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BI-DIRECTIONAL LOAD TEST: TO REMOVE UNCERTAINTY IN PILE LOAD TEST RESULTS INTERPRETATION

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Abstract

Bi-directional static load testing for piles has been around for long time. However, the loading mechanism is different from the conventional pile loading testing method, many practicing engineers have concern over its concern of the pile top settlement. Its proponents believe it is safer, easier, and capable of achieving higher loads than traditional top-loading methods. The traditional methods including the kentledge have constraints of performing higher loads, which may lead to fatal accidents. India has seen a lot of development in the field of infrastructure in the recent past and strive to build the biggest, the largest viz. cable stayed bridges, with speed and skills, and at the same time without compromising on the quality. For ensuring the quality of the foundations of such massive structures, Bi-Directional static load testing is coming into spotlight. Famous Aerospace Engineer Wernher von Braun quoted "one good test is worth a thousand expert opinion." Geotechnical Engineering and foundation design is no exception. This paper throws light on one of the bridge projects in India, where the Bi-Directional Load cell is used for the load testing for bridge where pile foundation is being carried out. This paper provides the details of the geological conditions of the project area and depicts the load mobilization details i.e., about the skin friction mobilization along the pile shaft and concludes that soil has much higher capacity in comparison to theoretical capacity being considered in the international practices. The focus of the paper is to emphasize that with the advancement in the construction methodology, and enhancement in the foundation testing methodology, the limitations imposed on these pile capacity components also should be re-assessed.

Keywords: Bi-Directional static loading, load cell, cyclic load, elastic compression, balance point

1 Introduction

Pile foundations are commonly adopted to transfer the loads from the superstructure through weak strata onto the stiffer soils or rocks. Therefore, the reliability of pile-supported structures depends largely on the behaviour of the piles [7]. The project is in the north-eastern state of India. A project of huge strategic relevance is being built as river bridge connecting the two states of the country over the river Brahmaputra that will reduce the distance between the two States drastically and improve the connectivity of the North-eastern States with the rest of the country. The 19 km long bridge will feature a navigation bridge of 12.625 km, approach viaducts of 3.5 km on one side and 2.2 km on the other side, connected with approach roads and interchanges on both sides. The foundation option designed for the approach viaduct is proposed as pile foundation. The bearing capacity of these foundations is

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calculated using various empirical formulas provided in various standards and codes of practices with keeping utmost assurance of quality in the construction. To assure that the design assumptions are accurately considered, pile load test is carried out. Considering the ground condition is uniform in viaduct portion, four initial pile load tests of each are proposed for viaduct portion. Conducting the load test using conventional method, would be difficult for enormous loads in river location, and hence conducting the Bi-directional load test seems to be the feasible option.

2 Bi-directional load test

The Bi-directional load test or abbreviated as BDSLT is a jack assembly system embedded in the pile foundation in which the hydraulic jacks are positioned between the two load bearing plates (as shown in Fig. 1) and attached to the reinforced steel cage before lowering. Location of the load cells at theoretical balance point within the pile is a crucial factor to completely mobilise the compression capacity, such that approximate capacity above the load cell equals the capacity below it. This factor can be addressed by studying the geotechnical investigation report, so that the location of jack assembly can be at a suitable level in the piles, chosen as to ensure that all calculated upward thrust and bottom thrust due to loading will be almost equal.

Figure 1 Bi-Directional Load Cell positioned inside the reinforcement cage

2.1 BDSLT Mechanism

After the concrete in the pile gains sufficient strength for testing (generally 28 days for curing), the test is performed using the application of load using an expandable jack (or multiple jacks), which is sandwiched inside the two bearing plates as illustrated in Fig. 2. After that, the cell is pressurised to break the welds which are holding the cell intact or till the maximum limit of the jack expansion. The pressure is then applied in incremental basis to impose the bi-directional load to the upper and lower side of the cell [2]. During the testing, the top portion offers reaction to the bottom portion and similarly the bottom portion provides the reaction to the top portion. Moreover, the reinforcement is not provided continuous as after the load application, the jack assembly is separated. The test is applied up to the maximum test load, or till the maximum capacity of the load cell or till the maximum expansion of the load cell, which is generally 150 mm. The Bi-directional load applied is monitored using the load cell, which is monitored and measured with the help of the pumps.

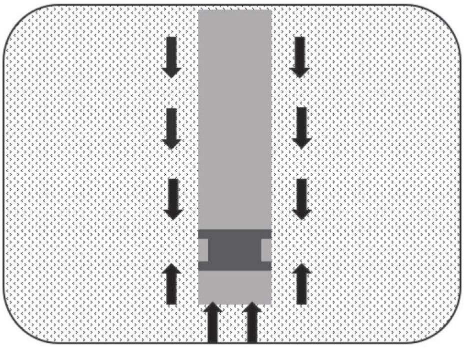

Figure 2 Bi-Directional Testing Scheme

The load cells are hence calibrated prior to the installation in the drilled shaft.

2.2 Analysis and Interpretation of the Test Results

BDSLT resultant curve is converted to an equivalent Top Load curve which is equivalent to the combination of the measured results achieved from the BDSLT and is the sum of the measured loads at equal displacements as well as elastic shortening which did not get mobilised during the BDSLT [4]. It is a good estimate for achieving the load – settlement curve at the pile cut-off level (as shown in Fig. 3).
Upward ($Q_u - S_u$) and Downward ($Q_d - S_d$) curve from the BDSLT is converted into a conventional load -deformation curves (Q-S curves). According to the load distribution of the two test methods, the formula for conversion is as following Eq. (1):

$$Q = \left[\frac{Q_u - W}{\gamma}\right] + Q_d \tag{1}$$

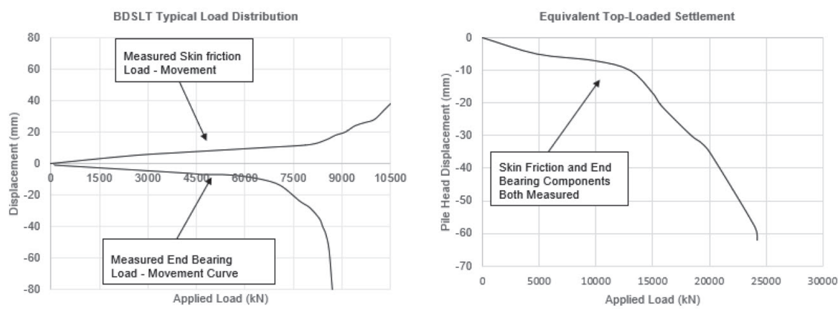

Figure 3 Conversion of BDSLT curve to conventional top -loaded pile load test result

$$S = S_d + \Delta S \tag{2}$$

where Q is equivalent pile top load after conversion, S is pile top displacement after conversion, Q_u is the upward load value of the cell, Q_d is the downward load value of the cell, ΔS is the pile shaft compression, S_d is the downward displacement as shown in eqns. 1 and 2. Upper pile compression ΔS is equal to the sum of elastic compression caused by upper pile and the lower pile as shown in Eq. (3).

$$\Delta S = \Delta S_1 \, \Delta S_2 \tag{3}$$

where:
ΔS_1 - elastic compression caused by the vertical load of the bottom compressed pile.
ΔS_1 - elastic compression caused by the frictional resistance of the upper compressed pile.

$$\Delta S_1 = \frac{QdL}{E_p A_p} \tag{4}$$

$$\Delta S_2 = \frac{(Q_u - W)L}{2E_p A_p \gamma} \tag{5}$$

$$\Delta S = \frac{\left[\frac{Q_u - W}{\gamma} + 2Qd\right]L}{2E_p A_p} \tag{6}$$

where:
Q_d – Load cell downward load [kN]
Q_u – Upper pile load when upper pile displacement absolute value equal to S_u in Q_u vs S_u curve [kN]
L – upper pile length [m]
E_p – Pile shaft elasticity modulus [kPa]
A_p – Pile shaft cross section area [m^2].

3 Project soil stratigraphy

The soil beneath the project location comprises pre-dominantly the poorly graded sand up to a depth of 70 m below the ground level. The sub-soil profile is consistent for the entire project location and only few patches of clayey soil is detected in between with thickness of one to two meters. The observed standard penetration test (SPT) values along with the corrected SPT values are represented in Fig. 4

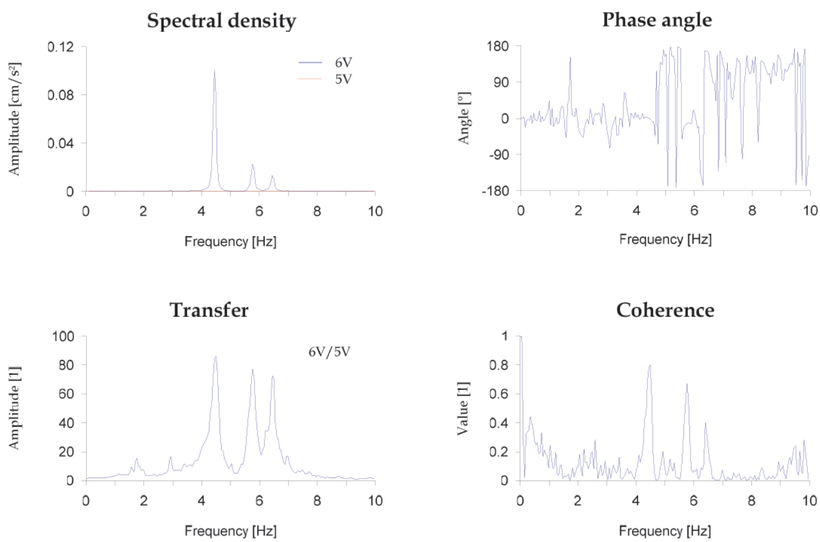

Figure 4 Observed and Corrected SPT below Ground level

3.1 Pile capacity design calculations (Theoretical)

Pile diameter of 1650mm is considered for the proposed location, with the pile length of 45 meters. The pile foundation is designed based on IS 2911 Part I Section II: 2010.
The ultimate load capacity of pile is based on the following Eq. (7):

$$Q_u = A_p X\left(0.5\gamma D N_\gamma + P_D N_q\right) + \sum_{i=1}^{n} K_i P_{Di} \tan\delta_i A_{si} \tag{7}$$

Considering the above formula mentioned in Eq. (7), the pile capacity is calculated, and the summary of the safe pile capacity considering the FoS of 2.5 and the theoretical representation of skin friction is illustrated in Table 1.

Table 1 Bearing Capacity Details of the test location foundation

Diameter [m]	**Pile cap bottom level** [m, RL]	**Length of pile** [m]	**Vertical capacity** [kN]		**Unit skin friction over the pile shaft** [kPa]
			Skin friction	**End bearing**	
1.65	24.025	45.00	22084	26665	110.89

3.2 Bi-Directional load test details

The maximum design load developed at the pile foundation is around 1000 tons. The initial test load to be conducted at the pile is around 2500 tons (2.5 * 1000 tons). As per Indian Standards/code of practice IRC 78: Standard Specifications and Code of Practice for Road Bridges, the initial pile load test is conducted for 2.5 times the design load.

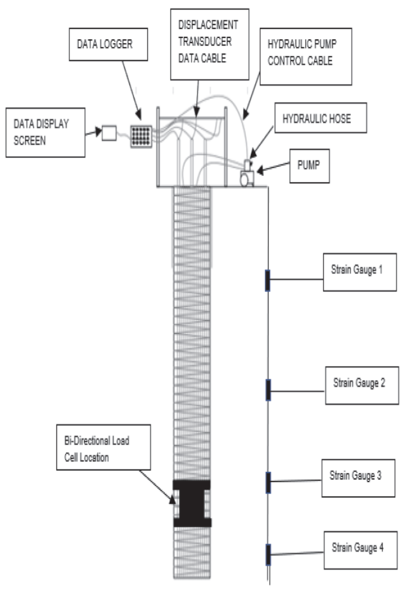

Figure 5 Load Cell Positioning provided in the pile

3.2.1 Load Cell Details and positioning

The Bi-directional load cell assembly comprises of a total of 4 hydraulic jacks, each of the hydraulic capacity of 450 tons, providing a total jack capacity of 3600 tons i.e. (4*450 = 1800 tons) in both the directions i.e., upward, and downward direction from the jack assembly [3]. As the pile capacity is governed by the end bearing, the jack assembly should be positioned at the pile toe, however as per section 6.2 of Appendix-9 of IRC 78: 2014 amendment no.1, the jack assembly shall be placed at a minimum distance of 1.50 times diameter above the pile bottom, as needed to place as sound concrete below it.

3.2.2 Load test procedure

Cyclic load test is performed in two cycles, in which the first cycle is performed for a test load equivalent to 100 percent of the working load. The load is provided in 5 equal increment of 20 percent each with a holding time of 50 minutes. After that, the unloading is done with the equal decrements of 20 percent of the test load with the holding period of 15 minutes.
In the second cycle, the load is initially provided in the increment of each of the 10 percent of the test load with a holding time of 20 minutes, then after that five equal increment of 10 percent of the test load with the holding period of 50 minutes and the last increment at a maximum test load of 250 percent of the working load for a holding period of 50 minutes. After that, the unloading sequence was conducted with the holding period of 15 minutes, with each of equal decrement of 20 percent of the test load.

3.2.3 Bi-directional load test results

Maximum Bi-axial load of 13760 kN was applied on the pile head. The equivalent pile top load curve is prepared and afterwards, the skin friction mobilised along the pile length and the details of the load test results are provided in the comparative graph represented in Fig. 6.

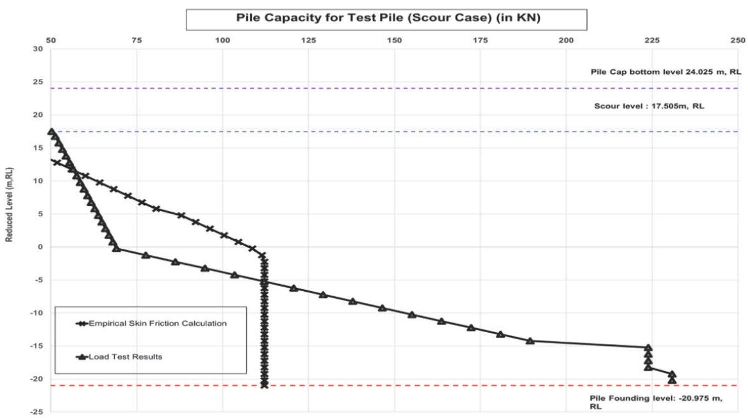

Figure 6 Skin Friction Comparison based on theoretical and load test results

4 Conclusion

The ultimate mobilised skin friction based on various international standards and codes suggests that generally the ultimate shaft friction is generally restricted to 110 kPa [6]. Moreover, as is represented in the comparison sheets provided in between the skin friction calculated theoretically and the results obtained based on the BDSLT represents completely contrast results and shows that the mobilised friction in the tested pile is having much more skin friction i.e., more than the maximum theoretical value of 110 kPa, and which shows that the capacity of the soil is much more than those provided and recognised in the international textbooks and standards. Refer below Fig. 6 providing the comparison b/w the theoretical and the load test results.

The limitation on the skin friction was provided by pile load testing for several locations, however at those time, the skin friction component was assumed based on the conventional load tests data, and there was no realistic method representing the actual skin friction. With the advancement in the field of load testing, and the instrumentation techniques, the different component i.e., skin friction and end bearing could be separately determined, and hence the optimisation in the pile lengths can be carried out which would lead to the overall reduction in the time and cost of the resources utilised for redundant drilling and material for additional pile length.

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