# A COMPARATIVE STUDY ON GEOTECHNICAL PROPERTIES OF SOIL IN DHAKA – A CASE STUDY USING DIFFERENT METHODS

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## ABSTRACT

For a consistent design of the foundation and to ensure structural safety, the modulus of elasticity of a specific soil must be accurately determined. Because, the uneconomical and flawed foundation design may cause a catastrophic failure of the entire structure, resulting in severe losses of lives and property. However, from the standpoint of Bangladesh, there are very few special researches have been done to date to ascertain the modulus of elasticity of Bangladeshi soil. This study mainly focuses on determination of elastic modulus of soil conducting plate load test and cone penetration test using theoretical equation and comparing the value of a selected location. Also, SPT the most common type of in-situ test to evaluate the geotechnical properties and to know the stratification of soil layers was conducted at the same location. The laboratory tests performed on the soil samples were the Unconfined Compression test, Direct Shear test, Atterberg Limit test, Grain Size Analysis, Specific Gravity test. The particular location is HBRI campus (Housing and Building Research Institute) at Mirpur, Dhaka. Roughly, the soil samples collected from the specific location represent the soil of Dhaka. The load settlement curve obtained from the plate load test characterized the soil as cohesive. The average value of elastic modulus was found 12500 kN/m2 from plate load test which conforms to the value obtained from cone penetration test (12456.40 kN/m2). As obtained from laboratory test results, the average liquid limit and the plastic limits values of 31.59% and 19.94% respectively shows that the soil under consideration was medium in compressibility which was also observed in the settlement variation plot. The average moisture content of soil was 21.64%. At the selected location of test, layers of very soft to stiff clayey silt have been encountered having thickness varying between 4 m and 3.10 m. The soil type we found from the overall research process is almost same (soft to medium cohesive clay). This study will be beneficial for future consequences to measure different geotechnical parameters of Dhaka city and for a nearly accurate estimate of the modulus of elasticity of soil.

***Keywords:*** *Plate load test, Soil modulus, Load-Settlement curve, Unconfined Compression, Direct Shear.*

## 1. INTRODUCTION

Settlement analysis is vitally important when planning and designing any constructions. A substantial portion of building failures have been attributed to either uneven settling or intolerable foundation settlement. Regarding these values, there are two types of settlement: consolidation and immediate. It is an important parameter to determine elastic or immediate settlement of foundations. The degree of quick settlement (elastic) is modified by the poisson ratio and elastic modulus. An indicator of the rapid settling is the modulus of elasticity, which is a basic material constant and a measure of the stiffness of the material. The plate load test method is widely used to determine a settlement. The plate load test's load settlement curve can be used to estimate an acceptable value in situations where the soil's elastic modulus changes very little or not at all. Determining the maximum bearing capacity of the soil and the probability of settlement under a certain load are both part of the plate load calculation. According to (Nwankwoala & Warmate, 2014), the test involves essentially loading a steel plate at the foundation level, and the settlement corresponding to each load increment is recorded. (Lambe & Whitman, 2000) proposed a stress-strain relationship for soils using plate load tests. The amount of strain depends on the void ratio, composition, past stress history of the soil, and method of stress delivery. In essence, the slope of a soil's stress-strain plot within the elastic range represents its modulus of elasticity, also known as the stress-strain ratio. This indicates the soil's deformation characteristics.

The elastic modulus, which represents the stiffness of the soil, can be graphically represented by the tangent modulus, or the slope of the tangent in a stress-strain plot. It is helpful for assessing the elastic theory and the semi-empirical influence factor approach for immediate soil settlements that was developed by (Schmertman & Hartman, 1978) . Depending on the kind of soil and the condition of loading, two basic foundation types—deep and shallow foundations—are typically used to design the foundation for a given structure (Nwankwoala & Warmate, 2014). When building a large, heavy structure on unstable soil, a deep foundation is always utilized. This typically consists of a number of piles covered with a cap (Abbas, 2014). The majority of earlier research has typically assumed that the soil surrounding the sample is composed of horizontal layers, even though this is not always the case.

At present, to determine the soil modulus of Bangladeshi soils, the formulas established and utilised in the United States, the United Kingdom, and other developed countries are being applied. The physical and geotechnical characteristics of the soil found in Bangladesh and the aforementioned countries differ greatly from one another. As a result, the soil modulus values obtained using various geological standards could not be appropriate or equivalent to the soil in our country. For this reason, the design and construction of the foundation may become riskier or more expensive. In order to solve the issue, the purpose of this study was to determine the modulus of elasticity value in the context of Bangladesh.

## 2. METHODOLOGY

The whole research program included the following sub-items of work.

### 2.1 Standard Penetration Test

Primarily a single standard penetration test (SPT) was conducted at every 5'-0" interval in the borehole at the site up to 40 feet to record density/stiffness characteristics of soil layers and for the simultaneous collection of disturbed samples and undisturbed tube samples. A detailed laboratory investigation was also carried out on soil samples collected from the selected location. Ground water level position was recorded by a measuring tape and found within depth of 5′ level measured from the existing level of the ground.

### 2.2 Static Cone Penetration Test

At every 0.5 m, a static cone penetration test was conducted. The main component of the apparatus is a steel cone with a cross sectional area of 10 cm2 and an overall base diameter of 35.7 mm. According to accepted practice, the friction sleeve on the 10 $cm^2$ cone penetrometer should cover an area of 150 $cm^2$. The friction ratio, which is the ratio of side friction to bearing resistance, allows for the identification of the soil type and offers helpful information, especially when borehole data are not available. The friction ratio provides a check on the precision of the boring log even when borings are made.

### 2.3 Plate Load Test

A steel plate of one square foot and having a thickness of one inch was used for the plate load. Data was logged using a data recorder for science. Following the gravity loading platform approach, the test plate was loaded. A load test was initiated with 3.3 kip of residual load still present in the load cell. After placing a sitting load of 42 kPa, a reaction load of 5 kip was imposed over a hydraulic jack with a 50-ton capacity that was lying on the test plate. The increment was subsequently applied, and observation was repeated, until the settlement significantly decreased (a value of 0.08 mm per minute). The test was carried out until a settlement of 10 mm was achieved. Due to specific loading arrangement limitations, the test could not be carried out to the maximum settling of 25mm.

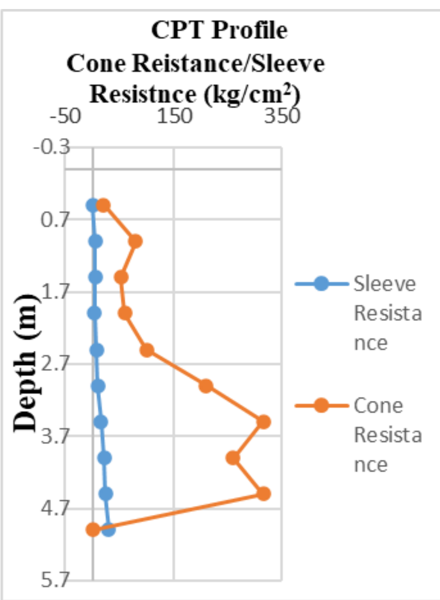
### 2.4 Laboratory Tests

The Atterberg Limit Test, Unit Weight (wet & dry), Unconfined Compression Test, Direct Shear Test, Specific Gravity Test, and other laboratory tests were carried out to ascertain the fundamental geotechnical characteristics of soil samples.

## 3. ILLUSTRATIONS

### 3.1 Results and graphs of field tests and laboratory tests

#### 3.1.1 Cone Penetrometer profile



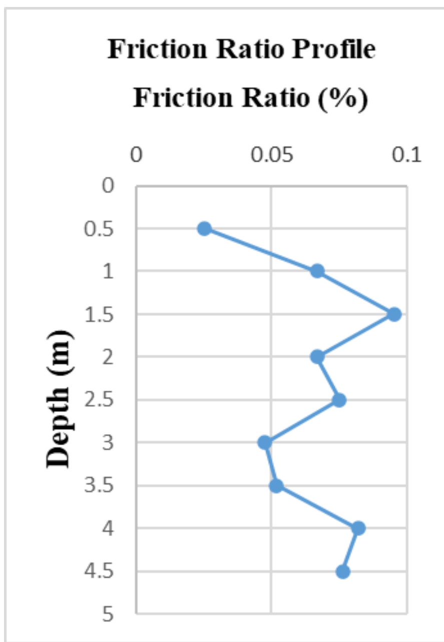




Figure 3.1: Cone Penetrometer Profile

### 3.1.2 Test result of Atterberg Limit

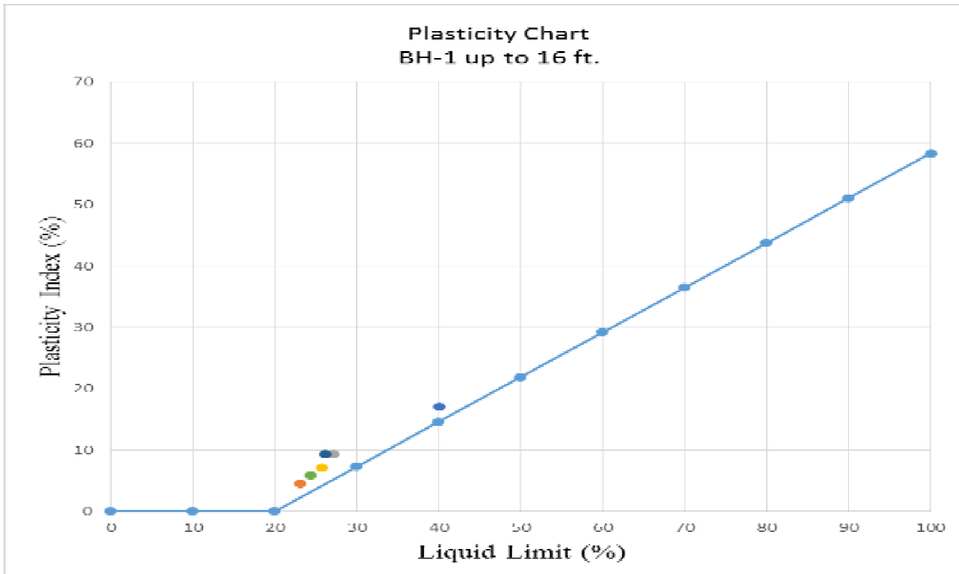
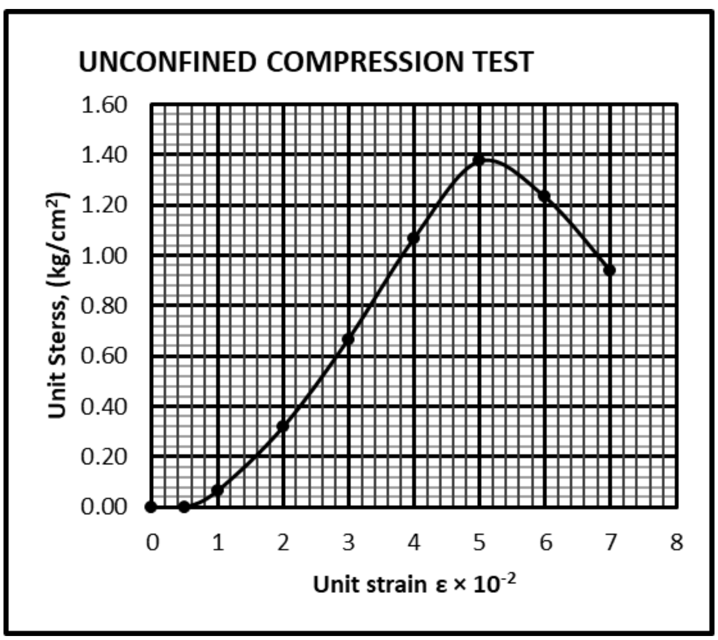



Figure 3.2: Plasticity chart of the study area up to 16 ft.

### 3.1.3 Test result of Unconfined Compressive Strength test




| | |
|---|---|
| Depth (m) | 3.00-4.50 |
| qu (Kg/cm$^2$) | 1.37 |
| Strain (%) | 5.00 |
| M/C (%) | 20.29 |
| $\gamma_{wet}$ (gm/cm$^3$) | 2.08 |
| dray (gm/cm$^3$) | 1.73 |

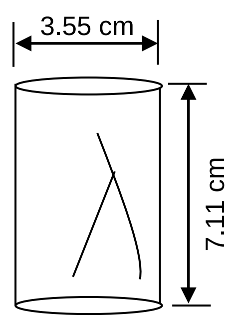
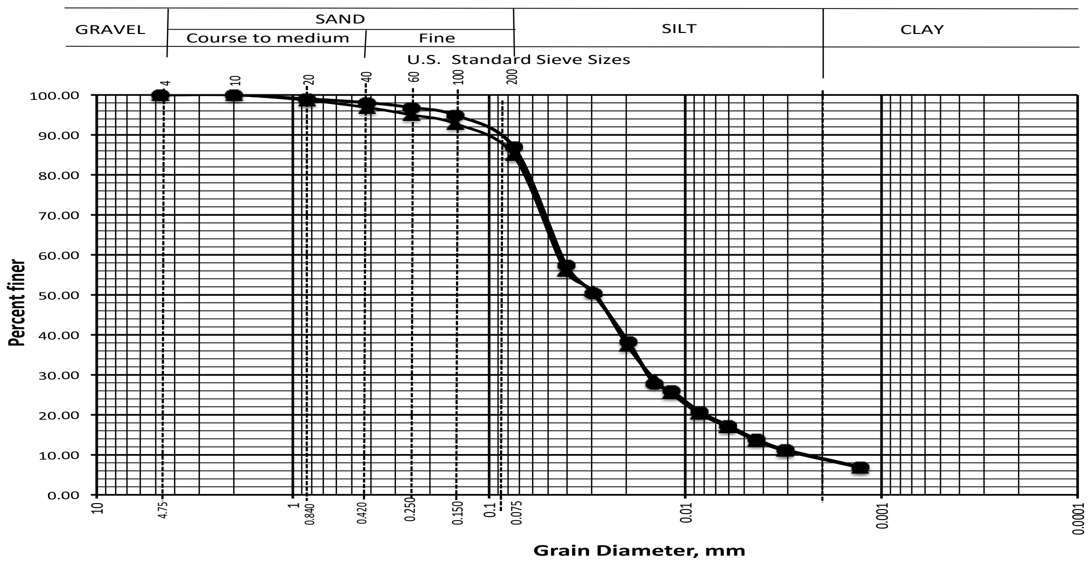



Figure 3.3: Curve of Unconfined Compression Test

### 3.1.4 Test result of Grain Size Analysis




| DEPTH (ft.) | SAND (%) | SILT (%) | CLAY (%) | Sg. Gravity |
|---|---|---|---|---|
| 3.00-4.50 | 15 | 76 | 9 | 2.63 |
| 7.00-8.50 | 13 | 78 | 9 | 2.66 |

Figure 3.4: Particle size distribution curve in the area

### 3.1.5 Test Result of Direct Shear

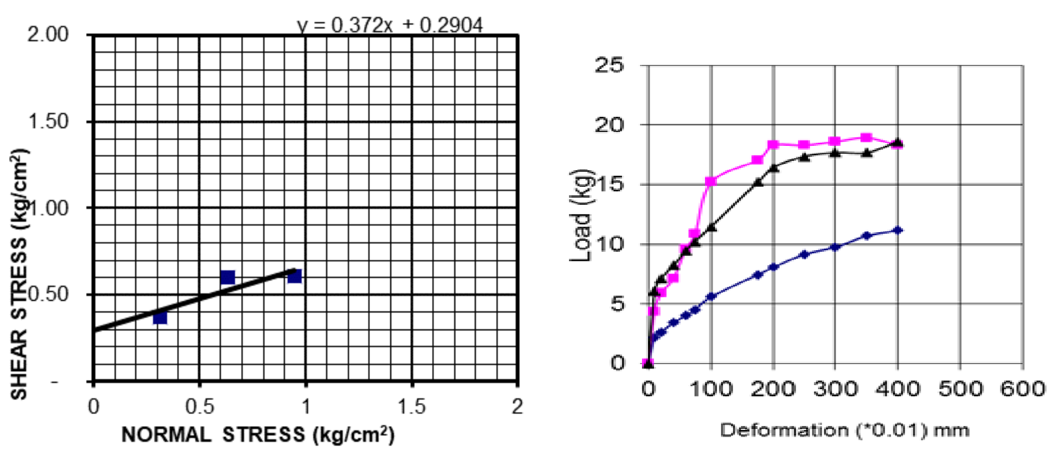



Figure 3.5 Direct Shear test

### 3.1.6 Test Result of Plate Load test

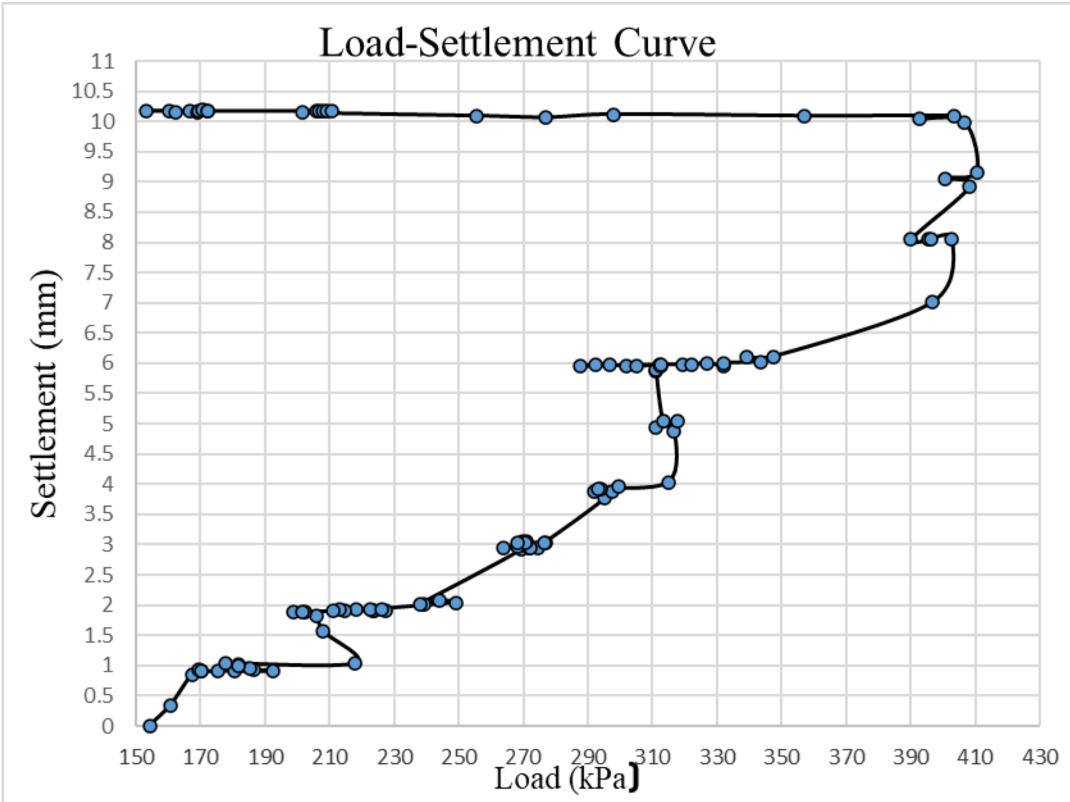



Figure 3.6 Load-Settlement Curve

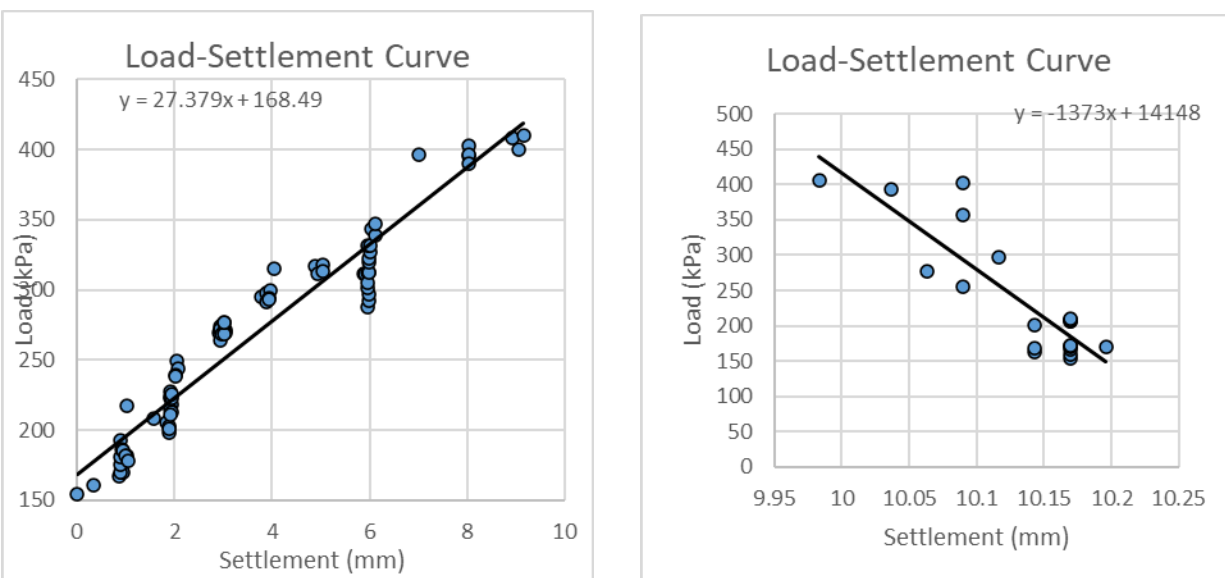



Figure 3.7 Correlating Load & Settlement (left: Loading & right: Unloading)

## 3.2 Equations

(Harr, Sharda, & Belafonte, 1966) made the following relations on the immediate settlement of a rigid foundation based on $E_s$ and υ

$$S_e = Bq(1-\upsilon^2)\,\alpha_r/E_s \quad [1]$$

Where

B = width
q = load, Kpa
υ = Poisson's ratio.
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, Sharda, & Belafonte, 1966) for rigid foundation, assuming υ = 0.25 and α = 0.85 for square foundation.

### 3.3 Tables

#### 3.3.1 Reference Tables

Table 1: Typical Elastic Moduli of soils based on soil type and consistency/ density (From USACE, Settlement Analysis)

| Soil | $E_s$ (tsf) |
|---|---|
| very soft clay | 5 – 50 |
| soft clay | 50 – 200 |
| medium clay | 200 – 500 |
| stiff clay, silty clay | 500 – 1000 |
| sandy clay | 250 – 2000 |
| clay shale | 1000 – 2000 |
| loose sand | 100 – 250 |
| dense sand | 250 – 1000 |
| dense sand and gravel | 1000 – 2000 |
| silty sand | 250-2000 |

#### 3.3.2 Test Results

Table 2 outlines key geotechnical parameters for the study area, presenting the minimum, maximum, and mean values. The natural moisture content ranges from 19.40% to 23.87%, with a mean of 21.64%, while the liquid limit varies between 23.09% and 40.09%, with an average of 31.59%. Plastic limit values fall within the range of 16.85% to 23.03%, with a mean of 19.94%, resulting in a plasticity index ranging from 4.49% to 17.06%, with a mean value of 10.78%. The unit weight of the soil ranges from 1.82 gm./cc to 2.29 gm./cc, with a mean of 2.06 gm./cc. Additionally, the undrained cohesion spans from 0.10 kg/cm2 to 0.73 kg/cm2, with a mean of 0.42 kg/cm2, and the angle of internal friction ranges from 19° to 20°, with an average of 19.50°.

Table 2: Geotechnical parameters of the study area

| Geotechnical parameters | Min | Max | Mean |
|---|---|---|---|
| Natural moisture content (%) | 19.40 | 23.87 | 21.64 |
| Liquid limit (%) | 23.09 | 40.09 | 31.59 |
| Plastic limit (%) | 16.85 | 23.03 | 19.94 |
| Plasticity index (%) | 4.49 | 17.06 | 10.78 |
| Unit weight (gm./cc) | 1.82 | 2.29 | 2.06 |

| | | | |
|---|---|---|---|
| Undrained cohesion (kg/cm$^2$) | 0.10 | 0.73 | 0.42 |
| Angle of internal friction ($^0$) | 19 | 20 | 19.50 |

Table 3 presents data on elastic modulus within the elastic range under loading and unloading conditions. In the loading part, the settlement increases from 2 mm to 8 mm, corresponding to stress values ranging from 223.25 kPa to 387.52 kPa, resulting in elastic modulus (Es) values of 27112.60 kN/m$^2$, 16881.46 kN/m$^2$, 13470.84 kN/m$^2$, and 11765.59 kN/m$^2$, respectively. During unloading, the settlement remains constant at 10 mm, with decreasing stress values from 418 kPa to 212.05 kPa, yielding elastic modulus values of 10152.80 kN/m$^2$, 8443.15 kN/m$^2$, 6750.42 kN/m$^2$, and 5074.37 kN/m$^2$, respectively. The average elastic modulus for the entire unloading process is calculated as 12456.40 kN/m$^2$. This table provides valuable information on the material's response to loading and unloading conditions, offering insights into its deformation characteristics and elastic behavior within the specified settlement and stress ranges.

Table 3: Elastic Modulus within elastic range

| **Condition** | **Settlement (mm)** | **Stress (kPa)** | **Elastic Modulus, Es (kN/m$^2$)** |
|---|---|---|---|
| loading part | 2 | 223.25 | 27112.60 |
| | 4 | 278.01 | 16881.46 |
| | 6 | 332.764 | 13470.84 |
| | 8 | 387.52 | 11765.59 |
| unloading part | 10 | 418 | 10152.80 |
| | 10.05 | 349.35 | 8443.15 |
| | 10.10 | 280.70 | 6750.42 |
| | 10.15 | 212.05 | 5074.37 |
| Average, Es | | | 12456.40 |

Table 4 compares average elastic modulus (Es) values obtained using different techniques for the specified depth within the top 3 feet. The first method involves assessing the average Es within the top 3 feet based on a 50 kg/cm2 average cone value, resulting in a value of 12500 kN/m2. The second method utilizes data from the Plate Load Test conducted within the same depth, yielding an average Es value of 12456.40 kN/m2. The table suggests a close agreement between the two techniques, indicating consistency in the estimation of elastic modulus within the specified depth range. This comparison is valuable for validating and cross-verifying the results obtained from different methods, enhancing confidence in the accuracy of the elastic modulus values for the specific geological conditions and depths under consideration.

Table 4: Comparing Average $E_s$ values using various techniques

| **Methods** | **$E_s$** |
|---|---|
| Average $E_s$ within the top 3 ft. from the 50 kg/cm2 average cone value | 12500 kN/m$^2$ |
| Average $E_s$ from the Plate Load Test within the top 3 ft. | 12456.40 kN/m$^2$ |

### 3.4 Results and Discussions

- At the selected location of test, layers of very soft to stiff clayey silt have been encountered having thickness varying between 4 m and 3.10 m. The presence of very soft to stiff clayey silt deposits indicates the strong possibility of substantial settlement. Below 23 ft. of EGL, the soil is totally silty sand. But required depth of plate load test is 3-5 ft. So, we will consider the soil parameter of cohesive soil (up to 16 ft.).
- The load settlement curve of plate load test at the chosen location which was carried out at HBRI campus shows that the soil under investigation was cohesive. This curve does not display the definite failure point as the test could not be continued to the final settlement (25mm) due to unavailable circumstances (constraints of loading arrangement). The test was stopped after obtaining 10 mm settlement and later it was unloaded. From the data, we found two curves for loading and unloading conditions. This is also verified by the geotechnical properties of the soil, (Table 3) which depicts values above the A line plot on the plasticity chart. Also, the average liquid limit and the plastic limits values of 31.59% and 19.94% respectively shows that the soil under consideration was medium in compressibility which is observed in the settlement variation plot. The average moisture content of soil was 21.64%. With the adoption of equation 1, assuming a poisson ratio of 0.25, an average elastic modulus value of 12456.40 kN/m$^2$ (125 tsf) was obtained in the elastic range (initial tangent modulus), which is indicative of soft clay (Reference: Table 1). This value correlate reasonably with those obtained by method proposed using Cone Penetrometer Test (CPT) with an average cone value of 50 kg/cm$^2$ with $E_s$ = 12500 kN/m$^2$.
- The lithology of the upper section of the site (up to 13 ft. below existing ground level) from borehole log is mainly clayey silt of medium plasticity (CL) with sand where water level was at 5 ft. below EGL. The particle size distribution shows 75 microns with about 86% passing sieve no. 200.

## 4. CONCLUSIONS

So far observations, we have found some significant results that may be helpful for structural designs for Dhaka city. The values of the elastic modulus found by analyzing the plate bearing test is very similar to that found by cone penetration tests at the specific location (HBRI campus within top 3 ft.). Additionally, we can match the type of soil from the range of the value of elastic modulus with Table 1 found in literature. Similarly, the geotechnical parameters of the study area reflect the type of soil that also match with the result of plate load test and cone penetration test.

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