International Journal of Natural Sciences Research
2014 Vol. 2, No. 11, pp. 237-248
ISSN(e): 2311-4746
ISSN(p): 2311-7435

DETERMINATION OF ELASTIC MODULUS USING PLATE LOAD TEST IN CALABAR, SOUTH-EASTERN NIGERIA

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ABSTRACT

This study evaluates the use of plate load test in ascertaining elastic modulus, E_s of a site in Calabar, Niger Delta, Nigeria. The area depicts a coastal plain environment with typical sandy and clayey formation. Four plate load test was carried out within the area of investigation , with load settlement curve which indicates a firm to stiff partial cohesive soil. The result shows geotechnical properties of the soil which depicts values above the A line plot on the plasticity chart. The average liquid limit and the plastic limits values of 30.65% and 15.9% respectively shows that the soil under consideration is low in compressibility. The average moisture content of soil is low. An average elastic modulus value of 4302.289 KN/m² was obtained in the elastic range (initial tangent modulus), which is indicative of a firm clay . This value conform reasonably with those obtained by method proposed using Cone Penetrometer Test (CPT) with an average cone value of 17Kg/cm² with E_s= 4165 KN/m². Generally, geotechnical parameters of the soil reflects the nature of the load settlement curve obtained from the test points. Immediate settlement analysis with E_s carried out showed low magnitude of compressibility in the study area.

Keywords: Plate load, Elastic modulus, Settlement, Calabar, Niger delta.

Contribution/ Originality

This study contributes in the existing literature on the determination of elastic modulus using plate load test and the deformation properties of soils in Calabar, southeastern Nigeria.

1. INTRODUCTION

The analysis of Settlement is highly imperative in the design and construction of structures. Failures of most structures have being attributed to either differential settlement or intolerable foundation settlement. These values are classified as immediate and consolidation settlement. The amount of immediate settlement (elastic) is a function of elastic modulus and poison ratio. The modulus of elasticity, which is an index of the material stiffness and a

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fundamental material constant, gives an indication of the immediate settlement. Load settlement curve generated from the plate load test, helps in the extrapolation of reasonable elastic modulus where the soil does not exhibit significant variation. The plate load involves the determination of the ultimate bearing capacity of the soil and the likely settlement under a given load. The test basically consist of loading a steel plate placed at the foundation level and recording the settlement corresponding to each load increment.

The plate load test gives the stress - strain relationship of soils. The amount of strain is dependent on the void ratio, composition, past stress history of the soil and manner in which the stress is applied [1]. The modulus of elasticity for a soil which is the stress strain ratio is basically the slope of its stress-strain plot within the elastic range. This gives an indication of the deformation characteristics of the soil.

The elastic modulus, which characterize the soil stiffness can be graphically defined by the slope of the of the tangent in a stress strain plot (tangent modulus) in the elastic range . It is useful in the evaluation of elastic theory and immediate settlements of soils by semi-empirical influence factor method proposed by Schmertman and Hartman [2]. In order to design the foundation for a given structure, two main types of foundation are usually utilized depending on the state of loading and type of soil (i.e. shallow and deep foundation) [3]. For the case of very heavy structure constructed on a weak soil, deep foundation is always used, which generally, consists of a group of piles covered by cap [4]. The axial performance of single isolated pile subjected to axial load has been assessed by Ismael [5], [6-8]. The pile group assessment is more complex when compared with single isolated pile [9-12]. Generally, most of the previous studies take into account the surrounded soil as horizontal layers while in fact the soil profile is usually not horizontal. This study therefore, determines the deformation properties of soil in the study area.

1.1. Description of the Study Area

The test points were sited in Calabar close to the Nigeria Television Authority (NTA), and Tinapa with latitude 05^{0} 02' 36.2"N and longitude 08^{0}18' 53.3" E. Geologically, Calabar (Fig. 1) is underlain by the Benin Formation, one of the formations of the Tertiary - Recent sediments of the Niger Delta, Oligocene to Pleistocene in age [13] and is locally referred to as Coastal Plain Sands. The type section of the Coastal Plain Sands according to Allen [14] is made up of fine grained sands, pebbles moderately sorted with local lenses of fine grained poorly cemented sands and gravels with clay and shale intercalations. The sands are sub angular to well rounded.

1.2. Methods of Study

Test pit of less than 1m was dug at the proposed foundation level , with width at least 5 times the width of the test plate. A circular steel plate with thickness not less than 25 mm and diameter 30cm was used. A reaction load was placed over a 700 bar capacity hydraulic jack , which lies on a test plate after the placement of a sitting load of

7KN/m^2. Each load increment was kept for not less than one hour or when the settlement gets appreciable reduced (a value of 0.2mm per hour) [15]. The next increment was then applied and observation repeated. The test was continued till a settlement of 25mm was obtained. The elastic modulus, indicative of the type of soil encountered as shown in Table 1 while the stress-strain plot showing elastic range is shown in Fig.2.

Also Schmertman and Hartman [2] proposed the following equation for the elastic modulus using values obtained by cone penetrometer method.

$E_s=2.5q_c$ for square foundation (1)

$E_s= 3.5q_c$ for strip foundation (2)

Where:

E_s= elastic modulus

q_c= cone penetrometer value

Timoshenko and Goodier [16] make a stress-settlement relation expressed as Eq. (3). Thisequation was based on the Boussinesq theory (1885), which defines the relationship between thesettlement of a smooth, rigid circular footing and normal stress applying on a homogeneous space.

$$E_s = \frac{\pi \sigma_o r}{2s}\left(1-v^2\right) \tag{3}$$

where

E_s = elastic modulus;

σ_o= average normal stress;

r = radius of the plate;

s = settlement of the plate associated with the pressure; and

v = Poisson's ratio.

Harr, et al. [17], also made the following relations on the immediate settlement of a rigid foundation based on E_s and v

$$S_e = \frac{Bq}{E_s}\left(1-v^2\right)\alpha_r \tag{4}$$

Where

B=width

q=load,Kpa

α= Coefficient relating various L/B ratio

Variation of immediate settlement with load within the study area was obtained using the method proposed by Harr, et al. [17] for rigid foundation, assuming $v = 0.3$ and α=0.85 for square foundation.

2. RESULTS AND DISCUSSION

The load settlement curve for the plate load test for Point 1 to Point 4, which was carried out in Calabar, shows that from the load settlement curve for points 1,2, 4, the soil under investigation is a partially cohesive soil while the load settlement curve for point 4 shows that the soil is cohesionless or stiff clay . These curves which display a definite failure Point (departure from the initial straight line) shows that the material under consideration is either a dense sand or firm to stiff sandy clay. This is also verified by the geotechnical properties of the soil, (Table 2) which depicts values above the A line plot on the plasticity chart. Also the average liquid limit and the plastic limits values of 30.65% and 15.9% respectively shows that the soil under consideration is low in compressibility which is also observed in the settlement variation plot. The average moisture content of soil is considered low. With the adoption of equation 3 , assuming a poisson ratio of 0.3, an average elastic modulus value of 4302.289 KN/m^2 was obtained in the elastic range (initial tangent modulus), which is indicative of a firm clay . This value correlate reasonably with those obtained by method proposed using Cone Penetrometer Test (CPT) with an average cone value of 17Kg/cm^2 with E_s= 4165 KN/m^2 . Also immediate settlement analysis was carried out with various loads, using relations proposed by Harr, et al. [17]. The plot depicts a low degree of settlement in relations to various load within the area of study.

The lithology of the upper section of the site (1m-3m) from borehole log is mainly sandy clay (SC) with water level at 26 m below ground level. The particle size distribution shows 75microns with about 35 percentage passing or greater than 12 finer on sieve no 200.

The load settlement analysis for single pile is important to evaluate the performance of single pile. This performance gives indication of pile group behavior. Therefore to understand the group behavior should firstly understand the single pile behavior. This study revealed that the differences in the measured settlement between the piles occurred due to different soil profiles under each pile. Table 3 shows the elastic modulus within the elastic range while Table 4 is a comparative average E_s values from different methods. Table 5 shows the load settlement value for point 1while Table 6 depicts the load settlement value for point 2. Table 7 shows the load settlement value for point 3 and Table 8 shows the load settlement value for point 4.

Fig. 3 shows the particle size distribution curve in the area while Fig. 4 shows the plasticity chart for BH-1 @ 1.6m. Fig. 5 depicts the lithology of BH-1 while Fig. 6 shows the cone penetrometer profile. Fig. 7 shows loading settlement plot for point 1 while Fig. 8 shows the loading settlement plot for point 2. Fig. 9 shows the loading settlement plot for point 3 while Fig. 10 is the loading settlement plot for point 4. Fig. 11 shows the variations of settlement with load.

3. CONCLUSION

The elastic modulus obtained through the analysis of plate load bearing test within the study area shows value that are highly close to those obtained by empirical methods. This value also correlates with soil types obtained from literatures. The elastic modulus values obtained from the method described in this study, is a quick method in the calculation of the magnitude of immediate settlement during design of structures.

The classification of the soil based on the index properties also conform reasonably with load - settlement curve obtained from the plate load tests. Also the load - settlement plot, provides an overview of the magnitude of settlement on various foundation loading within the area.

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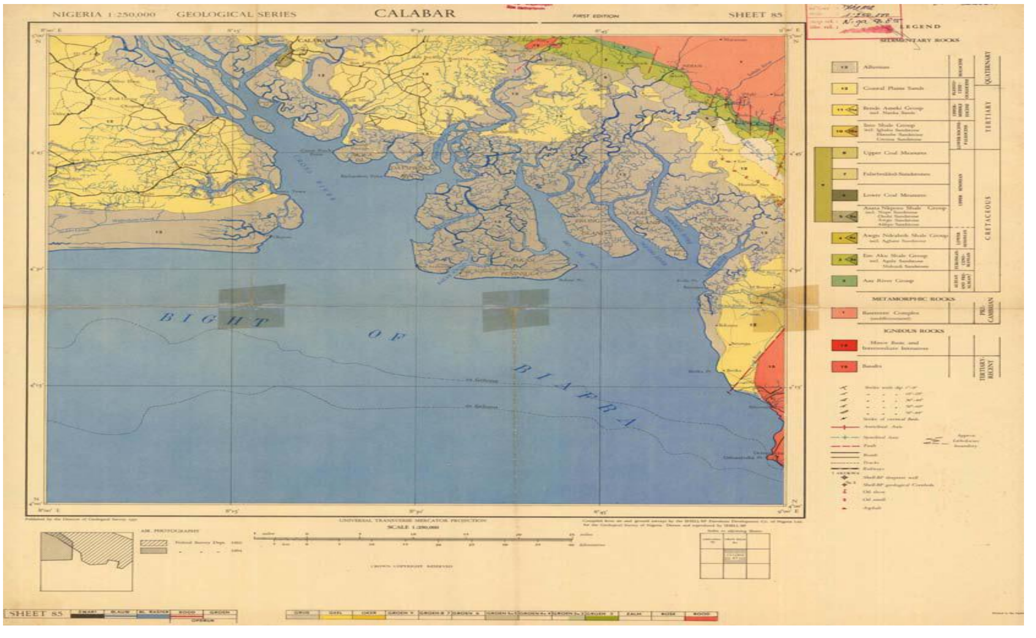

Fig-1. Geological map of Calabar (Source: Geological Survey of Nigeria [18])

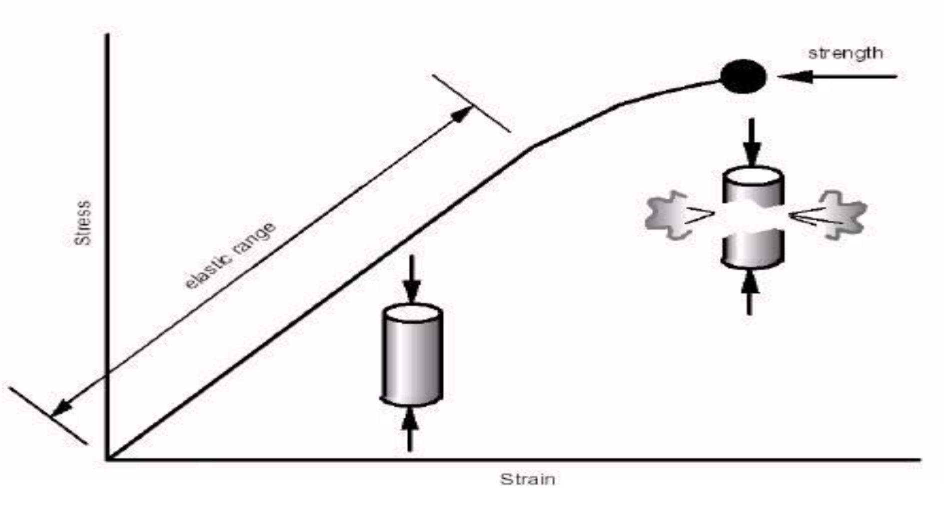

Fig-2. Stress-Strain Plot Showing the Elastic Range

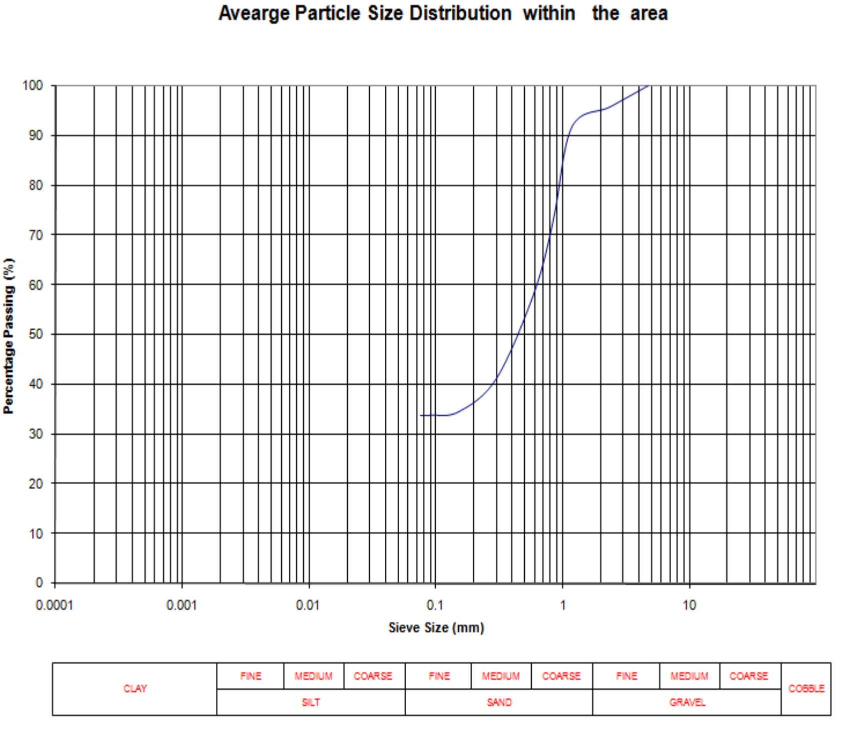

Fig-3. Particle size distribution curve in the area

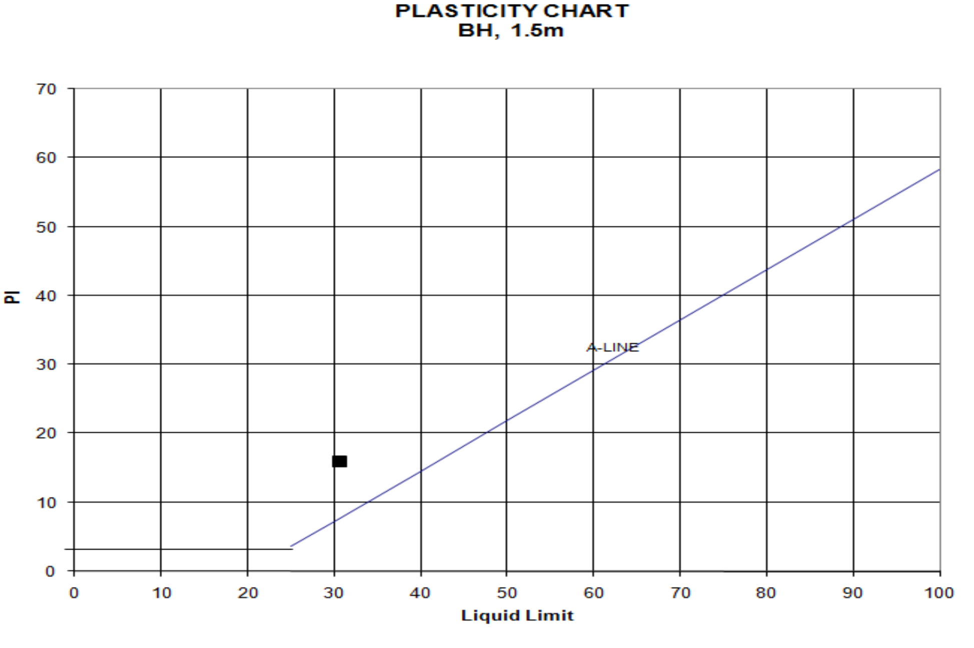

Fig-4. Plasticity chart for BH @ 1.6m

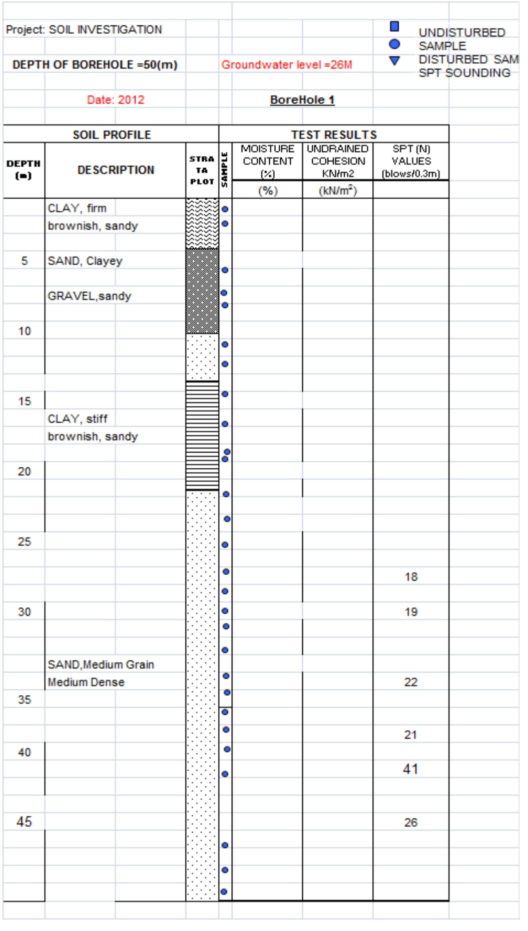

Fig-5.Lithology of BH-1

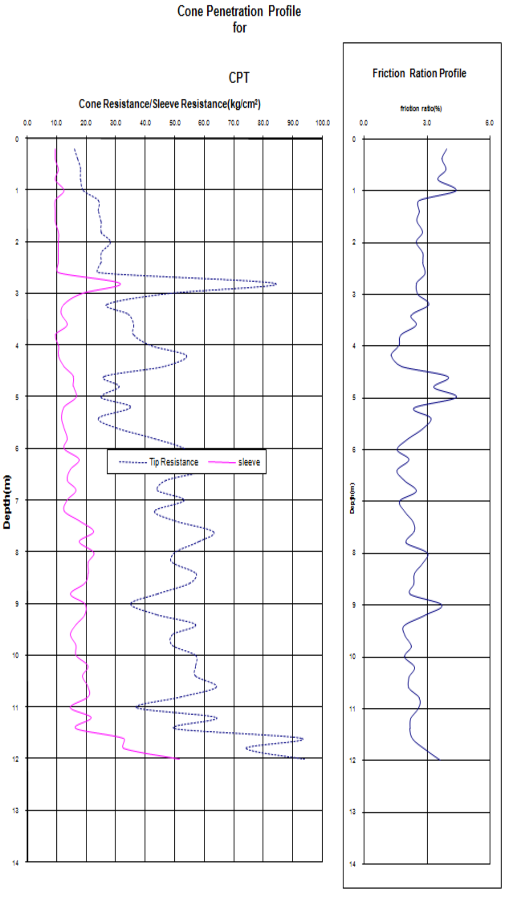

Fig-6. Cone Penetrometer Profile

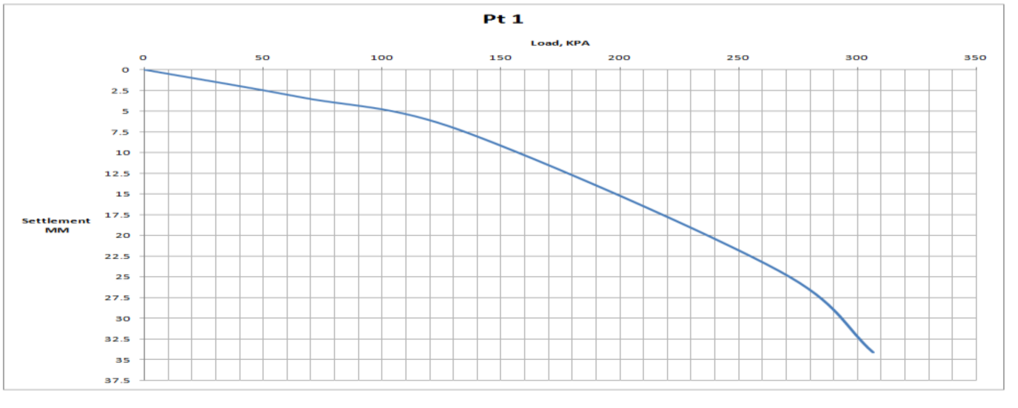

Fig-7. Loading settlement plot for point 1

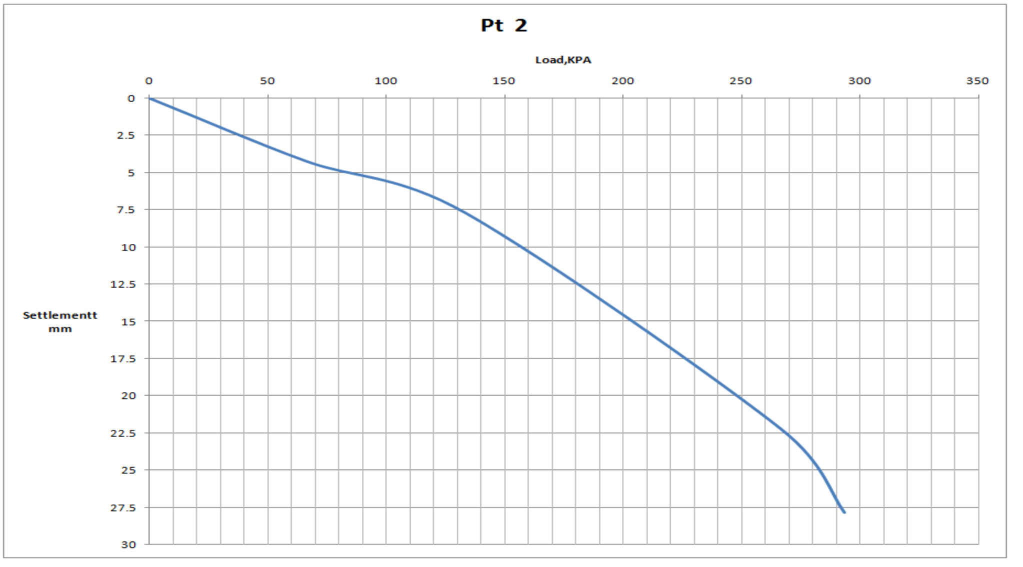

Fig-8. Loading settlement plot for point 2

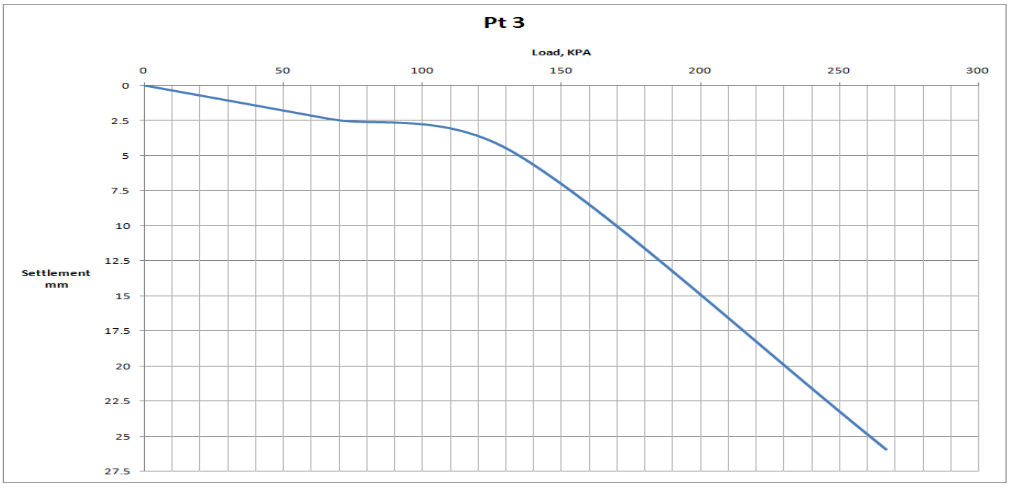

Fig-9. Loading settlement plot for point 3

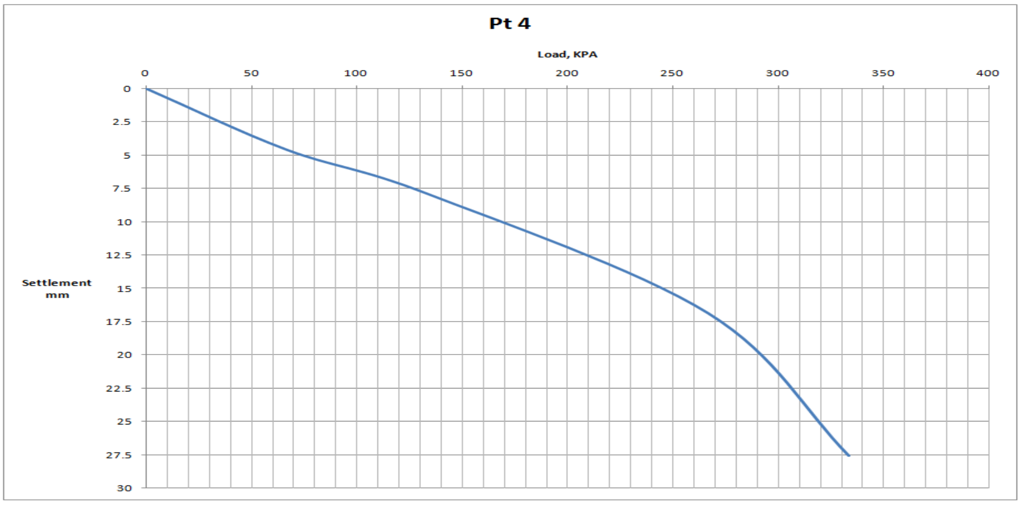

Fig-10. Loading settlement plot for point 4

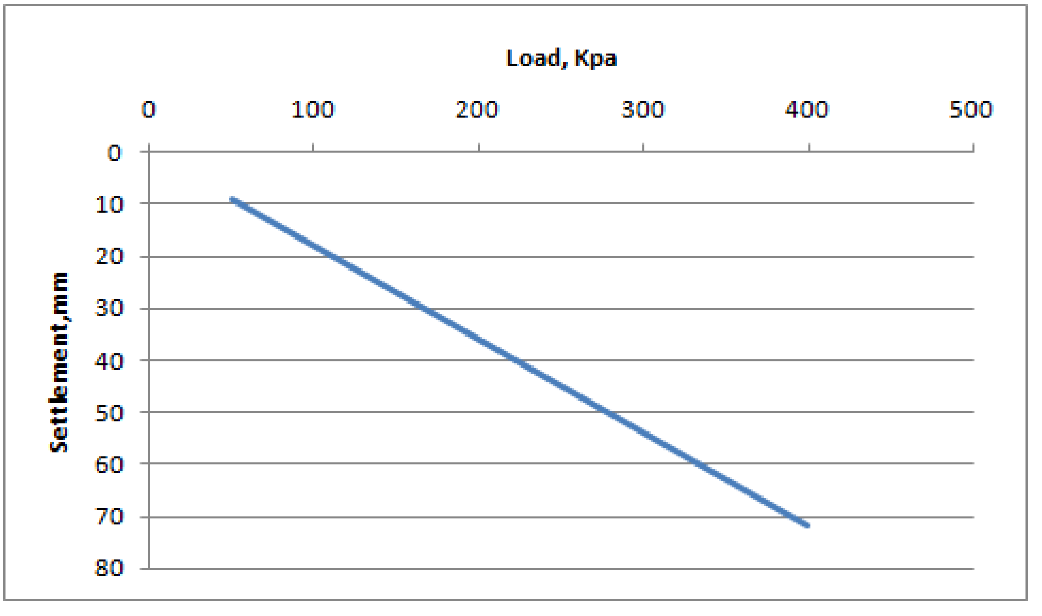

Fig-11. Variations of settlement with load

Table-1. Typical modulus of elasticity for some soils (Source: Arora [19])

s/no	Type of Soil	E (KN/m²)
1	Soft Clay	1500-4000
2	Hard Clay	6000-15000
3	Silty Sand	6000-20000
4	Loose Sand	10000-25000
5	Dense Sand	40000-80000
6	Dense Gravel	1x10^5 to 2 x10^5

Table-2. Geotechnical parameters of the study area

Geotechnical Parameters	Min	Max	Mean
Natural moisture content (%)	17.5	20.1	18.8
Liquid limit (%)	28.9	32.4	30.65
Plastic limit (%)	14.4	15.1	14.75
Plasticity index (%)	14.5	17.3	15.9
unit weight (kN/m^3)	19.5	19.9	19.7
Undrained cohesion	75	80	77.5
Angle of internal friction (^{o})	10	12	11

Table-3. Elastic modulus within the elastic range

Points	Stress(Kpa)	Settlement (mm)	Elastic Modulus(E_s) KN/m^2
1	105	5	4549.054
2	85	5	3647.826
3	70	2.5	6008.184
4	70	5	3004.092

Table-4. Comparing Average E_s values from different Method

Methods	E_s
Average E_s within the upper 1m from average Cone Value of 17Kg/cm2 (fig3)	4165 KN/m^2
Average E_s within the Upper 1m from Plate Load Test	4302.289 KN/m^2

Table-5. Load settlement value for point 1

Pressure (Kpa)	66.69444	133.3889	266.7778	306.7944
Initial Dial Reading	50.529	47.175	43.2	26.35
Final Dial Reading	47.175	43.2	26.35	16.47
Settlement	3.354	3.975	16.85	9.88
Cum. Settlement	3.354	7.329	24.179	34.059

Table-6. Load settlement value for point 2

Pressure,Kpa	66.69444	133.3889	266.7778	293.4556
Initial Dial Reading	50.15	45.89	42.45	27.91
Final Dial Reading	45.89	42.45	27.91	22.31
Settlement	4.26	3.44	14.54	5.6
Cum. Settlement	4.26	7.7	22.24	27.84

Table-7. Load settlement value for point 3

Pressure,Kpa	**66.69444**	**133.3889**	**266.7778**	**400.1667**
Initial Dial Reading	50.115	47.73	45.28	
Final Dial Reading	47.73	45.28	24.184	
Settlement	2.385	2.45	21.096	
Cum. Settlement	2.385	4.835	25.931	

Table-8. Load settlement value for point 4

Pressure,Kpa	66.69444	133.3889	266.7778	333.4722
Initial Dial Reading	50.21	45.619	42.32	33.345
Final Dial Reading	45.619	42.32	33.345	22.65
Settlement	4.591	3.299	8.975	10.695
Cum. Settlement	4.591	7.89	16.865	27.56