FOOTING LOAD TESTS ON SAND: VALIDATING THEORETICAL PREDICTIONS

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ABSTRACT: As structures get taller and the load demand on the foundation soils increases, it has become imperative to reconsider conventional geotechnics, and calibrate and validate our theoretical predictions with ground conditions. A prototype footing load test was conducted on a 2 m x 2 m size concrete footing for a better assessment of the load-settlement behavior at a site in Noida. This paper presents the test results and compares them to results from conventional methods of analysis. A numerical simulation of the test conditions has also been performed using finite element method to validate the field results with mathematical simulation. It has been found the results of the field test are in good agreement with theoretical predictions, thus enhancing the factor of reliability of our foundation analysis.

KEYWORDS: foundation design, footing load test, finite element analysis

1 INTRODUCTION

Delhi NCR has witnessed a spate of high-rise construction for residential and commercial projects in the past few years. For residential projects comprising of a group of high-rise towers, shallow foundations / raft foundations are typically considered as a practical and economic alternative to pile foundations.

For the geotechnical engineer, it is important to accurately characterize the ground, and reliably predict foundation settlements that will occur during the life span of the structure.

This paper presents a case study in which field results from a footing load test are compared to theoretical predictions of foundation settlement.

2 BACKGROUND

A residential project comprising of several group housing towers (14 to 24 storeyed structures with single basement) is being constructed in Greater Noida (U.P.), about 1.5 km west of the Yamuna Expressway. The project shall also boast of a central tower (studio) which is planned to have 36 upper floors with two basements.

The authors carried out a detailed geotechnical investigation at the project site, consisting of 23 exploratory boreholes to 30 m depth, along with Standard Penetration Tests (SPT) at 1.5-3 m depth intervals and a comprehensive laboratory test program.

1.1 Regional Geology

The project site is in the Indo-Gangetic plains. Greater Noida forms the part of Ganga-Yamuna doab; the eastern boundary is marked by Ganga River and the Yamuna River defines the western boundary. The area represents an almost monotonous flat plain, dissected by drainage of different orders.

Regionally, the eastern half of Greater Noida forms part of Ganga alluvial plain, whereas it's western part is in close proximity of Hindon and Yamuna rivers, representing a marginal alluvial plain.

Tectonically, the alluvial plain of Ganga basin represents a structural trough (fore-deep) or down wrap of earth crust, the origin of which is correlated to plate tectonics and Himalayan uplift. The area is underlain by Quaternary sediments, with thickness increasing from west to east and also towards the northeast.

2.1 Site Stratigraphy and Groundwater

Geotechnical investigations at the site revealed that the soils at the site are alluvial in nature and primarily consist of alternating strata of silty sand and sandy silt to the maximum explored depth of 30 m.

The top 5 m soil is loose fine sand. This is underlain by low plastic sandy silt to 11 m depth. A thick stratum of medium dense to dense silty fine sand is encountered between 11 m to 30 m depths, with an intervening layer of sandy silt (1-5 m thick) between 23-24 m and 26-29 m depths.

Groundwater was met at 2.0 m to 4.6 m depth below EGL (about RL 95 m) during the period of our field investigations (June, 2012).

A pictorial representation of typical borehole data has been shown on Figure 1. The stratigraphy encountered at the site is typical of the region.

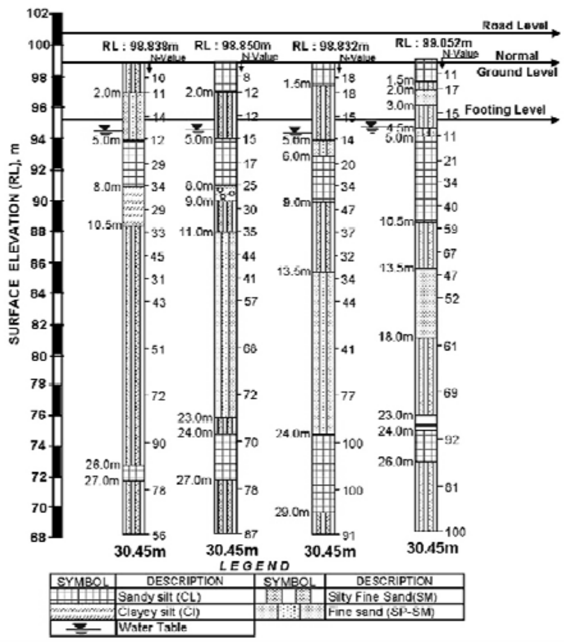

Fig. 1 Typical Borehole Data

3 FOUNDATION ANALYSIS

Settlement analysis has been done for a 2 m x 2 m size foundation by the following methods:

1) Classical approach, computing the immediate settlement using elastic theory.
2) Hough's curves
3) Finite Element analysis using PLAXIS software.
4) The computed settlements have been compared with the results of the footing load test to make an assessment of the expected foundation behavior versus the predictions.

4 CONVENTIONAL SETTLEMENT ANALYSIS METHODS

The immediate settlement has been computed using the theory of elasticity. Settlement analysis has also been done based on the methods proposed by Hough.

The following soil parameters were selected for the settlement analysis, based on the field and laboratory test results obtained from the borings done on site:

Table 1 Design Profile

Depth below NGL (m)		Density KN/m^3	N	Cohesion Intercept, kPa	Angle of Internal Friction	Modulus of Elasticity, MPa
From	To					
0	2	17.0	15	70	0	5
2	6	17.0	15	0	34	8.7
6	10	18.5	25	90	0	10
10	15	19.0	25	90	35	19
15	24	19.5	30	0	35	28
24	30	20.0	35	120	0	29

The modulus of elasticity values selected for analysis were based on empirical correlations with SPT values, as well as our experience on nearby sites. The weighted average of the modulus of elasticity values within the footing influence zone works out as about 13.3 MPa, which is in very good agreement with the modulus of elasticity value of 17.8 MPa as interpreted from the footing load test data (See Figure 4). However, the authors strongly recommend the use of pressuremeter and static cone penetration test data for a more realistic determination of the modulus of elasticity profile in-situ.

5 FIELD METHOD: FOOTING LOAD TEST

One (1) footing load test (FLT) was performed at the site at 4 m depth (RL 94.8 m) using a 2 m x 2 m size test RCC footing. M-35 grade of concrete was used in order to make the 1 m thick prototype footing. The test procedure was in general accordance with IS: 1888-1982.

A photograph and schematic sketch showing the test arrangement are presented on Figures 2 and 3, respectively. A load frame arrangement was used to carry out the test. Eight (8) anchor piles (bored, cast-in-situ, 500 mm diameter, 14m length) were used to provide the reaction system. The top 6 m length of the reaction piles was filled with a mix of sand and cement (designed to approximate the strength characteristics of the surrounding sand) to avoid any interference within the footing influence zone. The anchors piles were concreted and reinforced between 6 m and 14 m depths (i.e. 8 m effective length) to provide the uplift resistance.

The footing was loaded by pushing up against the anchor arrangement using two 3000 kN capacity hydraulic jacks. Four dial gauges measured the footing settlement with reference to a stable reference bar. The load was applied in 9 small increments of 282.5 kN each; up to a maximum loading intensity of 2545 kN.

Considering the loaded area of 4 m^2, this is equivalent to a maximum bearing pressure of 636 kPa exerted on the plate. Each load was held until the time rate of settlement became negligible (less than 0.02 mm per minute).

The settlement of the footing at the maximum test load of 2545 kN was 59 mm. Figure 4 represents the load versus settlement graph obtained from the Footing Load Test.

Fig. 2 Footing Load test in Progress

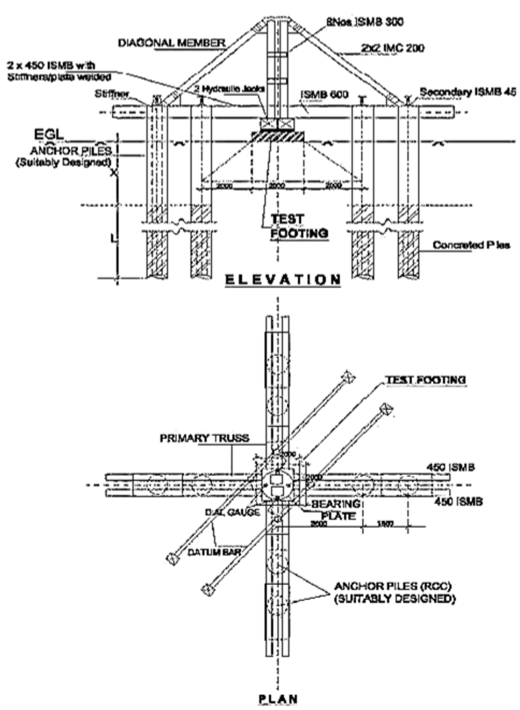

Fig. 3 Schematic Sketch of Footing Load Test Arrangement

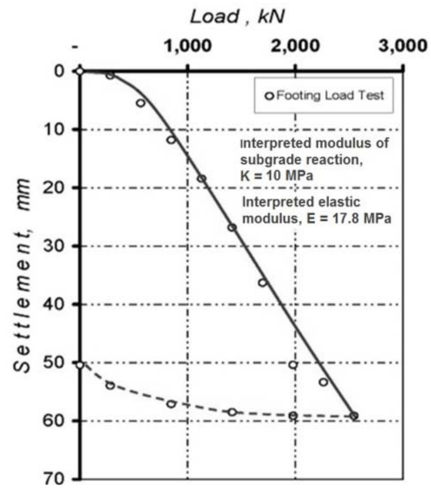

Fig. 4 Footing Load Test Results

6 NUMERICAL SIMULATION

The footing load test was simulated using a commercially available finite element software (PLAXIS 2D).

The coordinate system used is the standard Cartesian coordinate system, where y-axis corresponds to the direction of ground surface and the x-axis corresponds to the horizontal stretch of the ground. For the vertical boundaries at the nodes, the vertical displacement u_y is left free and the horizontal displacement u_h is restrained, allowing only for a normal stress σ and no shear stress τ. The problem was modelled as an axi-symmetric model considering the footing to be symmetrical about y-axis. Figure 5 illustrates the basic model used.

Mohr-Coulomb constitutive model was used to model the soil layers. The problem is modelled in two phases. In Phase 1, excavation till the foundation level is carried out. In phase 2, the footing is given a prescribed displacement. The corresponding load that causes the prescribed displacement was then calculated.

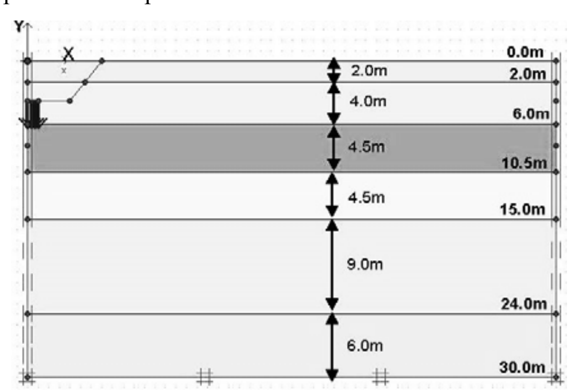

Fig. 5 Dimensions of the Basic FEM model

7 COMPARISON

Figure 6 shows the combined graph of load versus settlement measurements obtained from the four methods discussed above, namely- elasticity theory, Hough's method, PLAXIS 2D modelling and footing load test.

The results of field test are in good agreement with theoretical predictions, with most theoretical methods over-estimating the settlements. The results differ with each other within tolerable limits. Table 2 shows the settlements corresponding to different loads from the various methods used for analysis. Table 3 summarizes the factors of safety (predicted settlement / actual settlement) for each prediction, with respect to the footing load test results.

Table 2. Summary of Results

Load, kN	Bearing Pressure, kPa	Settlement, mm			
		Elastic Theory	Hough's	FEM	Footing Load Test
500	125	11.5	20.0	10.0	4.5
1000	250	23.0	32.0	21.0	15.0
1500	375	35.0	41.0	35.5	30.0
2000	500	46.0	48.0	50.0	51.0

Table 3. Factor of Safety

Load, kN	Bearing Pressure, kPa	Factor of Safety (with respect to FLT)			
		Elastic Theory	Hough's	FEM	Footing Load Test
500	125	2.6	4.4	2.2	1.0
1000	250	1.5	2.1	1.4	1.0
1500	375	1.2	1.4	1.2	1.0
2000	500	0.9	0.9	1.0	1.0

Based on the above, it is clear that the predicted settlements are in good agreement with the actual settlements recorded during the footing load test at site. The best prediction was obtained from Elastic Analysis and PLAXIS; whereas Hough's method tends to over-predict settlements at lower load levels.

Interestingly, while the predicted settlements are somewhat conservative (FS ~ 2.0-2.5) at lower load levels, the factor of safety reduces at higher loads to as much as 0.9-1.0. This is expected, since analytical tools are based on the assumption that the soil is linear elastic, which is naturally not the case.

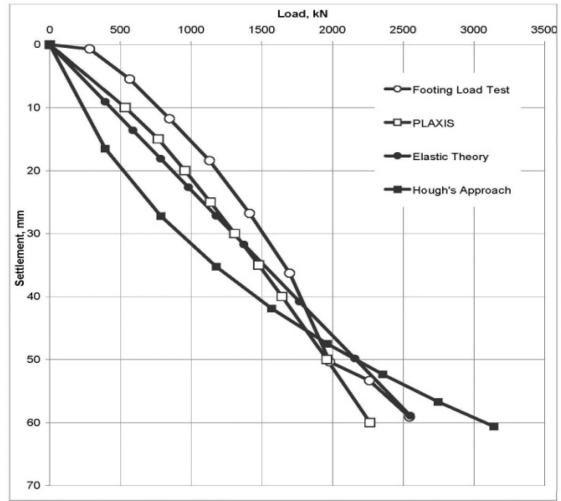

Fig. 6 Comparative Load-Settlement Graph

8 CONCLUSIONS

Conventional geotechnical wisdom is limited by empiricism, heterogeneity and complexity of geo-materials and intrinsic scatter in in-situ / laboratory test data. Our foundation settlement predictions are only as good as our test data, correlations used, and judgment exercised. The authors are of the opinion that footing load tests must be carried out where possible, in order to calibrate the theoretical design profiles against actual site performance. Footing load tests are particularly important for projects where the foundations are heavily loaded, or where the foundations are bearing on heterogeneous soils, weathered rock or boundary strata.

The innovative test setup for footing load tests developed by the authors helps reduce the size and cost of the footing load test arrangement. We hope that this will encourage greater adoption of this in-situ tool for performance-based design of shallow foundations.

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