High Strain Dynamic Pile Testing and Static Load Test – A Correlation Study

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ABSTRACT: High Strain Dynamic Pile Test (HSDPT) is increasingly being used for pile load testing. HSDPT offers a considerable savings of time, cost and requires very little space compared to the conventional static test. This study presents results of nine HSDPT carried out on rock socketed bored piles of 600mm, 800mm and 1000mm diameter. The load-settlement response derived from HSDPT is compared with that observed in conventional static load test. In all the piles, first static load testing was completed. The settlement values observed in HSDPT and static load test compare well up to 150% of working load. The paper also explains the test pile selection criteria adopted in the study.

INTRODUCTION

Attempts to determine the pile capacity using dynamic analysis date back to the 19th century. 'Hiley's or other formulae were widely used to predict the pile capacity and decide the pile termination for driven piles. Dynamic formula considers the energy of the pile driving hammer and the set of a pile to estimate the pile capacity. Numerous studies have concluded that their prediction accuracy is poor. A major limitation of dynamic formula in the context of driven piles is the fact that they cannot predict hammer efficiency and stresses during driving. The dynamic formulae do not take into account the changes in soil stratum and are not applicable to bored piles. These limitations are overcome by the High Strain Dynamic Pile Tests (HSDPT) which is sometimes referred as 'PDA (pile driving analyzer) Test'. In case of driven piles the pile capacity derived from HSDPT generally shows satisfactory agreement with that measured by static load test (Rausche et al., 1985). The HSDPT also offers the following advantages:

- piles can be tested in a day resulting time saving,
- HSDPT requires very little space,
- structural integrity of the pile is verified,
- it is possible to broadly estimate the frictional and end bearing resistance of the piles.

HSDPT is also gaining acceptance to check pile capacity for bored cast in situ piles (also known as drilled shafts). Project specific correlation studies comparing the results of static and HSDPT are reported by Seidel and Rausche (1984), Hussein et al. (1992), Nayak et al., (2000), Robinson et al., (2002), Chen and Lim (2006), Hussein and Likins (2005). Some of these studies are 'Class A' predictions where the static load test results are received only after submitting the dynamic results. These studies show encouraging results with respect to the applicability of HSDPT for pile testing. The objective of present study is to compare the load-settlement response of piles observed in HSDPT with that shown by static load tests. The study is conducted on rock socketed piles with relatively large test loads.

PROJECT DETAILS

A common user terminal building with an approximate footprint of 5 million square feet is under construction as a part of modernization work of Mumbai International Airport (MIA). The geotechnical investigation revealed the depth of rock varying from 1 m to 9 m. More than 45 boreholes (out of 65) showed the presence of highly to moderately weathered volcanic breccia and in remaining areas hard rocks such as basalt and trachyte were encountered. The engineering properties of soil and rock are reported in detail by Khare and Mhaiskar (2010). Bored cast-in-situ piles socketed in rock were recommended where rock strata was deep. All test piles were bored using hydraulic rotary rigs. The top stiff clay soil was supported with a casing and no bentonite was used. The piles were cased using M 30 grade of concrete. In all, nine HSDPT and nine static load tests were carried out.

METHODOLOGY

The HSDPT were carried out as per ASTM D4945-00. A Pile Driving Analyzer® (PDA) and its associated pile top force and velocity transducers were used to conduct the pile test. Two strain transducers and two accelerometers were attached to the pile head. They were mounted on opposite sides of the pile to cancel bending effects during each strike of the hammer. The signals of strain and acceleration were conditioned and processed by the PDA. Signals of pile top force and velocity were measured and analyzed during each strike of the hammer and stored in the analyzer. Real time analogue signals of the pile top force and velocity were also recorded using PDA and later stored in the field computer unit. At the time of testing, PDA uses a program based on closed form Case-Goble solutions to compute static pile capacity from pile top force and velocity data. This is subsequently checked with the more rigorous signal matching technique by a computer program 'CAPWAP®' (Case Pile Wave

Analysis Program) to confirm the static pile capacity obtained in site.

Some basic guidelines are to be followed to obtain a reliable ultimate capacity from dynamic pile testing. The hammer input must produce a minimum set per blow so that the soil is loaded sufficiently to mobilize the full soil strength. In cases where the set per blow is very small (e.g. large “blow count”), the dynamic pile test will activate only a portion of the full soil strength and thus will underpredict the true ultimate capacity (this is analogous to a static test), so the result is conservative (Likins, 2004). Higher hammer load is appropriate for piles with significant end bearing in cohesionless soils where large sets are necessary to activate end bearing resistance. For piles in cohesive soils, lower hammer weights are often satisfactory (Rausche, 1997). Robinson et al. (2002) suggested to use hammer weight (W) depending upon magnitude of required ultimate capacity (Q) to be proven, such that;

W/Q for piles embedded in hard cohesive soils or bearing on rock = 1%,
W/Q for friction piles in general= 1.5%,
W/Q for drilled shafts with end bearing in coarse grained soils = 2%.

In the present study, HSDPT were carried out by a specially manufactured hammer weighing 125 kN. The hammer was positioned on the top of the test pile using a safety guide frame as shown in Figure 1. The guide frame setup ensures safety during testing, is easy to shift, ensures hammer blows without eccentricity and can be utilized for various pile diameters. The drop height of hammer ranged from 0.25 m to 1.5 m.

The static load tests were carried out by taking reaction from rock anchors and piles were subjected to a maximum compressive stress of 18.75 MPa. The test pile details such as types of rocks and depth of rock socket is discussed in detail by Khare and Mhaiskar (2010).

PILE SELECTION FOR HSDPT

The piles subjected to HSDPT were selected either from piles used for static vertical load tests or adjacent piles used for lateral load tests. Four out of nine static vertical load tests showed a permanent settlement ranging from 12 mm to 50 mm. In these piles the full socket friction may have been mobilized. The magnitude of elastic rebound is also found to be negligible which indicates that the characteristics of the rock along the socket and below the pile toe may have altered during static load test. Therefore in such cases, where there is high settlement, HSDPT may underestimate the pile capacity if the test is carried out on previously loaded pile under static test. In such piles (which showed a high permanent settlement under static load test) the HSDPT were carried out on adjoining pile after completing the lateral load test. Since in the case of piles subjected to lateral load test, the frictional and end bearing characteristics of rock are unlikely to get altered, the results can be better correlated with the static load test. The test piles constructed for lateral load test were within a distance of 3.5 m of the piles used for static vertical load test and the rock properties can be considered identical for all engineering purpose. The pile selection was based on following settlement criterion:

- if static vertical load test showed a total settlement of less than 12 mm and if the elastic rebound was observed to be more than 75 % of the total settlement then the same pile was subjected to HSDPT,
- if static vertical load test showed a total settlement of more than 12 mm and if the elastic rebound was observed to be 75 % of the total settlement or less, then HSDPT was carried out on adjoining pile after completing the lateral load test.

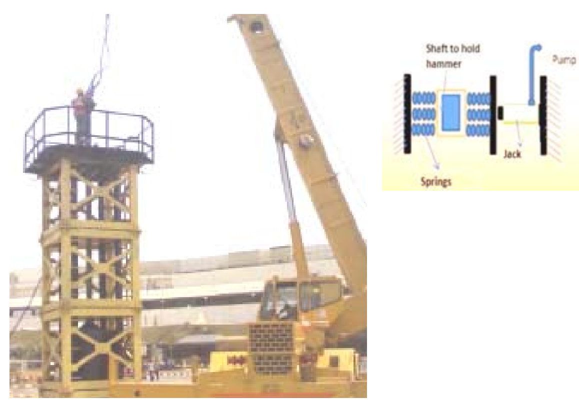

Fig.1 Safety guide frame for HSDPT

Table 1. Settlements observed in HSDPT and static load tests

Diameter (mm)	Design load (kN)	TP No.	Settlement at design load (mm)		Settlement at 1.5 times design load (mm)	
			Static Test	HSDPT	Static Test	HSDPT
600	1570	TP-1	1.43	-	1.71	-
		TP-2	1.01	1.8	2.5	2.76
		TP-3	1.30	0.99	2.68	1.51
800	3180	TP-4	0.58	0.82	0.87	1.19
		TP-5	2.83	-	15.9	-
		TP-6	2.66	2.08	3.64	3.12
1000	4620	TP-7	0.40	0.58	0.55	0.87
		TP-8	1.51	-	2.43	-
		TP-9	4.19	1.97	6.87	2.99

RESULTS AND DISCUSSION

The load-settlement response from static load test and that obtained from CAPWAP® analysis for 600 mm, 800 mm and 1000 mm diameter piles is shown in Figures 2, 3 and 4 respectively. The settlement values observed in HSDPT and static tests at design load and 1.5 times design load are compared in Table 1.

In case of TP-1 the maximum compressive stress experienced by pile was 40 MPa which is more than allowable limit of 30 MPa. This may have resulted in local crushing of concrete in pile shaft and high settlement at design and 1.5 times design load. In case of TP-5 and TP-8, the pile head cracked under second hammer blow and therefore could not be used for HSDPT analysis. Therefore results of TP-1, TP-5 and TP-8 are not used for correlation. From Table 1 it is evident that settlement values observed in HSDPT and static tests compare well up to 1.5 times design load. Studies conducted by Chen and Lim (2006) also found that load-settlement behaviour of piles predicted from dynamic tests show good agreement with static test when test load is low i.e. within design working load. From the present study it is evident that HSDPT is suitable for small as well large diameter piles with socketing lengths ranging from 1D to 4 D.

Extensive correlations between static and dynamic testing have verified the method's reliability (Likins et al., 1996). However selection of pile for correlation studies is important and needs to be understood before conducting a reliability or correlation study. If pile has already undergone substantial settlement due to geotechnical failure, then the second static or HSDPT may under predict the capacity. If the first test has soft toe conditions, then the second test may even provide better results in certain situations. Similarly correlation studies on adjoining piles may match reasonably well only when they have similar workmanship and geometry. Hence it is imperative to conduct project specific correlation study to confirm the suitability of HSDPT test and understand the reasons for match or mismatch of static and HSDPT results.

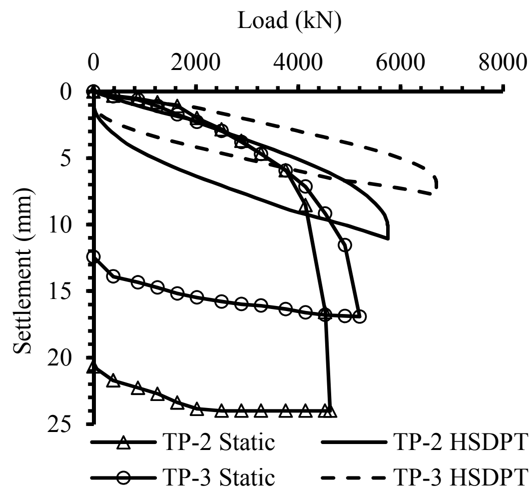

Fig. 2. Load-settlement response: 600 mm dia piles

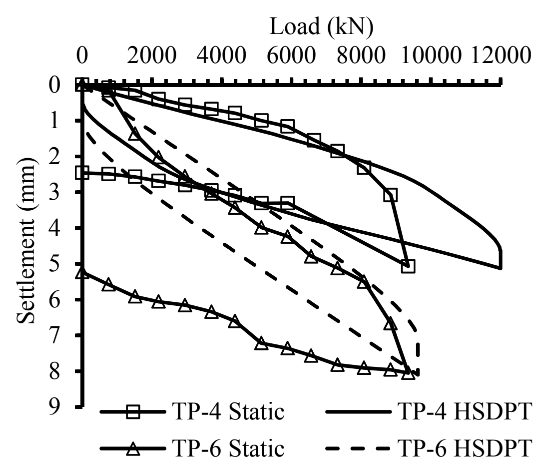

Fig. 3. Load-settlement response: 800 mm dia piles

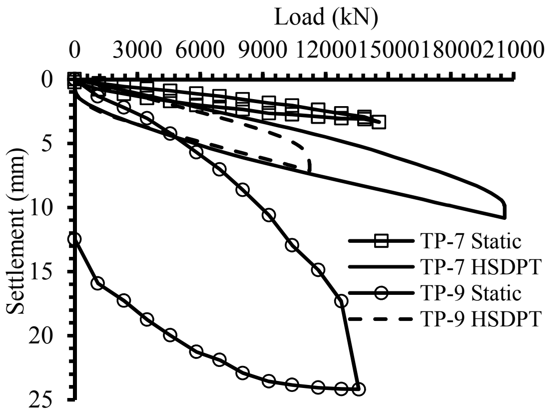

Fig. 4. Load-settlement response: 1000 mm dia piles

In many cases HSDPT has completely replaced static testing. When no site specific correlation is established then there is a higher risk since the correlation depends on geotechnical expertise and past experience. This additional risk requires more testing compared with static testing methods. The 'Pile Driving Contractors Association' (PDCA) code (PDCA, 2001) recommends a global safety factor of 2.1 when only 2% of the piles are tested dynamically and safety factor of 1.9 when at least 10% of the piles are tested dynamically. In India, generally only 0.5 % piles of working piles are tested. Since HSDPT can be conducted in quick time and in limited space too, it is recommended to conduct more tests for every static test replaced at the project site. This may also result in increased quality control and reduction in factor of safety.

CONCLUSIONS

HSDPT is increasingly being used to check the pile capacity of bored piles. The study presented here compares the load-settlement behaviour of nine rock socketed piles with diameters ranging from 600mm to 1000mm. Piles were tested to a maximum compressive stress of 18.75 MPa under static load. The load-settlement response observed in static and HSDPT compares well up to 1.5 times design load adopted in the present study. It is preferable to carry out project specific correlation study before adopting HSDPT at project sites. Since the HSDPT is conducted in quick time compared to static load tests, more number of HSDPT may be conducted for every static load test replaced at the project site. It is important to properly select a pile for correlation or reliability study. If adjoining piles are selected, then it is important to consider factors like soft toe, defects, bulbs which may not be present in one of the piles and may be a reason for mismatch of test results. If the same pile is selected which appears to be a better choice, it should be ensured that the pile is not loaded to excessive permanent settlement. The static load test results should also be monitored as errors in static load test may also affect the reliability or correlation studies.

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