Proceedings of Indian Geotechnical Conference
December 15-17, 2011, Kochi (Paper No.Q- 303)

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

S.S. Basarkar, General Manager, M/s ITD Cementation India Limited, Mumbai, sunil.basarkar@itdcem.co.in
Manish Kumar, Vice President, M/s ITD Cementation India Limited, Mumbai, manish.kumar@itdcem.co.in
Ravikiran Vaidya, Principal, M/s Geo Dynamics, Vadodara, ravikiran@geodynamics.net

ABSTRACT: High strain dynamic pile load tests (HSDPLT) are being increasingly used in conjunction with Static pile load tests (SPLT) for capacity and parametric assessment. SPLT is still considered as the first priority for pile capacity assessment and is preferred for modelling realistic load displacement behaviour of pile. Limitations of SPLT - large space and time requirements, tedious arrangements and highly labour oriented – have prompted situations where HSDPLT has to be solely relied upon. In this paper, reported studies carried out in the past and further field case studies in India between static and dynamic test performances indicates a good correlation which augment decision on using HSDPLT as a reliable pile load test in field.

INTRODUCTION

Static Pile Load Test (SPLT) 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 behaviour 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 SPLT or as a sole entity.

Dynamic pile load testing also known as High Strain Dynamic Pile Testing (HSDPLT) was introduced in India in the later part of eighties and became popular 2001 onwards. This test is faster and more convenient than SPLT and also offers significant cost savings especially for higher capacity piles. Present practice is to use this test as a replacement to SPLT 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 scepticism in India. Efforts to overcome this scepticism 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 paper:

(i) Do SPLT and HSDPLT produce similar pile capacity?
(ii) Does HSDPLT truly simulate static load displacement behaviour of a pile?

This paper intends to address the above queries 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 direct top static loading remains as one of the best understood assessments of the pile load-displacement behaviour. 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, HSDPLT 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, HSDPLT is performed by firms based on the methodology and equipments devised, developed and patented by Pile Dynamics Inc. (PDI), USA. The practice is standardised as per ASTM D4945.

HSDPLT: BACKGROUND AND PROCEDURE

The basic purpose of HSDPLT is to evaluate pile capacity, structural integrity of the pile and the total movement under 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 modelling 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). Likins and Rausche, 2004 report two major studies on analyses of field data carried out in the past by Goble et. al., (1980) and Likins et. al., (1996).

In both of these studies, data pertained to driven piles only, and were analysed by CAPWAP analysis. The 1996 study included investigation of the fully automatic CAPWAP method which performs all calculations without any human interaction. Correlation results were very good, demonstrating inherent reliability for capacity evaluation from dynamic testing (reported by Likins & Rausche, 2004). Likins & Rausche (2004) further extended the data base by compiling all relevant Stresswave Conference data (number of test samples, N=143) and through additional data received from a research project sponsored by FHWA (increasing the cumulative sample base to N=303) for correlation studies.

Above studies conclude that CAPWAP analysis can be very reliable for determination of ultimate capacity of both driven and bored piles. Better accuracy was seen in driven piles than for cast-in-situ piles. Their studies indicated an average CAPWAP/SPLT ratio of 0.98 with coefficient of variation of 0.169, indicating that CAPWAP results were generally more conservative. Only 9% of the cases reported CAPWAP to maximum applied static load exceeding a ratio of 1.1 – this was also considered well within a reserved margin of safety adopted in normal design.

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

Some of the studies undertaken above represent situations where static load tests and CAPWAP analyses yield differing results. Rausche compiled some of the valid causes for deviations seen in the two results. In many soils, pile capacity continually changes with time due to soil densification (referred as setup) or relaxation, and thus many specifications require a suitable waiting period after installation before static load test is performed.

Since static and dynamic testing usually occurs after different wait periods, further differences in capacity should be expected, and this difference increases as time between tests increases. Difference in tremie is expressed as Time ratio $T_r = T_1/T_2$, where T_1 is time difference between dynamic restrike test and pile installation; and T_2 is time difference between static load test and pile installation. Studies indicate that setup increases linearly with the log of time, the time difference is considered acceptably small when T_r is between 0.33 and 1.25.

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 HSDPLT and SPLT 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. 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.

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 behaviour. For a HSDPLT 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.

Table 1. Pile details

Sr. No.	Location	Pile No.	Pile Dia (m)	Pile Length Below COL (m)	Time Factor (T_r)
1	Dahej	B-3586	0.80	22.10	0.7692
2	Kochi	P-258	1.00	43.50	3.5700
3	Noida	TP-1	1.00	25.60	0.8140
4	Talwandi	Z4-3	0.60	28.10	1.6300
5	Talwandi	Z1-3	0.80	30.00	1.8300
6	Zirakhpur*	RP17-B[$] LP-44/D[#]	1.00	18.00	0.1560

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

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

HSDPLT was performed before SPLT at Dahej, Noida and Zirakpur sites whereas it was vice versa for Kochi. This is clear from Time factor values stated in Table 1, which are less than 1. 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 HSDPLT done first. Whereas, difference in loads (about 20%) is evident at Zirakpur because of very low time factor (T_r = 0.156). Also, as adjoining piles are correlated in this case, 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 HSDPLT 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, HSDPLT 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 SPLT. However, this task is not straight forward and involves many complex issues including testing the same pile twice, testing adjoining piles, time effects, 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 HSDPLT 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 SPLTs using conservative Davisson's criterion match very well with the estimated HSDPLT capacities. Large difference in time factors are observed in the Indian case studies, and in some soils, this may cause difference in the results. Hence concerted efforts are required to reduce time span between static and dynamic tests so that any changes in pile-soil performances can be marginalized.

Static load tests are reliable means of pile capacity verification but have major limitations such as space, time as

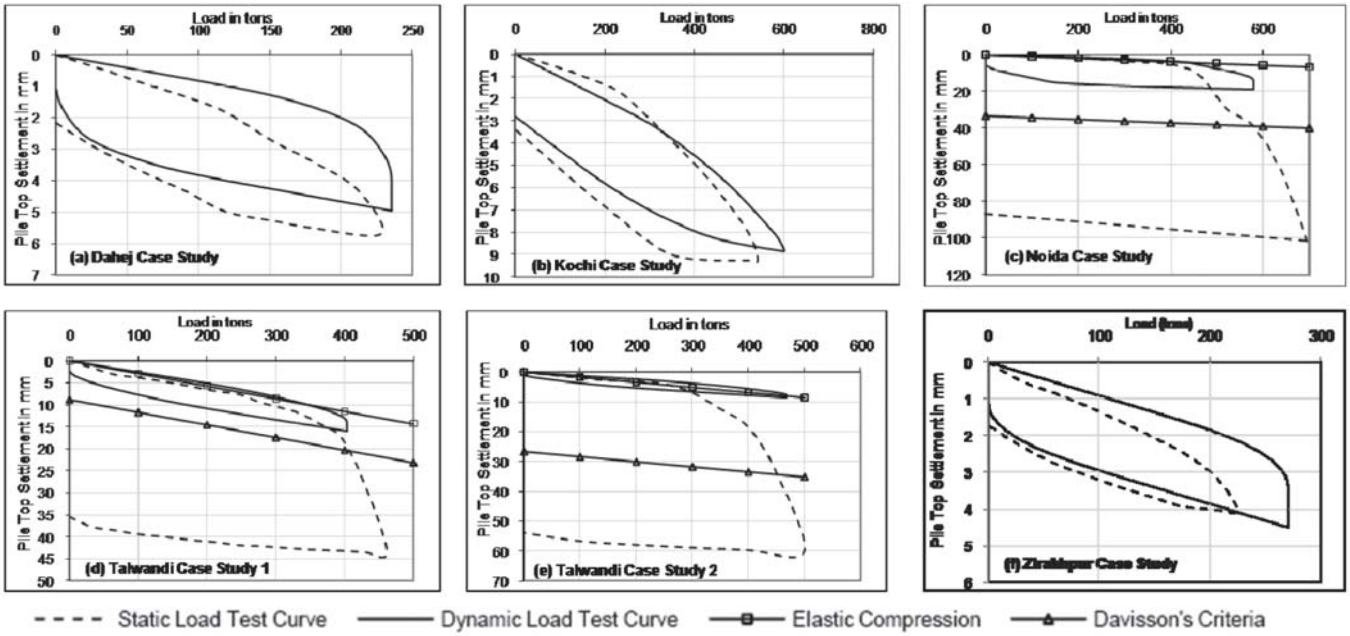

Fig. 1 Comparative Static and CAPWAP simulated Dynamic load test curves

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 Displace ment (mm)	Net Displace ment (mm)	Elastic Recovery (mm)	Activated /Ultimate Pile Capacity (MT)	Total Pile Head Displace ment (mm)	Net Displace ment (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

well as cost constraints. Hence, it is desirable to perform site specific correlation studies and then perform more number of HSDPLT to achieve higher degree of quality assurance. HSDPLT 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 SPLT, HSDPLT 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 SPLT to the extent desired, then HSDPLT provides an economical and viable alternative which also furnishes much more additional information on pile-soil and hammer-pile interactions.

ACKNOWLEDGEMENTS

Outcome of this paper is due to mutual collaboration, and constructive interactions between author' firms, clients and consultants. Authors gratefully acknowledge this symbiosis.

REFERENCES

1. Likins, G. and Rausche, F. (2004), Correlation of CAPWAP with static load tests. *Proc. 7th Int. Conf. On the Application of Stresswave Theory to Piles*, Petaling Jaya, Selangor, Malaysia, pp 153 – 165.
2. Likins, G., Rausche, F. and Goble, G.G. (2000), High strain dynamic pile testing, equipment and practice, *Application of stress theory to piles*, Niyama & Beim (eds), Balkema, Rotterdam, pp 327 – 333.
3. Mhaiskar, S. Y., Khare, M. and Vaidya, R. (2010), High strain dynamic pile testing and static load test – a correlation study. *Proc. Indian Geotechnical Conference 2010*, Mumbai, 16 – 18 Dec.
4. Vaidya, R. (2006), Introduction to high strain dynamic pile testing and reliability studies in southern India. *Proc. Indian Geotechnical Conference 2006*, Chennai, 14 – 16 Dec., pp 901 – 904.