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Quarterly Newsletter No.6 – April 2013 **Visit us at www.geodynamics.net**

HIGH STRAIN DYNAMIC PILE TESTING PRACTICES IN INDIA – FAVOURABLE SITUATIONS AND CORRELATION STUDIES

High strain dynamic pile tests (HSDPT) are being increasingly used in conjunction with Static pile load tests (SLT) for capacity and parametric assessment. SLT is still considered as the first priority for pile capacity assessment and is preferred for modeling realistic load displacement behavior of pile. Limitations of SLT - large space and time requirements, tedious arrangements and highly labour oriented – have prompted situations where HSDPT has to be solely relied upon. This paper is written on the basis of testing works carried out at various projects of ITD Cementation in India. In this newsletter, we have reported correlation studies based on dynamic load tests carried by us and static load tests conducted by ITD at their project sites. Generally, the tests indicate a good correlation which augment decision on using HSDPT as a reliable pile load test in field. Once again note that HSDPT using Pile Driving Analyzer require expert testers and interpretation requires knowledge of wave theory, soil, piling methods, equipment electronics and hence the method does not work like other laboratory tests but needs experience.

INTRODUCTION

Static Pile Load Test (SLT) for capacity assessment and as a quality assurance tool is well accepted practice across the globe. Load application in such tests is accepted as a real life loading behavior of the piles. This test has been in vogue in India since past sixty years. However in recent years, fast track construction schedule, very large test loads and peculiar site conditions etc. have brought to fore some of the limitations of this test, namely that, set-up is time consuming (arrangement and testing consume more than a week depending on magnitude and mode of load application) and large space requirements. Performing such test in compelling situations like crowded areas, marine conditions and scanty access to the site has prompted to look into faster and convenient alternatives – either to be used in conjunction with SLT or as a sole entity.

Dynamic pile load testing also known as High Strain Dynamic Pile Testing (HSDPT) was introduced in India in the later part of eighties and became popular 2001 onwards. This test is faster and more convenient than SLT and also offers significant cost savings especially for higher capacity piles. Present practice is to use this test as a replacement to SLT with few correlations so that the desired frequency for quality assurance as per contract or codal provision is fulfilled. How far this test delivers ultimate load and confirms safe pile capacity is still looked upon with a certain degree of skepticism in India. Efforts to overcome this skepticism have been made in the past by Mhaiskar et.al. (2010) and Vaidya (2006) and this paper is next step in this direction. Two queries and their answers serve as a prime objective to this article:

(i) Do SLT and HSDPT produce similar pile capacity?
(ii) Does HSDPT truly simulate static load displacement behavior of a pile?

The above queries have addressed through supporting facts based on available literatures; and through correlation studies on a limited load test data collected across project sites in India and findings are presented thereof.

LOAD TEST PRACTICE IN INDIA

Testing of piles by static loading remains one of the best understood assessments of the pile load-displacement behavior. Such tests are used to confirm the outcome of the fundamental pile design; and also form a part of quality assurance process on the contract piles. Pile load tests, whether static or dynamic, are classified under two broad categories, namely, Initial and Routine tests. In Initial load tests, performance of piles under ultimate conditions is intended and a minimum safety factor for safe load is assessed. These piles are generally tested to 2.5 times the estimated safe design capacity and many a times serve as a proof test when excessive pile movement is not seen. Routine pile load tests are carried out on randomly selected job piles to check the pile design capacities and also have an assessment of workmanship at the site. The piles are generally tested to 1.5 times the design capacity with frequency in a range of 0.5 to 2%. Currently, HSDPT is preferred method of testing when static load tests are prohibitive, when the load test frequency has to be expedited, and when the pile integrity is questionable. In India, HSDPT is performed by firms based on the methodology and equipments devised, developed and patented by Pile Dynamics Inc. (PDI), USA. The practice is standardized as per ASTM D4945.

HSDPT: BACKGROUND AND PROCEDURE

The basic purpose of HSDPT is to evaluate pile capacity, structural integrity of the pile and the total movement under

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the measured loading (Vaidya, 2006). Strains are recorded by strain transducers attached to the pile, while accelerometers record the accelerations generated in the pile resulting from the impact of a heavy hammer falling from a pre-determined height. The Pile Driving Analyser (PDA) converts strain to force, and acceleration records are converted to velocities. The resistance developed by the pile thus becomes a function of force and velocity and includes few assumed factors such as the quake and damping parameters as inputs based on the soil type. A more accurate value of these parameters is then obtained from Case Pile Wave Analysis Program (CAPWAP) signal matching analysis conducted on field data. Field results usually include capacity of the pile, based on an assumed damping value, stresses in the pile, net and total settlement of the pile, and so on. In fact, CAPWAP analysis is used to assess skin friction, end bearing pile displacement characteristics along with modeling of bulbs and/or defects and for determining ultimate pile load which is discussed in subsequent sections.

CORRELATION STUDIES IN THE PAST

The ability to accurately predict static capacity from dynamic pile testing has resulted in many research studies, and this has been the focus of dynamic pile tests on many project sites (Likins and Rausche, 2004).

Correlation studies for Indian scenario have also been reported (Mhaiskar et. al., 2010, Vaidya, R., 2006). These studies present qualitative comparison of CAPWAP simulated and field static load displacement curves. The authors conclude that close agreement in many of their case studies served as a pointer that dynamic test can be reliably deployed at sites, and valuable time and efforts could be saved.

REASONS FOR DEVIATIONS IN CORRELATIONS

Typically, for driven piles, changes in pile-soil performance due to differences in the time of testing after installation is a major reason for mismatch of HSDPT and SLT results.

Other smaller reasons include potential measurement errors in both static and dynamic tests, alternative failure definitions in static test evaluation, pile defects etc. Most bored piles in India are tested at least after 21 to 28 days and hence variation in the test results due to differences in time of testing is generally not observed as a reason for lack of correlations. This is probably only true when the time difference is accompanied by substantial changes in soil stratum due to water table or pore water pressure. For that matter, testing the same pile twice may also produce deviation in the results to some extent due to different toe conditions. Similarly, if two adjoining piles were to test then also results may differ due to possibly different pile geometry, installation differences, different toe conditions etc. The subject of deviation in pile test results and selection of pile for testing therefore warrants special attention.

RECENT CASE STUDIES IN INDIA

Performance of CAPWAP analyses are highlighted through six recent case studies. All the piles under consideration are bored cast-in-situ and abstract information are reported in Table 1.

Table 1. Pile details

Sr. No.	Location	Pile No.	Pile Dia. (m)	Pile Length Below COL (m)
1	Dahej	B-3586	0.80	22.10
2	Kochi	P-258	1.00	43.50
3	Noida	TP-1	1.00	25.60
4	Talwandi	Z4-3	0.60	28.10
5	Talwandi	Z1-3	0.80	30.00
6	Zirakhpur*	RP17-B$ LP-44/D#	1.00	18.00

*Separate piles for static & dynamic tests; $Dynamic pile; #Static pile

The damping coefficient estimated from CAPWAP analysis ranged from 0.4 to 0.6 which is typical for sandy soil. Brief sub-surface information of sites is stated as under:

Dahej: 0 -3m (Expansive soil, SPT, N= 10-19); 3-8m (Stiff silty clay, N= 11-16); 8 – 10m (Stiff hard silty clay, N=16); 10-30m (Dense silty sand, N=36 to 100). GWT: 9m.

Kochi: 0 – 19m (Soft clayey silt, N= 1 – 3); 19 – 43m (Soft to stiff clayey silt, N= 7 – 16); 43 – 47m (Dense sand, N= 55 - 65); 47 – 55m (Dense silty sand, N>100); GWT: close to GL.

Noida: 0 – 6m (excavated); 6 – 10m (Gravelly silt, N=18); 10 – 20m (Silty sand, N= 25 – 45); 20 – 29m (Dense silty sand, N>70). GWT: 8m.

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Talwandi: 0 – 3m (Fill, N=7); 3 – 13m (med. Dense silty sand, N = 23 – 35); 13 – 35m (Dense silty sand, N = 40 to 80); 35 – 40m (Stiff clay, N = 54); 40 – 47m (Dense silty sand (N > 100). GWT 7m.

Zirakhpur: 0 – 3m (Fill, N=15); 3-13m (Sandy silt, N= 25-30m); 13 – 24m (Silty sand, N =40 – 45); GWT: 6m.

CAPWAP analysis was performed to determine final soil resistance parameters; and static analysis with these parameters yielded simulated static pile top load versus displacement behavior. For a HSDPT if net settlement of a pile for a given blow is more than 3 to 4 mm then it is generally considered that the ultimate capacity of pile has been achieved. For piles subjected to static load test, Davissons's criterion was applied to estimate ultimate capacity of pile as it is known that HSDPT results correlate well with this criterion. In this method a failure criterion line parallel to the elastic deformation is plotted on the static load test curve (Figs. 1c, 1d and 1e). The point at which load-displacement curve intersects the failure criterion line is defined as failure load. If the load-displacement curve does not intersect the failure criterion line, the pile is understood to have an ultimate capacity in excess of the maximum applied load. For piles with inadequate movement, proof capacities and corresponding displacement were considered for correlation assessment. Comparative Static and CAPWAP simulated curves are presented in Fig. 1; while comparative static and dynamic load/capacity and displacement information for these case studies are summarized in Table 2.

DISCUSSIONS ON COMPARATIVE CURVES

HSDPT was performed before SLT at Dahej, Noida and Zirakpur sites whereas it was vice versa for Kochi. At Dahej, Kochi and Zirakpur, piles were not loaded till ultimate capacities while piles at other sites were tested till they reached ultimate capacities. In later case, Davisson's criteria was applied as discussed earlier to estimate ultimate capacity and then compared with the capacity estimated by CAPWAP (Refer Table 2). Dahej and Kochi cases indicate good correlation in terms of proof load and maximum pile top displacement. Slight overestimation of dynamic load at Kochi (about 15%) may be attributed to different pile toe movements and soil setup changes as there was considerable time difference between both the tests with the HSDPT done first. Whereas, difference in loads (about 20%) is evident at Zirakpur because of adjoining piles are correlated in this case and some variation is likely due to small variations in soil, concrete material property and toe conditions. Piles at Noida and Talwandi were loaded to ultimate conditions. At both the sites, the estimated CAPWAP capacity is in good agreement with the static capacity derived using Davisson's criteria. In case of Noida, the static load test probably eliminated the soft toe condition and hence the rebound was better in case of the HSDPT which was performed later. The soil in case of Talwandi was fine sand and hence there was less likelihood of remoulding after the first dynamic load test. Thus the piles show higher permanent settlement once the ultimate capacity was achieved as per Davisson's criterion. To summarize, the correlations for both Noida and Talwandi match well when Davisson's criterion of failure is considered.

CONCLUDING REMARKS

In India, HSDPT is gaining increasing popularity and is being used extensively to estimate the pile capacities and integrity. It then becomes necessary to evaluate its ability to produce similar results to that of SLT. However, this task is not straight forward and involves many complex issues including testing the same pile twice, testing adjoining piles, errors associated with testing, expertise of the test engineers etc. Literatures have indicated close agreement between field static and dynamically computed ultimate loads. Correlation studies between static and dynamic tests help in building more confidence in HSDPT and also checks the capability of the testing agency. The case studies at Indian sites presented in this paper indicate reliable predictions of ultimate/proof load within safe margin. Ultimate capacities derived for SLTs using conservative Davisson's criterion match very well with the estimated HSDPT capacities. Static load tests are reliable means of pile capacity verification but have major limitations such as space, time as well as cost constraints. Hence, it is desirable to perform site specific correlation studies and then perform more number of HSDPT to achieve higher degree of quality assurance. HSDPT also provides information on reason of failure (geotechnical or structural) and sometimes this is a useful tool to decide the ultimate pile capacity. Again, instead of merely relying on one test method, a combination of SLT, HSDPT and low strain integrity tests is expected to provide a safe and reliable assessment for pile foundations. It is also suggested that the client and / or the contractor is reasonably aware of the test methodology and procedures so as to avoid confusion in interpretations. In cases where more quality assurance is required or pile integrity is doubtful or the site conditions do not permit performance of SLT to the extent desired, then HSDPT provides an economical and viable alternative which also furnishes much more additional information on pile-soil and hammer-pile interactions.

2. NHI-05-043 (2006), FHWA publication: *Design and construction of driven pile foundation*, Reference Manual – Volume II.
3. Kataria, R., Subramanian, R. and Vaidya, R. (2003), High strain dynamic pile load test at Delhi Metro Rail Project, *The India Concrete Journal*, July 2003, pp 1197 – 1202.

Fig. 1 Comparative Static and CAPWAP simulated Dynamic load test curves

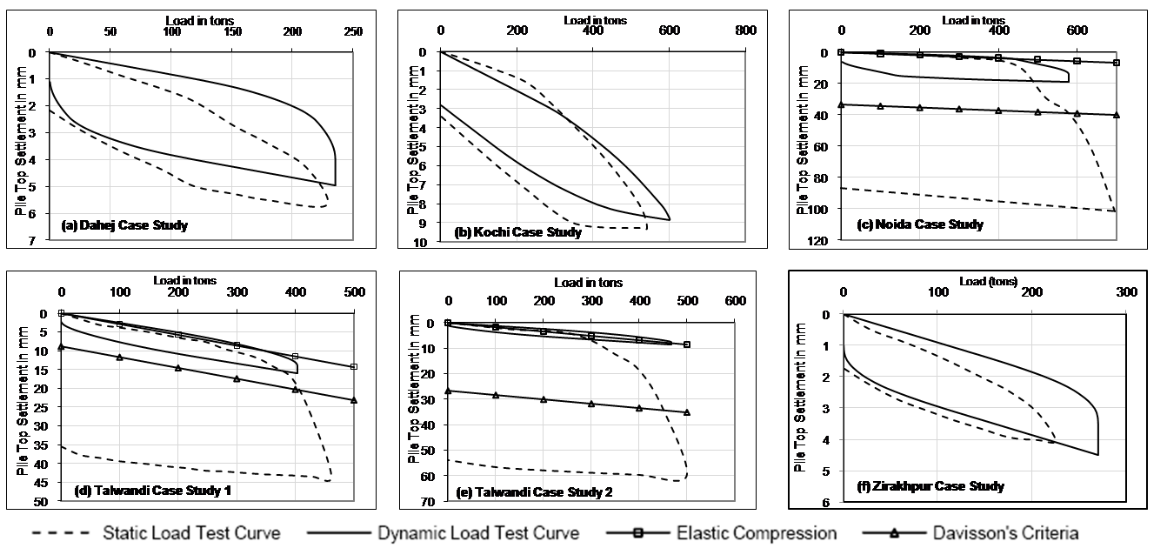

Table 2. Load displacement details

Sr. No.	Pile No.	Static Load Test					Dynamic Load Test			
		Max. Applied Load (MT)	Proof/ Ultimate Pile Capacity (MT)	Total Pile Head Displacement (mm)	Net Displace ment (mm)	Elastic Recovery (mm)	Activated/ Ultimate Pile Capacity (MT)	Total Pile Head Displacement (mm)	Net Displacement (mm)	Elastic Recovery (mm)
1	B-3586	228	228	5.71	2.17	3.54	236	5.00	1.100	3.90
2	P-258	520	520	9.31	3.37	5.94	600	9.00	2.800	6.20
3	TP-1	696	580	101.56	87.30	14.26	580	19.10	5.200	13.90
4	Z4-3	461	410	43.58	35.49	8.09	403	15.90	2.318	13.58
5	Z1-3	500	450	60.07	53.79	6.28	468	8.60	1.040	7.56
6	RP17-B LP-44/D	226	226	4.052	1.73	2.32	271	4.50	1.007	3.49

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GEO DYNAMICS RECENTLY LAUNCHED LATERAL LOAD TEST SERVICES!

As an extension of the range of services we provide, Geo Dynamics has now started providing testing services for lateral load testing for the pile foundation industry. Thus Geo Dynamics now provides vertical load tests by the dynamic method using a Pile Driving Analyzer and the lateral load tests by the conventional method using reaction from adjoining pile.

Geo Dynamics can also offer monitoring of lateral pile movement during a load test using an inclinometer previously installed inside the pile. A photo showing lateral load testing of two piles at the same time is shown below. Please contact Mr. Sujan Kulkarni (8000982277) for further details.

GEO DYNAMICS WISHES HAPPY GUDI PADWA/UGADI TO ALL!

Lateral Load testing of two piles simultaneously

CONGRATULATIONS TO MR. RAVIKIRAN VAIDYA

Mr. Ravikiran Vaidya was elected as a EC member for the two year period 2013-2014 during the elections held for the National Executive Committee of the Indian Geotechnical Society.

Mr. Ravikiran Vaidya also delivered a lecture at the IGS Hyderabad Chapter on 16th March 2013 on Ethical Testing Practices for Deep Foundation Testing.

NEW ADDITION TO GEO DYNAMICS FAMILY

Ms. Nidhi Sheth has recently joined the Geo Dynamics as a proposal engineer. She has taken over the charge from Ms. Neeti Patel who served for several years and is now on a sabbatical.

Nidhi will take over the responsibilities from Neeti Patel and can be contacted at 9227424754. We welcome Nidhi to Geo Dynamics and wish her all the best for her career growth.

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