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Prediction of settlement of high court building, kolkata using flat dilatometer- a case study

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ABSTRACT: Hon'ble High Court Building is situated in Kolkata, India by the river Ganges, locally known as the Hooghly river. The building is one of the most important structures in the region due to its heritage status. It was observed that excessive settlement had occurred on the North-West block of the building over a long period. Therefore some preventive measures had to be taken on urgent basis and that too in a precise manner. It was decided to minimise the settlement by improving the property of subsoil. For this purpose, it was essential to determine the engineering properties of the sub-soil and to estimate the settlement for the sake of effective ground improvement work. In this regard, Marchetti Flat Dilatometer Test (DMT) along with other conventional field and laboratory tests were carried out within Kolkata High Court premises. Marchetti Flat Dilatometer test is a very useful equipment to measure the soil stress history, age of soil, constrained modulus in a very accurate manner. This paper presents a case study regarding the usefulness of DMT for the computation of settlement along with other geotechnical parameters. Also an attempt was made to draw a comparison between the calculated settlement from field test with observed settlement from the settlement sensors fitted around the super structure of the affected portion of the building.

Keywords: high court building; settlement; dmt; settlement sensor; comparison

1. Introduction

Hon'ble High Court Building, Kolkata is a heritage structure in India. This building is situated by the river Ganges, popularly known as the Hooghly river. In recent times, it was observed that the North-West portion of that building had started showing tell-tale signs of settlement right from the superstructure level down to the ground floor level possibly due to shifting of the library towards this corner. As a consequence restoration of this structure was necessary. Ground improvement was proposed and by virtue of this, it was presumed that shear strength of sub-soil would increase and soil compressibility would decrease. Consequently, this would arrest the problem of settlement.

The assessment of geotechnical parameters, analysis and judicious design of the underground soil improvement work and also the appropriate prediction of settlement were necessary. Hence it was decided to carry out field tests around the periphery of the affected portion. Due to insufficient space around the affected zone of the building, Flat Dilatometer Test (DMT) was preferred for this case. From the last few decades the use of DMT has increased to a great extent for prediction of settlements. One of the most vital reasons was its ability to determine the stress history, age of soil, constrained modulus in a very accurate manner from in-situ tests.

In the present study, boreholes were dug around the building of High Court and Standard Penetration tests were also performed. The representative and undisturbed samples were collected from different depths. The depth of borehole was 25.60m from existing ground level. The engineering properties of sub-soil were evaluated from laboratory tests for calculating the bearing capacity and settlement of the building foundation.

In addition to the above soil exploration work, Marchetti Flat Dilatometer (DMT) test was carried out to estimate the settlement and subsoil profile characteristics based on four test locations (namely Pit 1, Pit2, Pit3, and Pit4) around the North West corner of the building.

For inspection of daily settlement, six numbers of settlement sensors had been installed around the building locations where the Dilatometer tests were performed.

In the present paper, the settlement of North West corner of Hon'ble High Court Building, Kolkata is assessed by means of DMT test. The settlement was calculated from DMT test data by using SDMT-Elab software (provided with Marchetti DMT instruments). Besides, based on the conventional soil exploration, settlements were evaluated from the borehole data and laboratory tests. In addition to all of these, settlement sensors were used to monitor the actual settlement at site.

2. Different tests

Marchetti flat dilatometer (DMT) test along with other conventional field and laboratory tests were carried out within Kolkata High Court Building premises to estimate the settlement for the sake of effective ground improvement work. These tests are summarized below.

2.1. Flat dilatometer test

The flat dilatometer (DMT, Fig. 1.) was developed by Prof. Marchetti in 1980 [1] in Italy. The DMT has been used frequently in many countries including North and South America, Europe, Asia, during the last decade. The main advantages of DMT are its user interface and its simplicity from the economical point of view [2]. It can also be used in a repetitive manner.

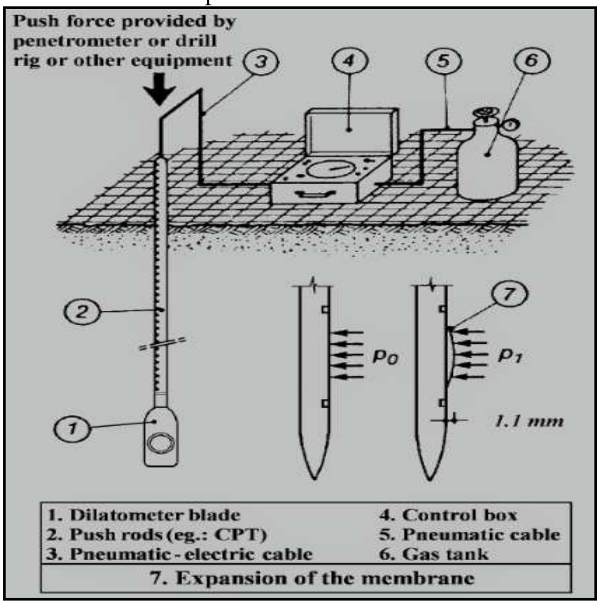

Figure 1. Diagram of Marchetti flat dilatometer set up. (Source: TC16,2001)

This instrument (DMT) along with one penetrometer (TG63-150, Fig. 2.) are recently been procured by Jadavpur University, Kolkata in India. Earlier, based on some tests data obtained from the field tests in Kolkata region and outside the country, an overview was presented on DMT tests to predict subsoil profiles and settlements of post-earthquake condition [3].

Figure 2. TG63-150 penetrometer. (Source:Pagani)

2.2. Conventional boring approach

Conventional wash boring was used to drill holes and whenever an undisturbed sample was required at a particular depth, the boring was stopped. Then a sampler was used in place of chopping bit. Standard penetration Test (SPT) was also conducted at certain intervals of depth. The disturbed and undisturbed samples were collected from different depths upto 25.60m below existing ground level. The soil samples were tested in laboratory for predicting the bearing capacity and settlement of the building.

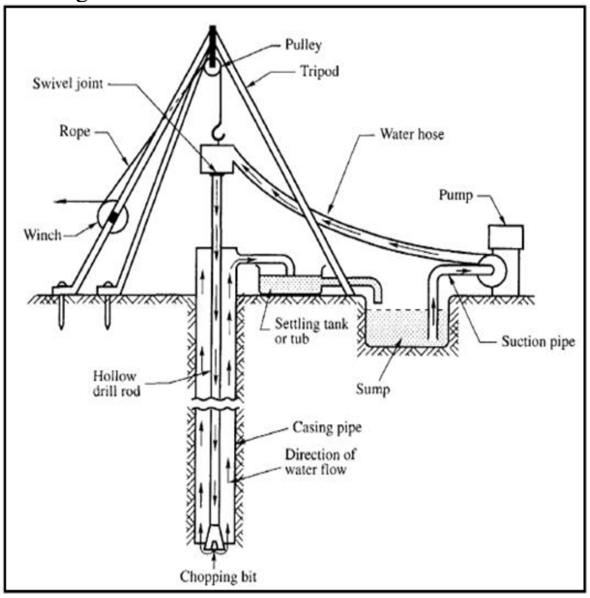

Figure 3. Conventional wash boring process, schematic diagram. (Source: Google Image)

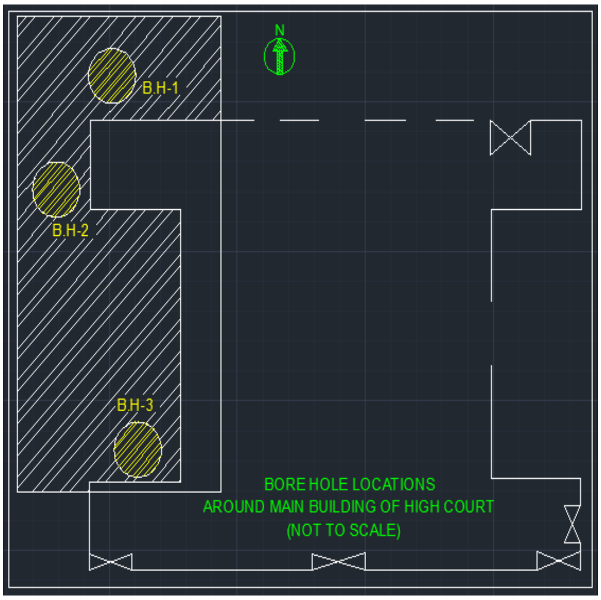

Figure 4. Borehole location plan.

2.3. Use of settlement sensors

Six numbers of settlement sensors were installed on 01/01/2018 around the affected portion (North-West block) of the building to monitor the day to day change of settlement. The photograph showing settlement sensors is shown in Fig. 5., and Fig. 6. The location map of all sensors is shown in Fig. 7.

Figure 5. Photograph of settlement sensor.

Figure 6. Photograph of settlement sensor.

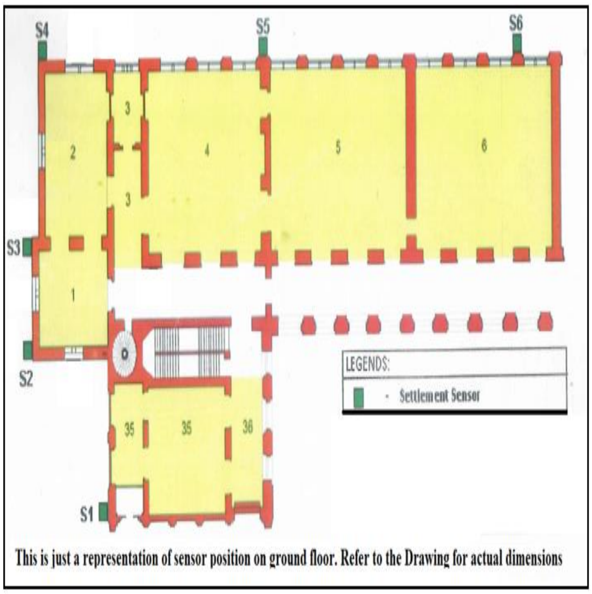

Figure 7. Location map of settlement sensor.

3. Background of Hon’ble High Court Building test site

Kolkata “High Court Building” was constructed in 1872 (about 147 years ago) [9]. The design of building was based on the Cloth Hall at Ypres, Belgium, (Fig. 8.).The building was constructed after ten years of establishment of the court itself. The design was based on neo-gothic type and it was designed by the architect Walter-Granvelle. In recent times, the library of Hon’ble High Court had been relocated to the north-west corner of the building. Immediately after this shifting, the structure around this portion of the building started showing distress and developed considerable cracks on walls, floors, arches etc. All these pointed towards telltale sign of settlement of foundations due to placement of the new load. This additional loading due to books, almirah etc. resulted in total foundation pressure to the tune of about 200 kPa. In the above context it was necessary to predict the amount of settlement alongwith the soil parameters by soil exploration technique. In this regard, use of some technically modern geotechnical equipment, which will give most accurate results and also be operated within a limited space, became obvious. It was thought that Marchetti flat dilatometer (DMT) was more suitable for this type of job. The photograph of DMT which was conducted in “High Court Building” site is shown in Fig. 9.

Figure 8. Kolkata High Court Building. (Source: Google Image)

Figure 9. Photograph of test site.

3.1. Test procedure of flat dilatometer

DMT is operated by push in type [1, 2, 10] mechanism which can be assembled to a machine namely TG63-150 manufactured by Pagani Geotechnical equipment, Italy (Fig. 2.).

Four numbers of points surrounding the affected part of the “High Court Building” were selected to conduct DMT test. But it was difficult to conduct DMT test at ground level because of the brick bat soling up to the depth of 2.00 meter.

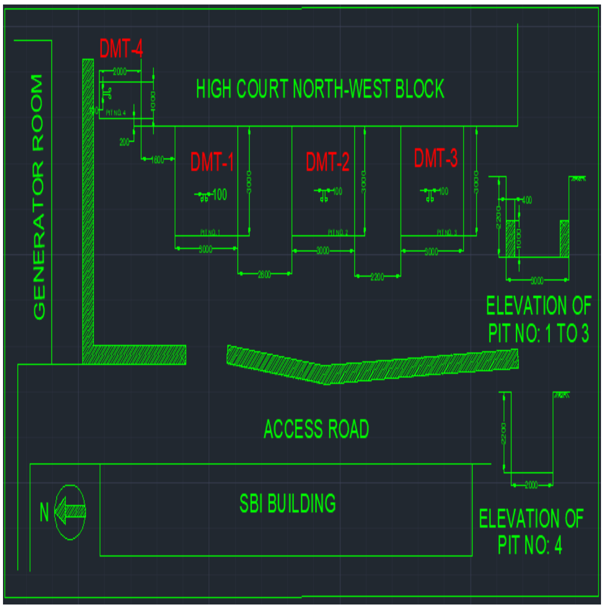

Figure 10. Drawing of site plan.

As a consequence, four numbers of pits (Three pits are in one line and one is at corner side of the building, Fig. 10.) were excavated manually. Three consecutive pits measured 3m in length, width 3m and depth 2.2 m. The corner side pit measured 2m in length, width 1m and depth 2.2m. These borrow pits were excavated at a distance of approximately 600mm from the edge of the wall (from the edge of N-W block). The spacing of pits was about 5.2 m center to center (Fig. 11.). After the excavation, flat dilatometer tests were started by using the penetrometer TG63-150 for each of the pit.

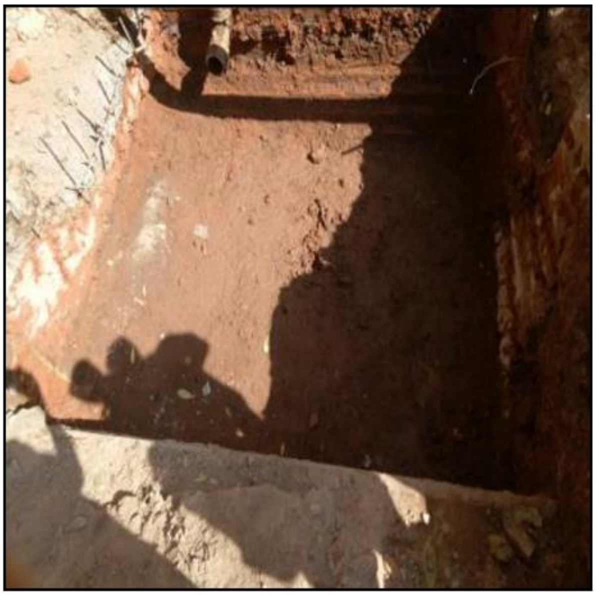

Figure 11. Photograph of borrow pit.

Figure 12. Photograph of placing of ramp.

The ambience was very difficult to conduct all the tests, mainly due to insufficient space for placing the penetrometer. To overcome this difficulty, four numbers of steel ramps were used. Each ramp measured 2.72 m in length, 0.4 m in width and 0.18 m in thickness. These ramps were joined together through bolts as shown in Fig. 12. After cleaning the side of the excavated pit, these ramps were placed as shown in Fig. 12.

Thus four numbers of shorter ramps were converted into two longer ones having length of 5.4m. In the next step these ramps were laid horizontally above the borrow pit. The gap between these two parallel ramps was maintained as 200mm so that the DMT blade could easily pass through this space.

Subsequently, penetrometer TG63-150 was placed on these ramps and the tests were started, Fig. 13.

Figure 13. Photograph of tests set up.

4. Test results

All the test results supported by graphs and tables are presented below.

4.1. Subsoil profile of High Court Building site

Initially, bore holes were dug in order to identify the sub-soil properties. For the purpose of predicting the settlement, the soil strata were investigated in terms of strength and deformability parameters.

Boreholes were driven to a depth of 25.60m. Undisturbed soil samples were collected and standard penetration tests were also carried out. Description of stratigraphy and the strength and stiffness parameters had been estimated from the laboratory investigation of collected soil samples (representative and undisturbed).

The laboratory investigation was carried out to determine the soil index properties (grain size distribution, moisture content and atterberg limits) and also the shear strength parameters by triaxial tests. On the other hand DMT test was carried out upto a depth of about 8.0m to 10.0m below the ground level.

From the DMT tests, sub soil properties such as shear strength parameters, constrained moduli [1,2,10] were predicted.

It was observed that the top layer in the tested subsoil is formed by a filling of rubbish and brickbats with an average depth of 3.0m. This layer is followed by soft/ firm brownish grey silty clay/clayey silt with an average depth of 3.00m. The next subsoil layer is of soft dark grey silty clay/ clayey silt with organic matter and decomposed vegetation with average thickness of 9.0m. This layer is underlain by light bluish/ brown grey silty clay/clayey silt with an average depth of 8.0m. This layer is finally followed by medium dense/ dense brownish grey silty fine sand with mica extending up to the termination depth i.e, 25.60m.

DMT tests were conducted upto such a depth so as to obtain the soil engineering properties within the zone of influence of the pressure bulb and these were done upto the depth of 10 m which more than sufficed this condition. From DMT tests subsoil profile is found to be almost similar to that of the conventional boring tests. Google location of “High Court Building” is shown in Fig. 14.

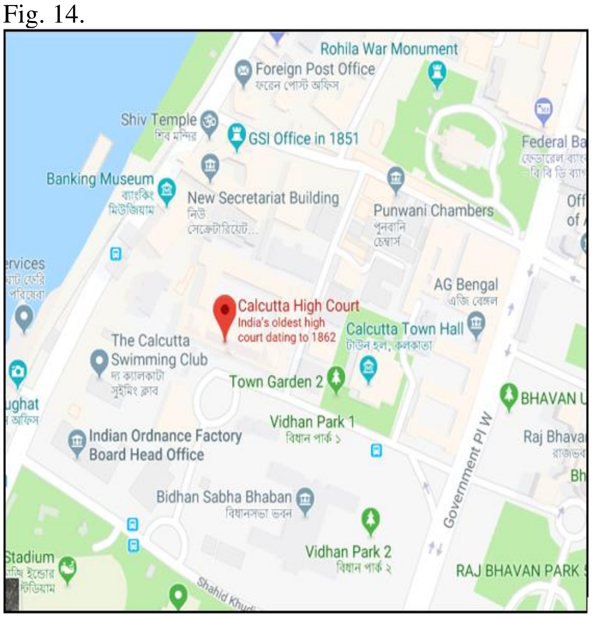

Figure 14. Google location of the High Court site. (Source: Google Map)

Fig.15., shows the comparison of soil profile obtained from conventional boring approach and DMT test. It is observed that both the profiles give similar stratifications.

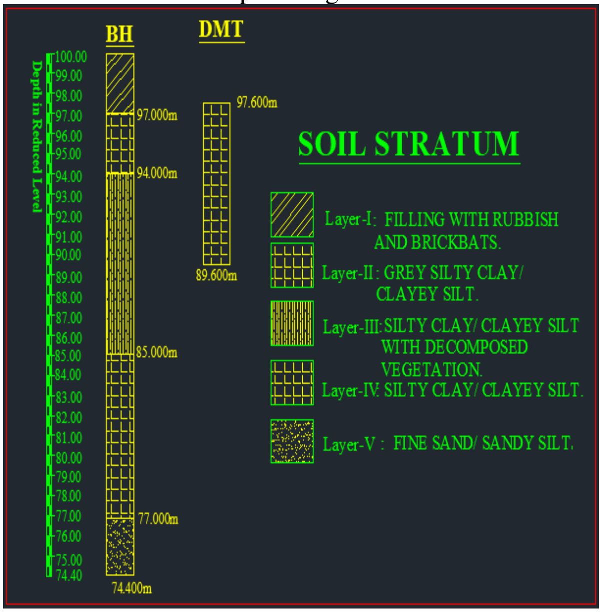

Figure 15. Typical cross section of soil profile.

4.2. Soil parameters of the High Court Building site

A typical depth-wise Undrained Cohesion (C_u), Constrained Modulus (M) alongwith two numbers of basic parameters i.e., Material Index (I_d) and Horizontal Stress Index (K_d) of DMT test for the High Court Building site are shown in Fig. 16., and Fig. 17.

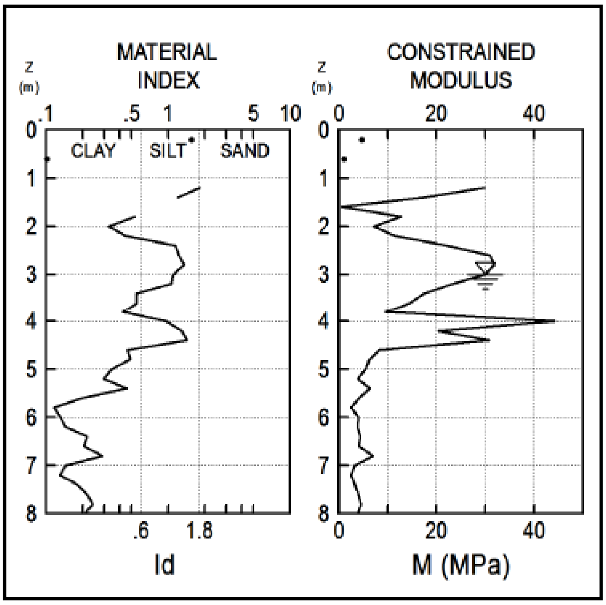

Figure 16. Profile of I_d and M indices from DMT Result.

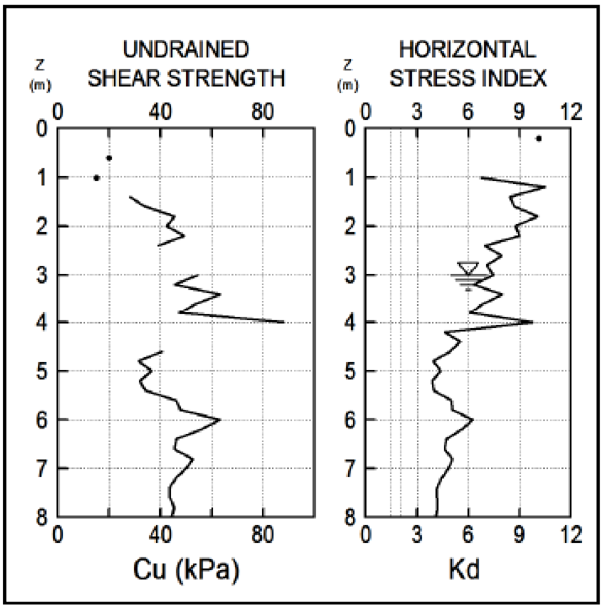

Figure 17. Profile of C_u and K_d indices from DMT Result.

Undrained shear strengths obtained from DMT test and Triaxial test are listed below in “Table 1.”.

Table 1. Comparison of undrained shear strengths obtained from DMT test and Triaxial test

DMT		Triaxial	
Depth (m)	S_u (kPa)	Depth (m)	S_u (kPa)
0.00 - 3.00	-	0.00 - 3.00	-
3.00 - 4.00	16.73	3.00 - 6.00	36
4.00 - 5.20	25.17		
5.20 - 6.40	31.22	6.00 - 15.00	20
6.40 - 7.60	34.51		
7.60 - 8.80	33.99	15.00 - 20.00	55
8.80 - 9.80	39.73		
9.80 - below	35.85	20.00 - 23.00	65

The undrained shear strength, S_u, was obtained from both triaxial test (unconsolidated undrained) and DMT test. A comparison of the results is shown in “Table 1.”. For better prediction of the soil behavior, this evaluation is very much important because it shows the correlation between different important soil engineering properties.

Fig. 18., shows comparison between undrained shear strength [6] obtained from DMT and Triaxial test. It is evident from this figure that DMT trend line is on the upper side depicting higher values of shear strength for the same depth. As a result, it will give more economical results for the given design criteria.

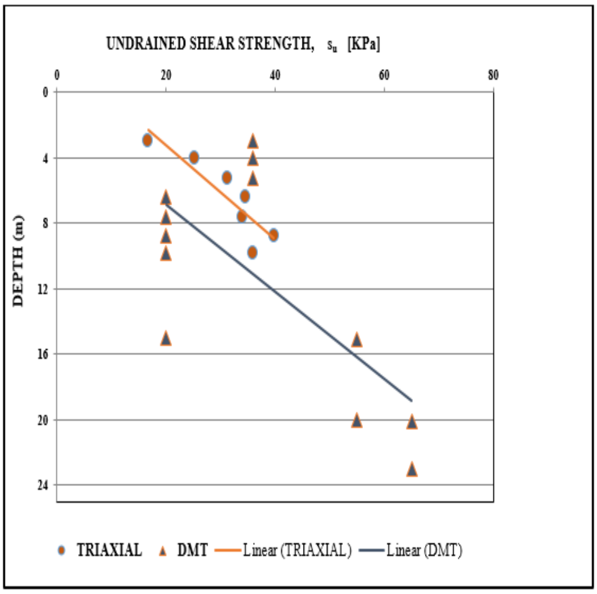

Figure 18. Depth vs undrained cohesion obtained from DMT test and Triaxial test.

4.3. Settlement analysis of High Court Building site

For the purpose of settlement prediction from the DMT data [11], a software was used namely DMT settlement [12] provided with the DMT machine. This software is based on the one dimensional elastic theory. For calculation purpose the depth of foundation was assumed as1.9m below the ground level. The foundation of the building was strip footing (length is 21m and width is 2.1m). Total load intensity on the footing was assumed as 200 kPa (Fig. 19.).

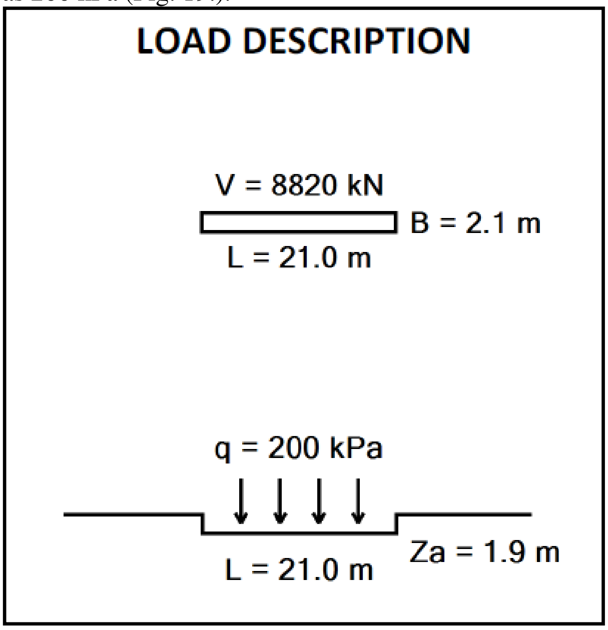

Figure 19. A schematic diagram of load case.

4.4. Soil parameters for settlement calculation

The settlement of the foundation was calculated by one dimensional consolidation theory [5, 6, and 7, 8]. The vertical stress increment was calculated by using Boussinesq's equation. The main parameters to calculate the settlement are constrained modulus (M), vertical stress increment (Δσ), and vertical strain (ε). The variation of those parameters [12] are shown in Fig. 20., Fig., 21, Fig. 22., and Fig.23.

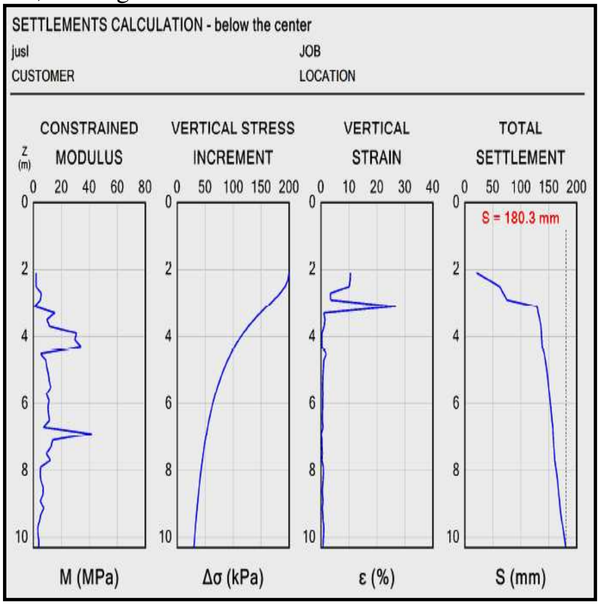

Figure 20. Variation of soil parameters with depth.

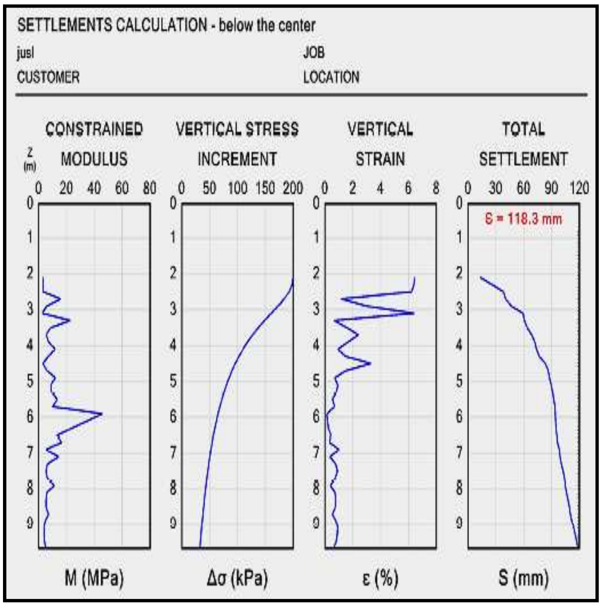

Figure 21. Variation of soil parameters with depth.

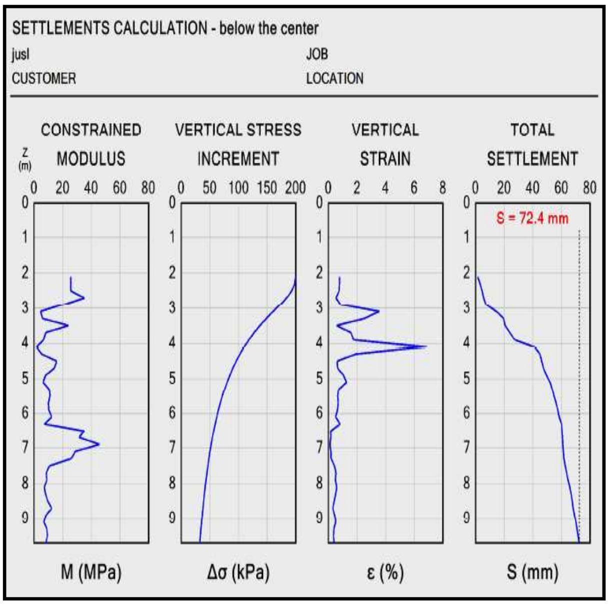

Figure 22. Variation of soil parameters with depth.

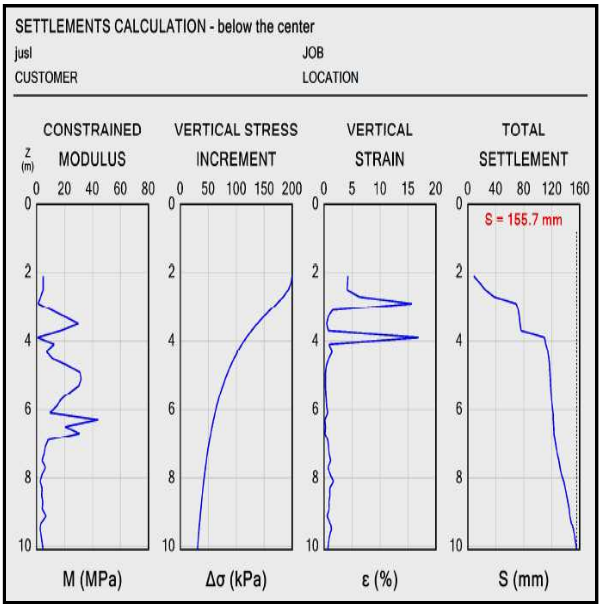

Figure 23. Variation of soil parameters with depth.

4.5. Settlement Calculation

The settlement was calculated based on results obtained from the four numbers of pits. After that the total settlements were calculated to the center of the footing shown in Fig. 24., Fig. 25., Fig. 26., and Fig. 27. The calculation of the settlements were done by taking the thickness of each soil layer as 20 cm. The calculated settlements are obtained using the interpretation formulae and the calculation method as recommended in the TC16 DMT Report [10].

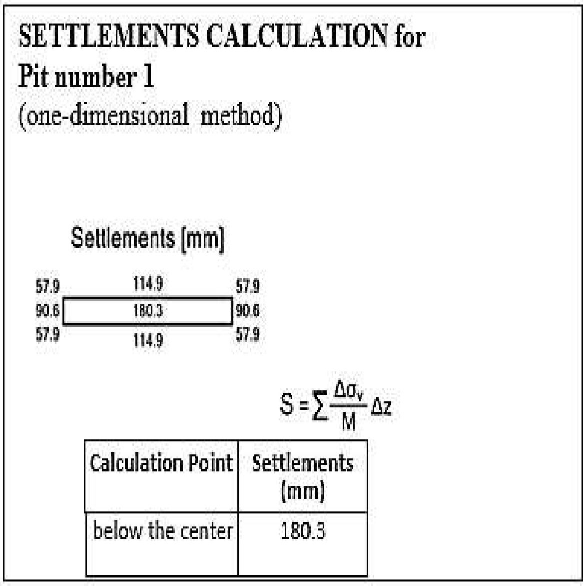

Figure 24. Settlement calculation for pit no-1.

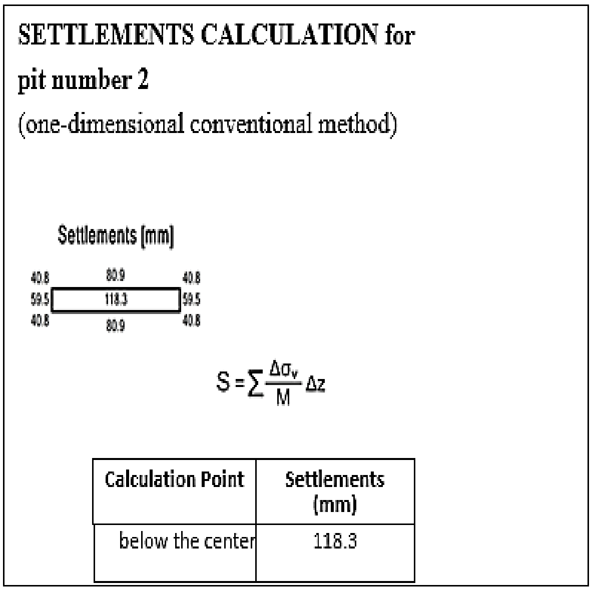

Figure 25. Settlement calculation for pit no-2.

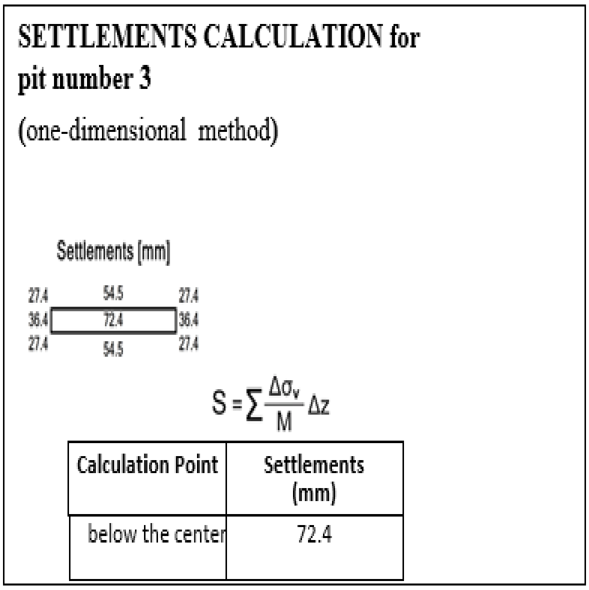

Figure 26. Settlement calculation for pit no-3.

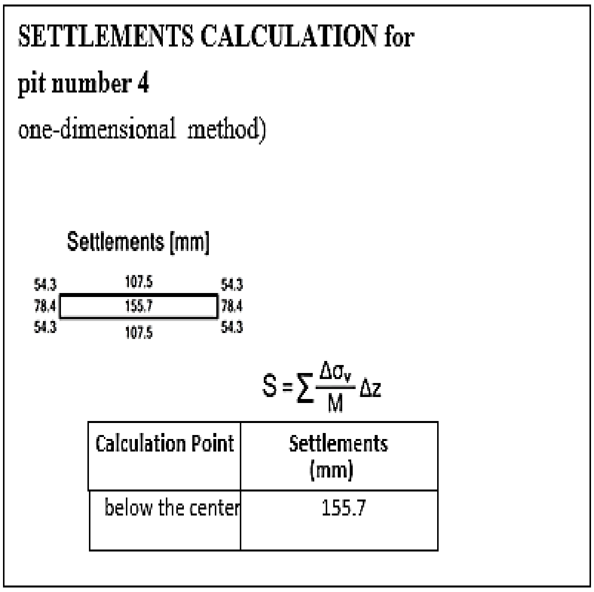

Figure 27. Settlement calculation for pit no-4.

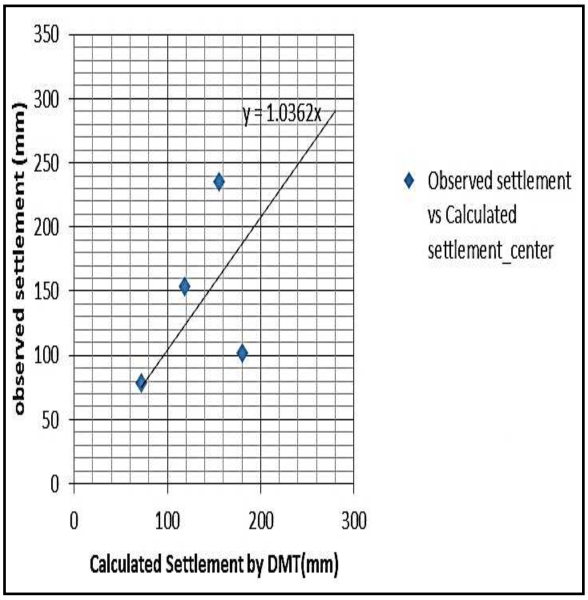

Figure 28. Observed settlement vs calculated settlement from DMT at center of footing.

4.5.1. Settlement calculated from conventional boring approach

On the basis of settlement analysis for a typical foundation considering an expected average pressure of 200 kPa, it was reported that settlement of the foundation would be in the order of 170mm.

4.5.2. Settlement observed from settlement sensors

Total settlement observed from settlement sensors are shown in "Table 2.". (Total Settlement up to Feb, 2018)

Table 2. Settlement observed from settlement sensors

S1(mm)	S2(mm)	S3(mm)	S4(mm)	S5(mm)	S6(mm)
101.63	153.42	78.55	234.91	41.49	0.0

4.5.3. Settlement calculated from DMT results

Settlement calculated from DMT results is shown in following "Table 3.". (Date of Testing: 15-17th Feb, 2018)

Table 3. Settlement calculated from DMT results

Description	DMT1 (mm)	DMT2 (mm)	DMT3 (mm)	DMT4 (mm)
Calculated average settlement by DMT for pit 1,2,3 and 4 below the center of footing	180.30	118.30	72.40	155.70

4.6. Comparison of DMT-calculated settlement vs observed settlement

Settlement observed from settlement sensors and calculated settlement from DMT [6] is presented in Fig. 28.

Fig. 28., shows a trend line of settlement obtained from DMT and settlement sensors. Equation of the trend line is

$$Y = 1.0362X \quad (1)$$

Equation (1), which represents a straight line going through the origin and having slope almost equal to unity.

This is an important observation which shows that settlement observed by sensors and settlement calculated from DMT is almost same.

5. Conclusions

From the present investigation, it was observed that the nature of the soil profile obtained by Marchetti flat dilatometer was similar to that obtained by conventional boring approach.

It is also found that DMT gives more economical values of the undrained shear strength than conventional boring approach for the given design criteria.

Last but not the least, the settlement values obtained by using DMT was nearly equal to those of the settlement sensors installed at the site.

Acknowledgement

This work would not have been completed without the active support of the Public Works Department, Government of West Bengal. Their kind assistance in carrying out this work is sincerely acknowledged.

The DMT tests were performed with the equipment received from Studio Prof. Marchetti s.r.l., Rome, Italy and the penetrometer equipment TG63/150 static/dynamic penetrometer provided by Pagani Geotechnical Equipment, Calendasco, Italy (www.pagani-geotechnical.com). The kind patronage of these two companies are gratefully acknowledged.

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