 and 17.108 kN/m^3, also the Poisson's ratio of the different seismic profiles ranges between 0.235444 and 0.235456. The variation in the Poisson's ratio indicate variability in the level of compression of the studied site.

The shear modulus of the four profiles ranges between 0.081 and 0.147 GPa, the Young's modulus on the other hand varies between 0.202 and 0.365 GPa. It was observed that the Young's modulus is greater than the shear modulus by a factor of 2.48. The shear and the Young's modulus are measures of the strength of the study site. The average allowable bearing capacity $({}_a q_f)$ for each profile was obtained by using equation (7). The values ranges between 2247 and 4882 kN/m^2, these variation indicates the differences in the bearing capacity of each profile surveyed. This also goes further to show that because of the heterogeneity of the soil formation, a construction site may not be subjected to similar condition if adequate test has not been conducted to characterize the site.

The depth of settlement of each soil profile is presented in Table 1 as calculated with equation (9), the depth of settlement was observed to vary across the site. The depth of settlement ranges between 0.019 and 0.035 m, this may be as a result of various degrees of sorting and the time of deposit of the geologic formation that compose the near surface layer. It was observed in S 2 and S 3 that the depth of settlement is high, this may as a result of the fact that the formation that constituted greater resistance to the test equipment was found at depth greater than 7 m to the subsurface (Figure 1 and Figure 2), whereas, the subsurface material for S 1 and S 4 poses much resistance to the cone of the penetrometer at a depth of about 6 m to the subsurface. This shows that the thickness of a profile does not guarantee its resistance or its rate of settlement but the nature of the geologic formation such as the rate of sorting and the degree of saturation of the subsurface materials (Atat et al., 2013). The result shows that the rate of settlement in soil varies in response to the condition of the geologic formation. The rate of settlement for the four profiles varied between 0.019 m and 0.035 m.

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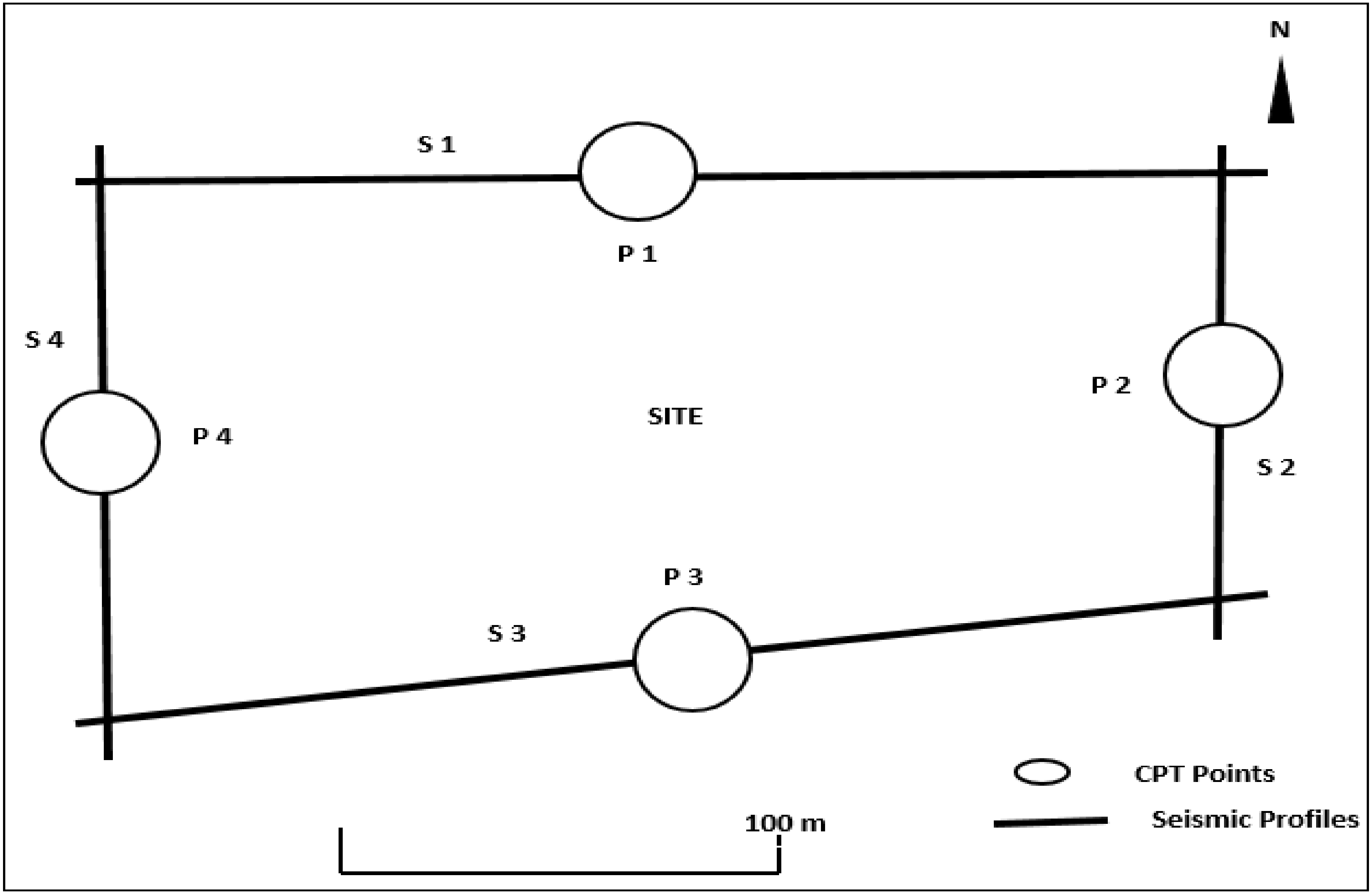

Figure 1. Base map of the Site, indicating the seismic profiles and CPT points.

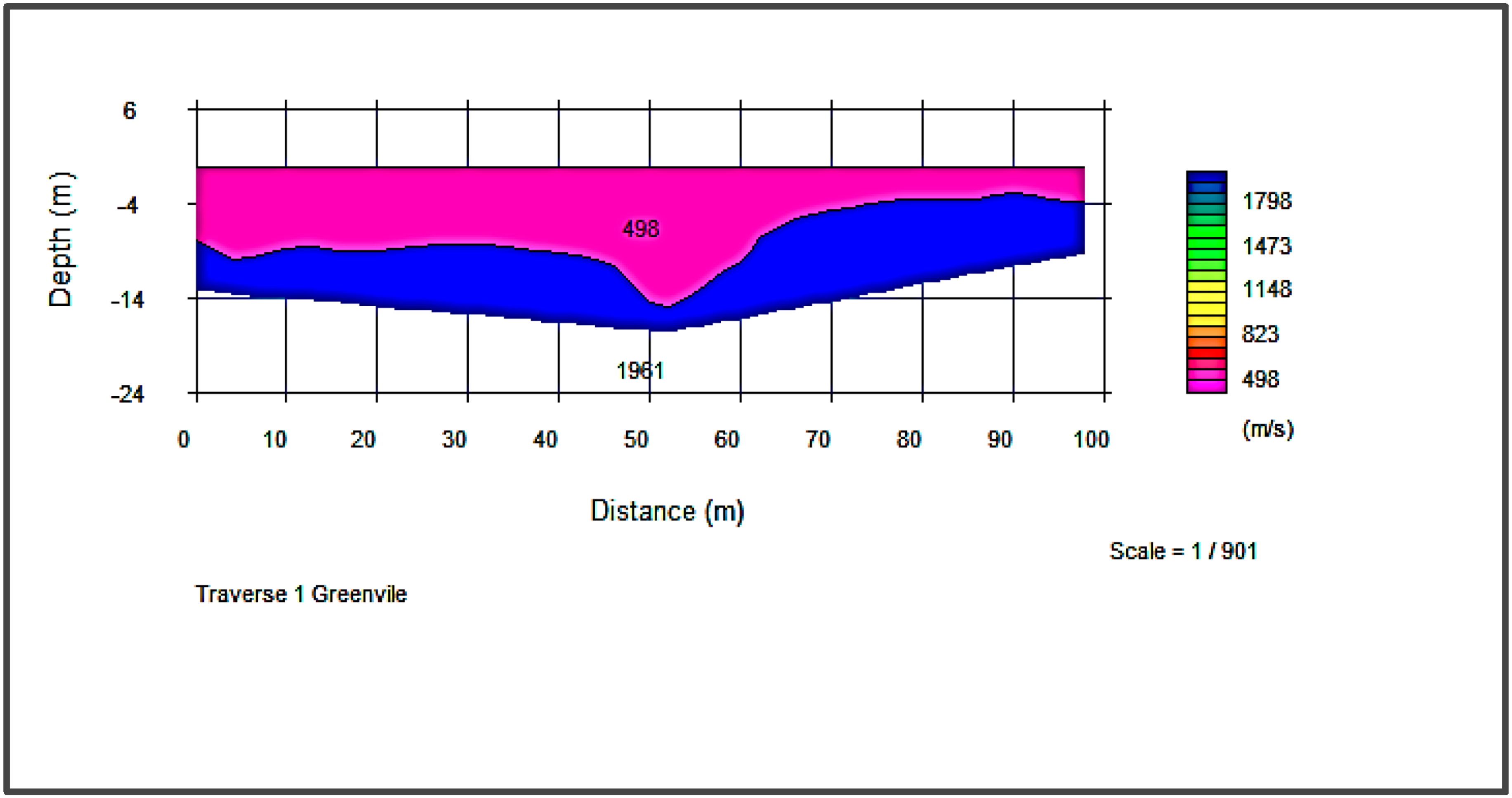

Figure 2. 2D seismic refraction sections at the Site, indicating the number of layers, their velocities, and the depth of investigation for Profile 1.

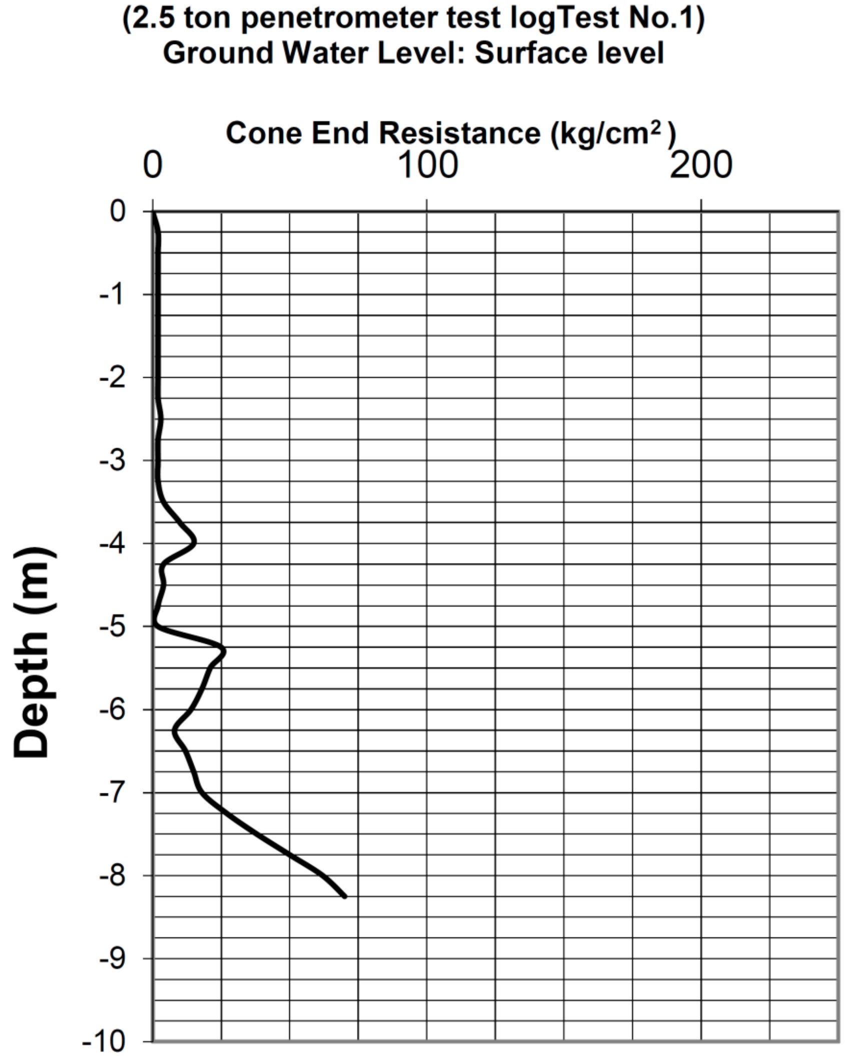

Figure 3. Result of one of the cone penetrometer test carried out at the Site for Test 1

Profiles	V_p (m/s)	V_s (m/s)	Depth (m)	γ (kN/m^3)	σ	μ (GPa)	E (GPa)	$_aq_f$ (kN/m^2)	$d(m)$
S 1	498	292.94	7.6	16.996	0.235453	0.147	0.365	2376	0.019
S 2	554	325.88	8.7	17.108	0.235456	0.117	0.455	4882	0.035
S 3	460	270.59	7.9	16.920	0.235444	0.125	0.310	3940	0.034
S 4	373	219.41	7.0	16.746	0.235456	0.081	0.202	2247	0.024

Table 1. Summary of elastic moduli, average bearing capacity and the depth of settlement for each profile.